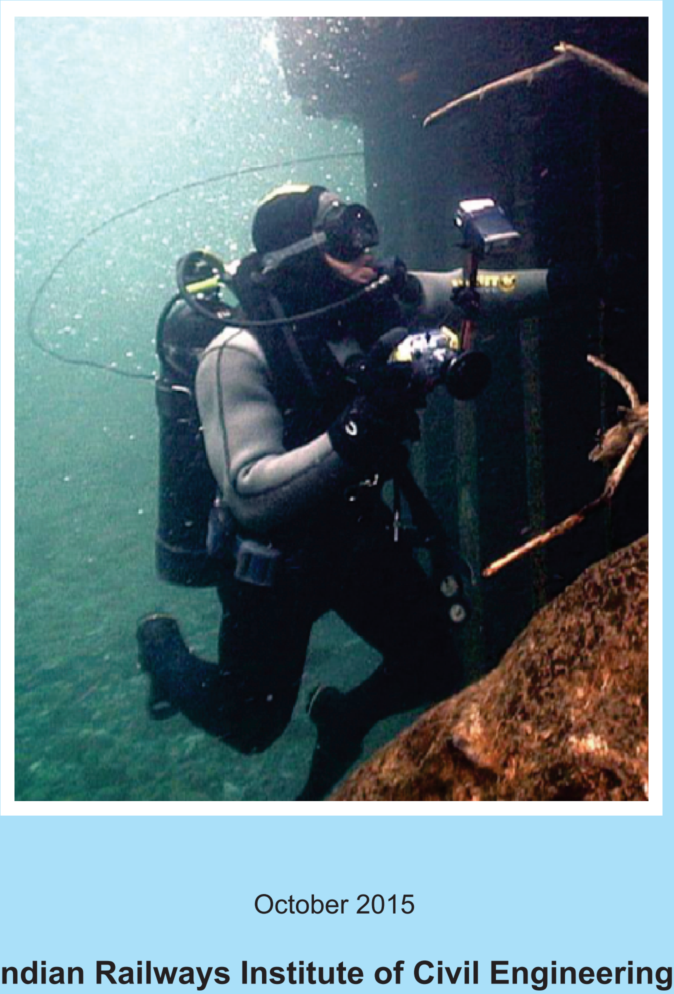
ज्ञान ज्योति से मार्गदर्शन
To Beam As A Beacon of Knowledge

Under Water Inspection of Bridges



October 2015

Indian Railways Institute of Civil Engineering
Pune 411001

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Preface to the Second Edition

Book on Underwater Inspection of Railway Bridges was first published in year 2005. Now the second revised and enlarged edition is being brought out.

Content of the book is thoroughly supplemented with several photographs for better understanding. While revising latest supplements, RDSO publications and recommendations of Bridge Standards Committee have been included.

The second chapter on Underwater Inspection has been revised duly incorporating the cause of damages, growth of aquatic life on underwater structure etc. A new chapter on Underwater Inspection Method is introduced with a section on equipment and apparatus needed.

The chapter on documentation and reporting is supplemented by adding real life case studies on underwater inspection of Railway Bridges on Indian Railway.

It is hoped that this book will fulfil the need and assist the field engineers in bringing awareness about the aspects to be inspected and corrective action to be taken.

Suggestions for improvement may be sent to the undersigned.

14th October, 2015

Vishwesh Chaubey
Director
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Acknowledge to Second Edition

Book on Underwater Inspection of Railway Bridges was first published in Year 2005. Subsequently BS-96 was brought out in year 2008. Underwater Inspection was also discussed during various Bridge Standard Committee meetings. Underwater Inspection is regularly carried out in Indian Railways; therefore, a need was felt to update the earlier edition. Now the second revised and enlarged edition is being brought out to fulfil the continuous demand for the book.

This book is thoroughly supplemented with several photographs collected from various resources and references to make the topics more clear. Almost all the chapters were revised in terms of content as well as presentations.

Topics related to natural phenomena causing damage to bridges, growth of aquatic life etc. was included in second chapter on Underwater Inspection problems and material defects.

The Chapter on Underwater Inspection methods is bifurcated in two Chapters. In the Underwater Inspection methods, emphasis is given on the various modes of inspections and their related operations, codal provisions etc. A new Chapter on Underwater Inspection Programme is added which includes the revised guidelines by RDSO issued vide BS-96 (2008) and recommendations of Bridge Standards Committee.

The chapter on Underwater Inspection Procedure is revised duly incorporating various aspects related to diving operations of diving team.

The Chapter on documentation and reporting is supplemented by incorporating two case studies on Underwater Inspection; one bridge is situated on Chalakudi River in Thiruvananthapuram Division of Southern Railway and other bridge is on River Sankaosh in NF Railway.

Efforts have been made by IRICEN faculty and staff to bring out this new edition as more useful guide for the field engineers. In this process the contribution of Shri K. Kurian, SSE/Br./TVC, Shri Harish Trivedi, Shri Praveen Kotkar, Shri V.N. Sohoni and the DTP by Shri Aman Aparadh is most notable. I am grateful to Shri Venkateshwara Rao, Sr. DEN/Co/TVC/S. Rly., for arranging field visit and demo of Underwater Inspection related to the bridge situated in Thiruvananthapuram. I am also thankful to Shri Ashok Kumar, DyCE/Br/HQ/S. Rly., for providing details on rehabilitation of above bridge.

I am also thankful to Shri C.S.Sharma, Sr. Professor IRICEN and Shri N.K. Khare, Professor, IRICEN for arranging the DTP work and proof checking. I am also thankful to faculty of IRICEN for giving useful suggestions for improving the presentation of this book.

Above all I am grateful to Shri Vishwesh Chaubey, Director IRICEN for his encouragement, regular guidance to bring out the book in its present form.

Pune
October 2015

Sharad Kumar Agarwal
Professor/Bridge
IRICEN

Preface to the First Edition

Underwater inspection of bridges is one of the key activities to be undertaken for maintenance of bridge substructures and foundations. With few recent collapses of bridges in India and other countries, those responsible for ensuring the safety of the bridges have become increasingly aware of the need for such underwater inspections.

Indian Railways Bridge Manual (IRBM) provides for underwater inspection of all bridges that cross bodies of water. Irrespective of the fact that the engineer may use expertise of specialised divers or his own staff or a diving sub-contractor, it is important to understand the various aspects of underwater inspection, as the engineer may be required to supervise the work at site, or utilise the information obtained during the inspection and formulate strategy for the rehabilitation, if need arises. Since underwater inspection is a new activity not fully covered in the manuals and other codes, this booklet will bridge the gap in these publications.

It is hoped that this booklet will act as a guide for bridge engineers who are entrusted with the inspection of underwater bridge components.

Shiv Kumar
Director
Indian Railways Institute of
Civil Engineering, Pune.

Acknowledge to the First Edition

Systematic and scientific underwater bridge inspections are very important in bridge maintenance and management. Railway Board desired that IRICEN should bring out publications on specialised bridge topics. IRICEN publication on “Underwater Inspection of Bridges” is an effort in that direction.

The IRICEN publication is an attempt to compile the relevant information regarding underwater inspection of bridges. Even though the publication is primarily aimed at Railway Engineers, the basic concepts are equally applicable to road bridges also.

It would not be out of place to acknowledge the support and assistance rendered by IRICEN faculty and staff

in the above effort. I am particularly thankful to Shri. Praveen Kumar, Prof. (Computers), who has provided logistic assistance for printing of this book. The word processing of the manuscript and repeated editing thereof has been done by Shri Ganesh Srinivasan. I also acknowledge the help of drawing staff of IRICEN who have assisted in preparation of drawings.

Above all, the author is grateful to Shri Shiv Kumar, Director, IRICEN for his encouragement and advice for improving the publication.

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CONTENTS

CHAPTER - 1

UNDERWATER INSPECTION GENERAL

1.1 Introduction

Bridges that cross waterways often have foundation and substructure elements located in water to provide the most economical total design. It is important that entire bridge is inspected at specified interval not only to ensure safety of the bridge, but also to initiate any repair/rehabilitation work well in time so that the bridge remains functional. Unfortunately, the conditions of substructure and foundation located below waterline is not as easily determined as the condition of parts of the bridge located above waterline. The environment under water is harsher and affects inspecting official's mobility and visibility. Wherever these elements are continuously submerged, underwater inspection and management techniques must be used to establish their condition so that failures can be avoided.

The underwater inspection of bridges is becoming key activity to be undertaken for maintaining bridge substructure and foundation. Indian Railways Bridge Manual (IRBM) provides for underwater inspection of all bridges whose substructures and foundations are perennially under water.

Underwater inspection has four primary purposes - ensuring public safety, protecting public assets, preventing or reducing facility downtime and initiating proactive maintenance.

In general, the term “underwater inspection” is taken to mean a hands-on inspection requiring underwater breathing apparatus and related diving equipments. However, it is a more specialised operation than a routine bridge inspection because a fair amount of sophisticated equipments are required as well as a high degree of skill and efforts of both the bridge inspector and a diver. The bridge inspector and the diver must be able to act as a team in relaying the proper information to each other and coordinating the whole inspection procedure. The expense of such inspections necessitates careful consideration of bridges to be selected for inspection.

1.2 Bridge Selection Criteria

Various factors influence the bridge selection criteria. Factors to consider in establishing the inspection frequency and levels of inspection include:

- Age
- Type of construction material
- Configuration of the substructure
- Adjacent water features such as dams, dikes or marines
- Susceptibility of stream bed materials to scour
- Maintenance history

- Saltwater environment
- Waterway pollution
- Damage due to water borne traffic, debris etc.

1.3 Requried Information

Those bridges, which require underwater inspection must be noted for individual inspection and inventory records as well be compiled in a master list. For each bridge requiring underwater inspection, the following information should be collected as a minimum and considered while planning its inspection.

- Type and location of the bridge
- Type and frequency of the required inspection
- Location of members to be inspected
- Inspection procedures to be used
- Special equipments requirement
- Dates of previous inspections
- Findings of the last inspection
- Follow up action taken on findings of the last inspection
- Type of foundation
- Bottom of foundation elevation or pile/well tip elevation

1.4 Frequency of Inspection

Underwater inspections must be done on every bridge identified for such inspection as per the Indian Railways Bridge Manual (IRBM) provisions. As a minimum, all structures must receive detailed underwater inspection at intervals not to exceed five years. This is the maximum interval at which all underwater elements of a bridge, even if it is in sound condition, must be inspected. More frequent routine and in-depth inspections may be desirable for many structures and necessary for critical structures. Inspection frequency may be increased in those bridges where deterioration has been noticed during previous inspections. It should be also carried out after any collision with the bridge superstructure or after a major storm so that physical evidence is inspected and recorded.

■ ■ ■

CHAPTER - 2

UNDERWATER PROBLEMS AND MATERIAL DEFECTS

2.1 Introduction

Defects or damages to under water structure depends upon factors such as construction material, type of water body, water bound vessel etc. Due to these factors the damages could be permanent deformations, tilt and settlement, abnormal vibration in slender structures etc.

The major bridge construction materials are steel and concrete. In the past, stone and brick masonry, with lime mortar as binding agent, have been used extensively for building bridges. Cast iron piles have been used as substructure in many bridges. These materials are prone to different types of failure and, therefore, require different inspection strategies. The major problem in steel bridges is corrosion. Concrete bridges are susceptible to spalling. Bridges built in masonry have the problem of deterioration of brick / stone elements accompanied with loss of mortar.

Aquatic environment has significant effects on bridges in addition to those mentioned above. Heavy current is especially destructive. Floods cause damage from rapidly moving water as well as from the impact of large moving debris. Generally scour of bed and erosion of construction material takes place. The bridge substructure can also get damaged due to accidental man inflicted causes and earthquakes.

Collisions - Structural damage to underwater portions of a bridge can either be collision related or direct result of a collision. Collision impact can damage immediate area as well as adjacent or even distant structural components depending upon the structural frame and connection system. Fig. 2.1(a) shows effect of collision of a sea vessel on Pambhan bridge near Rameshwarm and Fig. 2.1(b) shows condition after rehabilitation.

Fig. 2.1 (a) : Damage to bridge pier due to collision of a sea vessel

Fig. 2.1 (b) : View from other end after rehabilitation

Storms - Storms can have a detrimental effect on bridge substructure. The velocity and depth of water and debris carried increase in relation to the intensity and storm of water. The erosion of bed increases with increase in velocity. Debris accumulation at the bridge also increases potential for scour by concentrating the flow.

Earthquake and Tsunami - Tsunami waves can be triggered by various geological factors, viz. underwater earthquakes, volcanic eruptions, and submerged or aerial landslides. However, the vast majority of tsunamis are generated by a sudden vertical uplift of the ocean bottom induced by a seismic event. The vertical displacement of such an enormous volume of water generates tsunami waves that propagate at high speed in deep ocean waters. However, as a tsunami wave advances toward the shoreline its height increases while its speed decreases. Flow velocities can vary in magnitude, while flow direction can also vary due to the local onshore topographic features, as well as soil cover and obstacles. The damages to underwater structure caused by tsunami waves are due to forces associated with tsunami bores mainly consist of hydrostatic / hydrodynamic force, buoyant & surge force and due to debris impact.

2.2 Damage Due to Water

The bed level may be affected due to deposit of suspended sediments or washing of deposited sediments. Both of this may cause adverse effect on structure in terms of stability and forces. The velocity of water and presence of sediments causes erosion of construction material. Sometimes the air bubbles present in the turbulent water strikes the structure and bursts, this acts as tiny hammer which causes cavitation or loss of material from the structure. (Fig. 2.2)

The aquatic life in the water body may cause deposition on the surface of underwater structure which may interfere with inspection of underwater structure. Secretion of chemicals from these organism also attack the construction material and cause damage.

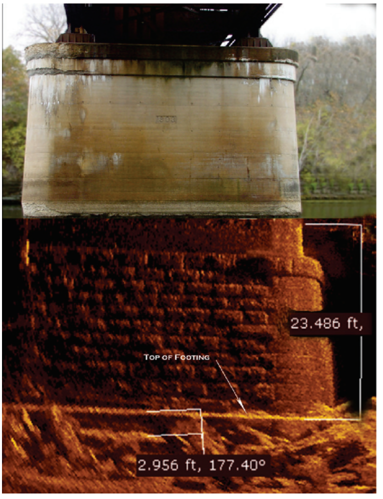

Fig. 2.2 : Weathering of underwater pier on open foundation

2.3 Scour

Whenever a bridge crosses a waterway, even a small or intermittent one, scour is a dangerous effect that can damage bridge piers and undermine foundations. Scour is the hole left behind when sediment (sand and rocks) is washed away from the bottom of a river. Scour action is especially strong during floods. Swiftly flowing water has more energy than calm water to lift and carry sediment down the river. Following three types of scour affect bridges:

i. Local scour is removal of sediment from around bridge piers or abutments. Piers are the pillars supporting a bridge. Abutments are the supports at each end of a bridge. Water flowing past a pier or abutment may scoop out holes in the sediment; these holes are known as scour holes. The scour holes formed during high floods are likely to be filled up when flood recedes. Fig. 2.3

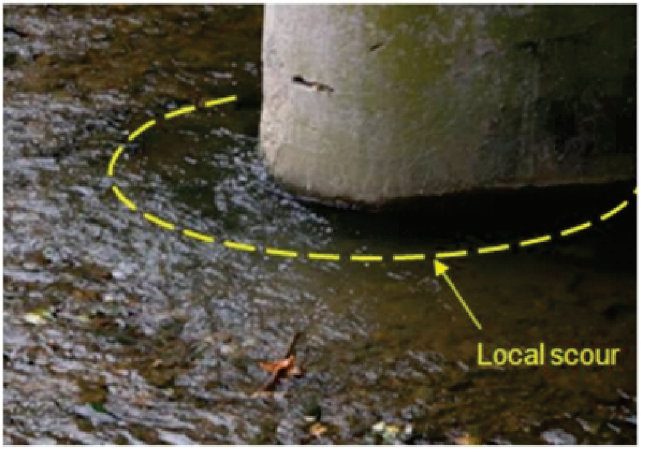

Fig. 2.3 : Local scour around pier

ii. Contraction scour is the removal of sediment from the bottom and sides of the river. Contraction scour is caused by an increase in speed of the water as it moves through a bridge opening that is narrower than the natural river channel. It may cause scour below foundation and form cavity as shown in Fig. 2.4

iii. Degradational scour is the general removal of sediment from the river bottom by the flow of the river. This sediment removal and resultant lowering of the river bottom is a natural process, but may remove large amounts of sediment over a period of time.

Fig. 2.4 : Scour at open foundation

All piers and abutments erected in water are generally designed to be protected from scour or erosion. However, both stream and structure conditions may undergo changes during the service life of the structure. Exposure or undermining of pier and abutment foundations due to erosion of flowing water can result in the structural failure of a bridge. When the sediment or rock on which a bridge is supported is lost the bridge becomes unable to carry the design loads. Partial or full exposure of the foundation footings / or removal of tremie concrete seal can also adversely affect the safety of the structure by causing sliding or lateral movement. This becomes more critical when vertical movement (settlement) is also present. The vertical or lateral movement of a pier or pile produces over design stresses, which may ultimately lead to full structural failures. (Fig. 2.5)

Fig. 2.5 : Settlement of foundation due to scour

The variable conditions of river flow and health state of structure demands constant supervision. Although scour may occur at any time, it is significantly more intense during floods and storms when stronger currents are generated, allowing more sediment to be carried away downstream. It is, therefore, necessary that structures with foundations that are subjected to erosion scour be inspected just after the storms that result in flooding and strong currents.

During flood or storm due to building up of hydrostatic pressure many times portion of protection work also washed away (Fig. 2.6). this needs to be inspected for loose stones at down stream side.

Fig. 2.6 : Damage to protection work

Fig. 2.7 : Deposit of debries

When the flood recedes along with silt and debris, floating material like trees, trunk/bushes also entangle the bridge substructure and block the waterway (Fig. 2.7). This needs to be cleared before next monsoon or storm season.

2.4 Growth of Aquatic Life on Underwater Structure

The build-up of marine growth will have two effects. First it will increase the area of the profile presented to the water flow and so increase the force on the structure. Second, marine growth will change the texture of the surface from a smooth surface to a much rougher surface by the presence of marine growth on it (Fig. 2.8) .

Fig. 2.8 : Hard fouling deposit on underwater structure

This roughness will increase with time as the surface becomes more irregular due to parts of the dead marine growth sloughing off. The effect of this is to increase the drag coefficient. Both these effects increase the force on the structure. Information on the types and amounts of marine growth build-up is required to confirm or modify the design and predicted loads on the structure. The combined effect on the structure will manifest in the following manner.

(i) By producing an increase in mass without any significant change in stiffness. This causes a reduction in its natural frequency.

(ii) By increasing the added mass of water and the drag forces on the structure. Marine growth being most abundant at and just below the water level coincides with the zone of maximum wave and water force, so that the forces on the structure are increased in the region of maximum water force.

(iii) By affecting the corrosion rate, either by accelerating or retarding it.

(iv) By obscuring the important features on the structure, such as diver orientation marks.

(v) By making inspection impossible before cleaning.

Bridges on many inland waterways are relatively clean and free of marine growth. However, there is likelihood of marine growth and incrustations on underwater structures especially in marine/coastal areas. Acid generated by the marine growth attacks concrete. This can lead to corrosion of reinforcing steel.

2.4.1 Types of Marine Fouling

From an engineering point of view, there are two main categories of fouling, soft fouling and hard fouling. Soft fouling is caused by those organisms which have a density approximately the same as seawater. They are important because of their bulk. Organisms in this group are algae, bacteria, sponges, sea squirts, hydroids, seaweeds, bryozoa, and anemones etc. They are easy to remove to facilitate inspection. A typical anaerobic bacterial growth on a bridge pier is shown in Fig. 2.9.

Fig. 2.9 : Anaerobic bacterial growth on a bridge pier

Organisms causing hard fouling are much denser and more firmly attached to the structure and are therefore difficult to remove. Composed of calcareous or shelled organisms, the common types in this group are barnacles, mussels, tube worms etc.

Cleaning marine growth from the underwater portion of the bridge may be necessary during an underwater inspection. The extent of cleaning depends on the amount of growth present and the type and level of inspection.

2.4.2 Growth of Marine Fouling

If no steps are taken to prevent growth, such as application of an anti-fouling solution, then formation of bacterial slime occurs in two to three weeks. Barnacles and soft fouling have been known to attach themselves and reach maturity in three to six months. It generally takes two seasons for mussel colonies to develop, often on top of the earlier dead fouling. The type of organism, its development and growth rate will depend on several factors, such as depth, temperature, water current, salinity, food supply etc.

2.5 Material Defects

2.5.1 Plain or Reinforced Concrete Substructure

Plain, reinforced, and pre-stressed concrete are used for construction of underwater elements. Since the majority of substructures are basically compressive units, concrete is nearly ideal material choice as concrete is relatively strong under compressive loading and with steel reinforcing can resist bending and tensile forces.

The performance of a concrete structure is most affected by the care taken in its construction and installation. Properly made concrete is highly durable in marine environment. However, due to faulty construction, poor concrete, continuous weathering, and attack of water coming in contact with the structure, concrete may get damaged over a period of time. Some concrete damage tends to occur as surface damage, which does not jeopardize the integrity of the system. However, concrete deterioration that involves corrosion of the reinforcement can be very serious.

Construction negligence - Construction damage can result from improper procedures during the construction phase. Some examples are:

(a) Pieces of steel left protruding out in concrete to secure equipments and formwork can be a starting point for corrosion.

(b) Insufficient cover to reinforcement.

There are two principles deterioration of concrete viz. physical and chemical.

2.5.1.1 Physical deterioration

Typical defects due to physical deterioration includes:

a) Scaling

b) Cracking

c) Spalling

d) Honey combing and disintegration

e) Abrasion

f) Cavitation

g) Impact damage and fracture

a) Scaling - Scaling is the gradual and continuing loss of the surface mortar and aggregate over an area (Fig. 2.10). This condition is commonly formed at the water line on piers and piles and is more common in colder climates.

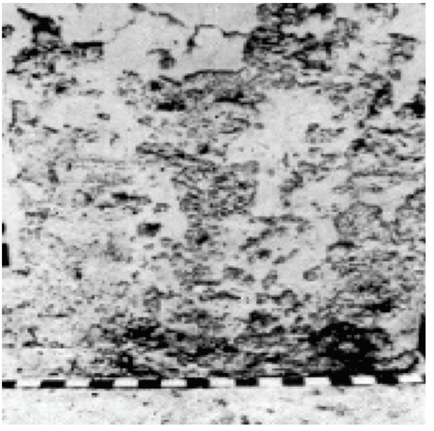

Fig. 2.10 Medium scaling of concrete

Scaling is classified into following three categories:

i. Light scale – loss of surface mortar up to 5 mm deep, with surface exposure of coarse aggregates.

ii. Medium scale – loss of surface mortar from 5 mm to 10 mm deep, with mortar loss between the coarse aggregates.

iii. Heavy scale – loss of surface mortar from 10 mm to 25 mm deep; coarse aggregates are clearly exposed.

b) Cracking - A crack is a linear fracture in concrete. There can be several types of cracks starting from surface and going into the concrete element. However, all cracks are not critical. Vertical cracks in pier and abutments (Fig. 2.11) are indicative of differential settlement of the foundation.

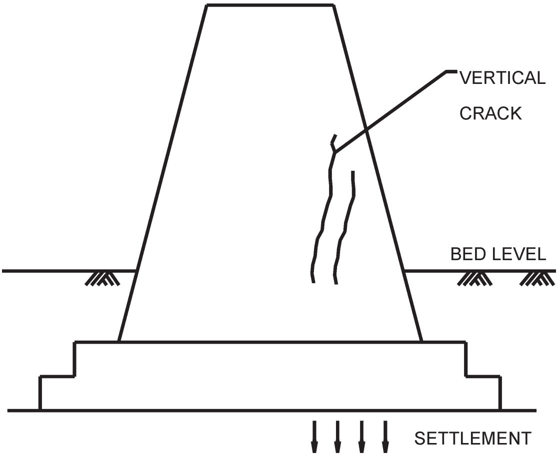

Fig. 2.11 : Vertical cracks in pier due to settlement

Excessive compression in concrete becomes evident by a series of progressive cracks parallel to the force (Fig. 2.12). When reporting cracks, the length, width, location, and orientation (horizontal, vertical, or diagonal) should be noted.

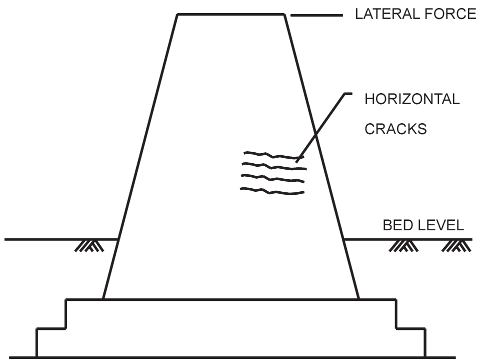

Fig. 2.12 : Horizontal cracks due to excessive lateral forces

c) Spalling - A spall is a roughly circular or oval depression in the concrete. Corroding reinforcement can cause spalls and reinforcing steel is often exposed. Spalling occurs as the cracks worsen. Spalls result from the separation and removal of a portion of the surface concrete (Fig. 2.13).

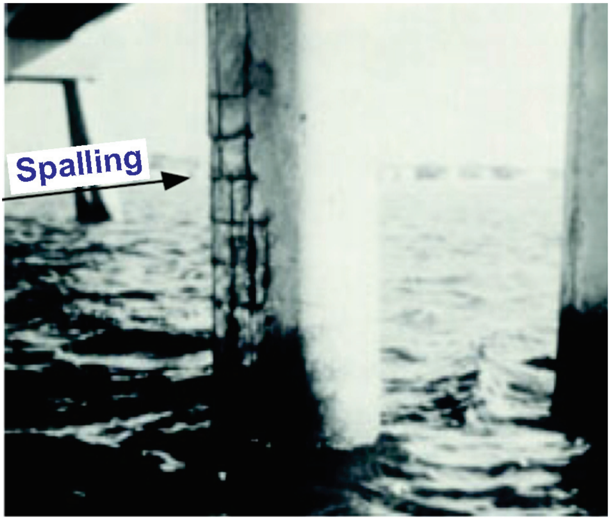

Fig. 2.13 : Spalling of concrete

Spalls are classified as follows:

i. Small spalls – up to 25 mm deep or approximately 150 mm in diameter.

ii. Large spalls – are more than 25 mm deep or greater than 150 mm diameter.

d) Disintegration - Disintegration of concrete may be defined as the deterioration of concrete into small fragments or particles resulting from any cause. Disintegration may be differentiated from spalling by the mass of particle being removed from the main body of concrete. Disintegration is usually the loss of small particles and individual aggregate particles, while spalling is typically the loss of larger pieces of intact concrete. Fig. 2.14 shows disintegration of concrete caused by exposure to aggressive water.

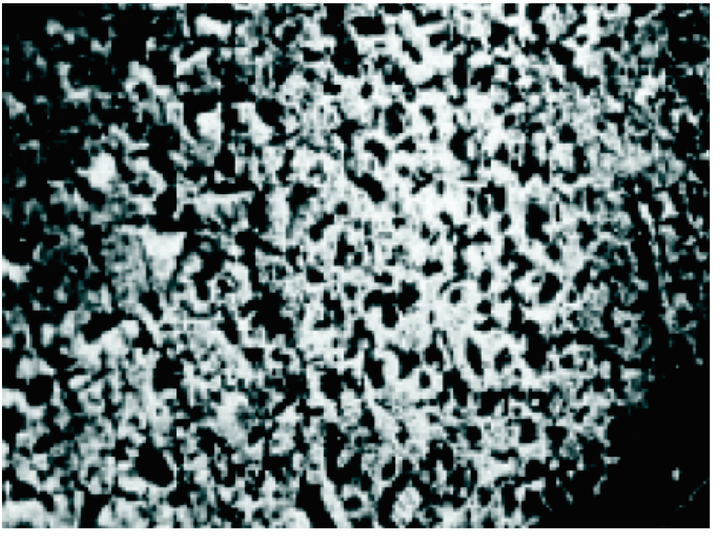

Fig. 2.14 : Disintegration of concrete caused by exposure to aggressive water

e) Abrasion - Abrasion damage is caused by continuous action of external forces on the surface of the concrete element. Erosive action of silt-laden water running over a concrete surface can cause considerable abrasion damage to concrete piers and piling. In addition, concrete surfaces in surf zones may be damaged by abrasive action of sand and silt in water. Fig .2.15 shows a smooth, worn, abraded concrete surface caused by abrasion of waterborne debris.

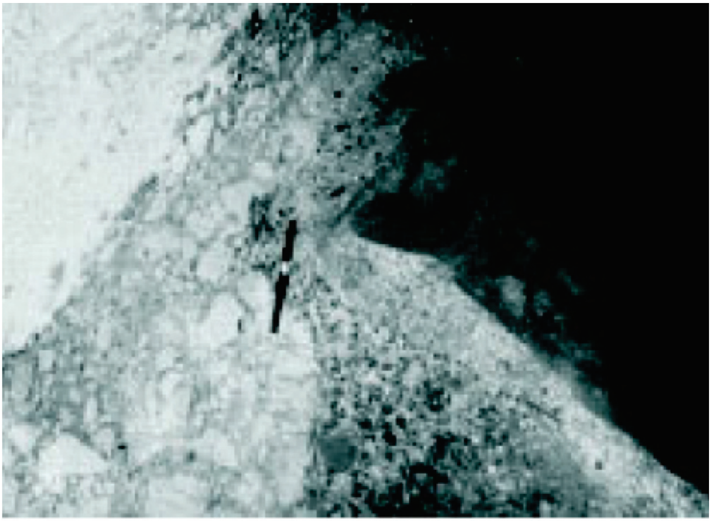

Fig. 2.15 : Smooth, worn, abraded concrete surface caused by abrasion of waterborne debris

f) Cavitation - Cavitation damage is caused by repeated impact forces caused by collapse of vapour bubbles in rapidly flowing water. The appearance of concrete damaged by cavitation is generally different from that damaged by abrasion erosion. Instead of a smooth, worn appearance, the concrete will appear very rough and pitted (Fig. 2.16).

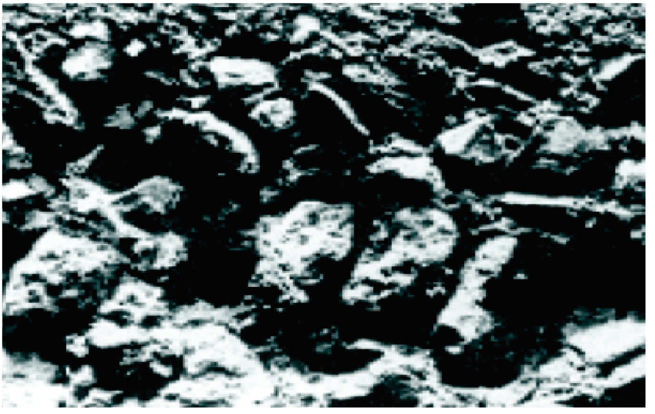

Fig. 2.16 : Rough, pitted concrete surface caused by cavitation

In severe cases, cavitation may remove large quantities of concrete (Fig. 2.17) and may endanger the structure. Usually cavitation occurs as a result of water velocities greater than 12 m/sec.

Fig. 2.17 : Deep cavitation

g) Impact Damage: Impact from moving vessels or logs carried during the floods can inflict damage to the structure. The impact or collision damage can be recognised by crushed or chipped concrete.

2.5.1.2 Chemical Deterioration

Deterioration of concrete may occur due to presence of harmful chemical in water or concrete. This accelerates if the concrete has not been properly compacted, or due to severe environmental pollution. The chemical attacks ultimately lead to corrosion of reinforcing steel, which finally results into physical deterioration of the concrete i.e. cracking or spalling of concrete. The reinforcement corrosion problem aggravates further arises due to seepage of water through concrete cracks. The causes of chemical deterioration are:

a) Sulphate attack - Cement contains a proportion of tricalcium aluminates, which takes part in the hydration process. These can react with magnesium sulphate, which is present in concentrations of about 0.5% in seawater. The reaction is expansive, but the presence of chlorides inhibits the degree of expansion. The net result is softening and disruption of the concrete in the form of crumbling.

b) Chlorides - Chlorides do not attack plain concrete when present in the concentrations that normally exist in seawater, but may greatly accelerate the corrosion of reinforcing steel by destroying the passivity of the concrete coating.

c) Carbonation - Carbon dioxide is present in the air and attacks the concrete directly. It has the effect of destroying the normal passivity of the concrete coating, thus leading to reinforcement corrosion, but its effects are generally limited to a penetration of approximately 50 mm.

d) Alkali aggregate reaction - Sometimes high alkali cement reacts with minerals in certain aggregates and forms expansive compounds resulting into swelling of concrete which may cause cracking and spalling.

e) Contaminants - There are various substances that may be inadvertently incorporated into the concrete matrix (e.g. glass, coal, gypsum), which can react with the cement in the presence of seawater.

2.5.2 Masonry Substructure

In early days, masonry, particularly stone masonry was extensively used for bridge piers and abutments. Typically, bricks and quarried stone were set with lime mortar or Portland cement mortar.

Stone masonry structures develop problems at the joints between pieces of stone. Failure of these types of structures usually occurs as a result of wash out of the joints. In addition, increased earth or hydrostatic pressure causes joints to crack and masonry to fall out. Weathering of masonry under constant wave action of water is another cause of deterioration. Fig. 2.18 shows a typical damage to a stone masonry pier base. Damage at masonry structures may be as follows:

- Deteriorated masonry blocks (stones/bricks)
- Deteriorated joints

- De-bonding of stones/bricks to form cavities
- Cracks
- Unintended eccentricities
- Overloading
- Moisture penetration
- Impact damage
- Fracture

Fig. 2.18 : Typical damage to stone masonry pier base

2.5.3 Steel Substructure

Steel is used as a structural material and as external protective cladding on concrete foundation elements. Steel foundation elements located in water, commonly H piles, or sheet piling can suffer distress in the form of corrosion. The corrosion can be especially severe when the bridge is located in salt water or brackish water. The most important factors influencing and providing corrosion are the presence of oxygen, moisture, chemicals, pollution, stray electrical currents, and water velocities.

Major types of deterioration in steel substructure in the marine environment:

a) Corrosion

b) Abrasion

c) Loosening of structural connectivity and unintended eccentricities

d) Fatigue, cracks and fracture

e) Overloading and impact damage

a) Corrosion - Corrosion is the principle cause of deterioration of steel structures. Corrosion of steel is an electrochemical process that converts the steel into iron oxides. These iron oxides are easily recognised by their reddish brown colour and commonly called rust. The rust may remain in place in the form of an incrustation or may naturally fall away or be removed by wave action or abrasion. The corroded surfaces are usually irregular and in some cases the attack in localised areas will be much greater than in other areas resulting in pitting. Over a period of time, unchecked corrosion will reduce the structural integrity of steel components of the structure. Corrosion of steel structures can be classified as under:

- Atmospheric corrosion
- Underwater corrosion
- Corrosion under mud line
- Bacterial corrosion

The predominant factor in atmospheric corrosion in areas located above splash zone (Fig. 2.19) is moisture as there is an excess availability of oxygen. In the part of steel member, located above water line but within the splash zone, corrosion is accelerated by water / salt water and the effect of wetting and drying cycles. The predominant cause of corrosion in the submerged portion of steel member is the concentration of dissolved oxygen. The predominant causes of corrosion in the part of steel structures that are below the mud line are electrical conductivity, total acidity, water contamination, and dissimilar metals.

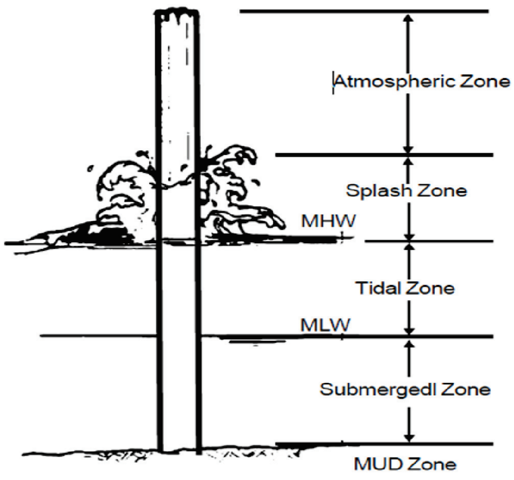

Fig. 2.19 : Various zones of influence

Corrosion can also be accelerated by the action of bacteria. In the absence of oxygen, sulphate-reducing bacteria can grow, and the sulphides produced by these can cause rapid attack on steel. Some bottom sediments are oxygen deficient and sulphate-reducing bacterial attack can occur on buried steel in such sediments.

The presence of limited growth of barnacles tends to increase the amount of pitting. There are opinions that heavy growth of barnacles tends to check corrosion. However, there are contrary views also.

b) Abrasion - Abrasion of steel structures can generally be recognised by a worn, smooth, polished appearance of the surface. Abrasion is caused by continual rubbing of adjacent moving steel surfaces, or by the exposure of structural components to wave action in areas of sandy bottom. Steel sheet piling and pile-supported structures are particularly susceptible to sand abrasion in exposed locations. Abrasion of steel structures is a problem because it removes both protective coatings and protective layers of corrosion products, thus accelerating corrosion.

c) Loosening of structural connectivity and unintended eccentricities - Structural connections joined together by rivets or bolts have a tendency to work loose over an extended period of time. Connection loosening can result from impact loading of the type imparted by a vessel striking substructure. Wave action is another source of possible connection loosening. Corrosion of bolts, rivets, nuts, washers, and holes can also contribute to connection loosening. Loosening of connections will tend to produce misalignment in mating surfaces, which in turn can result in unintended eccentricities and cause distortion and stress concentrations in framing members.

d) Fatigue, cracks and fracture - Fatigue failure results in the fracture of structural members as a consequence of repeated high loading. Fatigue distress can be recognized by a series of small hairline fractures perpendicular to the line of stress in the member. Fatigue cracks are difficult to locate. Since fatigue cracks represent an extremely dangerous condition in steel marine structures, extreme care must be undertaken when inspecting structural members subjected to repetitive loading, particularly high wave loading.

e) Overloading and impact damage - Steel structural elements are sensitive to impact damage from moving vessels and other types of accidental overloading. Impact or collision damage can generally be recognised by the appearance of local distortion (deformation) of the damaged member. This damage is generally characterised by a sharp crimp or a warped surface.

2.5.4 Cast Iron Substructure

Cast Iron also has the problem of corrosion due to atmosphere, which is similar to that of steel. However, in acidic or brackish water graphitic corrosion occurs. In this case, parts of corrosion products are formed underneath the normal surface layers. There is little visual evidence of the attack since the original dimensions and shape of the component are retained. However, the corroded metal, bound together by graphitic ions, which are part of original make up of grey cast iron, is soft, porous and of very low mechanical strength. It can easily be cut with a knife or a light chisel and if lightly tapped with a hammer does not ring like a sound metal. This process is called graphitization and is usually a slow process.

Br.no. 924(12x19.51m) steel girder bridge on river Kadalundi was built in 1861. The substructure is made using cast iron screw piles. During 2001 due to failure of one screw pile, third pier collapsed and Manglore-Chennai express got derailed (Fig. 2.20 (a) & Fig. 2.20 (b)).

Fig.2.20 (a) : Kadalundi train mishap (Calicut-Shoranur section of Palghat Division during 2001 due to failure of pile)

During subsequent enquiry it was found that the thickness and density of cast iron pile shell was reduced from 28mm and 7.5gm/cm^3 to 6mm and 2.5 gm/cm^3 respectively, which causes collapse of the pile.

Fig. 2.20 (b) : Damaged top of cast iron screw pile after derailment.

2.6 Deferred Maintenance

Many problems of the substructure can be traced to lack of any maintenance in time, which again can be due to lack of any underwater inspection. Thus a system of underwater inspection and any repair required in time can lead to plugging of these shortcomings.

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CHAPTER - 3

UNDERWATER INSPECTION METHODS

3.1 Introduction

Method for underwater inspection of a bridge depends on type and extent of damage expected, inspection intensity level, and type of inspection. The location of underwater elements must be identified and a description of the underwater elements must be included in the inspection records. Selection of a particular method of inspection and inspection intensity level will determine the effectiveness of inspection as well as inspection cost. The inspection frequency and procedures for each bridge requiring underwater inspection must be included in the inspection record. The elements requiring underwater inspections must be inspected according to these procedures.

3.2 Methods of Underwater Inspection

There are three general methods of performing underwater inspection of bridge elements.

- Wading inspection
- SCUBA diving
- Surface supplied air diving

In some situations, one mode may have significant economic benefits over the other, while allowing for the gathering of all the inspection information required without, in any way, compromising safety. The appropriateness of a particular mode for any specific diving situation depends on a number of factors including depth, bottom time, inspection tasks, waterway environment, presence of hazards, and the experience and capability of the diver. Each mode has unique operational advantages and disadvantages.

3.2.1 Wading Inspection

Wading inspection is the basic method of underwater inspection used on structures over wade-able streams (Fig.3.1). A wading inspection can often be performed by regular bridge inspection teams. A probing rod, sounding rod or line, waders, and possibly a boat can be used for evaluation of a substructure unit.

Fig. 3.1 : Wading inspection

During wading inspection, one should preferably wear hip boots and chest waders. Boots and waders provide protection from cold and pollutants as well as from underwater objects. In deeper water, wearing of a personal floating device (PFD) may be desirable during wading activities. As a rule of thumb, one should not attempt to wade a stream in which product of depth multiplied by velocity exceeds 3m^2/sec.

3.2.2 SCUBA Diving

The acronym “SCUBA” stands for Self Contained Underwater Breathing Apparatus. This is the most common type of self-contained diving equipment used. In SCUBA diving, the diver is provided with portable air supply through an oxygen tank, which is strapped to the diver’s back (Fig. 3.2). In this mode, the diver operates independently from the surface, carrying his/her own supply of compressed breathing gas (typically air).

Fig. 3.2 : Oxygen tank strapped to SCUBA diver’s back

SCUBA utilizes high pressure steel or aluminum air cylinders with two-stage regulators to deliver air to the diver. High pressure compressors are used to fill the SCUBA tanks. The first stage of the regulator is attached directly to the valve of the high pressure tank. This first stage reduces the high pressure air (generally 3,000 psi) in the tank to an intermediate pressure (110 to 150 psi above ambient). The second stage of the regulator reduces the intermediate pressure air to ambient pressure and delivers it to the diver on demand. As the diver inhales, a valve is activated which allows the air to flow to the diver. Air is inhaled from the supply tank and the exhaust is vented directly to the surrounding water.

Self-contained diving is often employed during underwater bridge inspections. This dive mode is best used at sites where environmental and waterway conditions are favorable, and where the duration of the dive is relatively short. Extreme care should be exercised when using self-contained equipment at bridge sites where the waterway exhibits low visibility and/or high current, and where drift and debris may be present at any height in the water column. Often the diver is connected through an umbilical cable or life line with the surface and has sufficient freedom of movement.

3.2.2.1 Equipments

The equipments required are open circuit SCUBA, life preserver, weight belt, knife, face mask, swim fins, buoyancy compensator-personal flotation device, wristwatch, depth gauge, submersible pressure gauge, reserve breathing gas supply etc.

3.2.2.2 Operational Considerations

SCUBA is well suited for inspection work because of its portability and ease of maneuverability in the water, in particular where many dives of short duration at different locations are required rather than one long sustained dive. SCUBA equipment weighs about 30 kg and requires no elaborate topside support operation. It has the advantage that the diver does not have to drag an air hose along.

Diving team should have at least 3 men, because one partner and one stand by diver are required. Moderate to good visibility is necessary for inspection. The areas of coral or jagged rock should be avoided. A single commercial diver using SCUBA be line-tended when in the water. When a diver is accompanied by and in continuous visual contact with him, then another diver, line-tending is may not be required. Divers using commercial SCUBA must be line-tended where visibility is poor, when the current exceeds one knot, or when diving is conducted within enclosed or physically confining spaces.

The use of commercial SCUBA is limited to water depths of 130 feet and the bottom time is limited by the amount of air the diver can carry. The depth and bottom time requirements of most bridge inspections are well within the no-decompression limits of commercial SCUBA diving. Generally, the maximum sustained time and working depth in SCUBA diving is one hour at 18 m depth. However, an expert diver can go up to 36 m for short duration of about 10 minutes. One tank holds about 2 m^3 air supplies. As the water depth or the level of exertion increases, the “bottom time” decreases.

3.2.2.3 SCUBA Diving with Mixed Gas

SCUBA diving with mixed gas is used for the same situations as normal SCUBA diving, but it has the advantage of extending the diving time for a great deal. The disadvantage is that it needs more preparation and equipment than SCUBA diving on air.

3.2.2.4 SCUBA with Full-Face Mask and Communication

Surface-to-diver communication may be desirable for certain SCUBA dive operations in order to enhance safety or inspection efficiency. Communication is possible using SCUBA, with a full-face mask, with either hard wire or wireless systems (Fig.3.3).

Fig. 3.3 Self contained inspection driver with wireless communication system

This has many advantages. During all kinds of dive work such as inspections, the diver can report directly to the surface and the surface engineer can guide or give instructions to the diver. Another advantage is the safety. The full-face mask gives protection against cold or contaminated water. When diver is using NDT equipments, he reports immediately his findings to the supervisor. The state of the technology for wireless systems has progressed to the point where direct line-of-sight conditions are not necessary for adequate transmission.

3.2.2.5 Advantages and Disadvantages of SCUBA Diving

Advantages

- Most suitable for short duration dives and shallow depths
- Low-effort dives
- Allows increased diver mobility
- Best in low velocity currents
- Not always necessary to have boat
- Lower operating cost.

Disadvantages

- Depth limitation
- Limited air supply
- Lack of voice communication with surface

3.2.3 Surface Supplied Air Diving

As its name implies, surface-supplied diving uses a breathing gas supply that originates above the water surface. Commercial surface-supplied air diving equipment used for bridge inspection is commonly referred to as lightweight diving equipment. It requires more equipment than the SCUBA diving. Surface supplied air diving (Fig. 3.4) uses a body suit, a hard helmet covering the head, and a surface supplied air system.

Fig.3.4 : Surface-supplied equipment including helmet or hand hat

In a surface-supplied system, air is supplied by a high volume, low pressure compressor (Fig.3.5) or from a bank of high pressure cylinders (tanks) equipped with a regulator to reduce the high pressure. When a compressor is used, air is sent through a filtering system into a volume tank at about 150 to 200 psi. From the volume tank, the air goes to a manifold to which the diver's umbilical is connected. Surface-supplied equipment provides the diver with a nearly unlimited supply of breathing gas and also provides a safety tether line and hard-wire communications system connecting the diver and above water personnel. Fig. 3.6 shows a diver using a lightweight helmet.

Fig. 3.5 : Surface- supplied Air equipment, including air compressor, volume tank with air filters and umbilical hoses

Fig.3.6 : Driver using surface supplied air with a lightweight helmet

The diver's umbilical is composed of a breathing air hose, a pneumofathometer air hose, a communication cable, and a strength cable. The strength and communication cable may be an integrated unit. The pneumofathometer hose is used by a tender at the surface to monitor the diver's depth. With a surface-supplied system, a tender must monitor the diver's air supply and depth, and maintain continuous communication with the diver. Umbilicals may also include hot water hoses for heated exposure suits and video cables.

Using surface-supplied equipment, work may be safely completed under adverse conditions that often accompany underwater bridge inspections, such as fast current, cold and/or contaminated water, physically confined space, submerged drift and debris, and dives requiring heavy physical exertion or of relatively long duration.

3.2.3.1 Equipments

Lightweight equipment usually consists of a full face mask or helmet or Jack Brown mask, safety harness, knife, weight belt, boots or fins, back-up air supply, and an exposure suit (a wet or dry suit). There are free-flow air helmets in which a constant stream of air is supplied to the diver, but the more commonly employed commercial helmets and full face masks incorporate demand regulators similar to those used in the second stage of SCUBA equipment. Fig. 3.7 shows a diver using a full face mask for surface-supplied diving.

Fig. 3.7 : Driver using surface supplied air and full face mask

3.2.3.2 Operational Consideration

Surface supplied air diving is well suited for waterway inspection with adverse conditions, such as high stream flow velocity up to a maximum of 4 m/s polluted water, and long duration requirements. Surface-supplied air diving provides “unlimited” breathing gas supply and communication, which greatly enhance operational safety. Helmets and dry suits also provide protection from polluted waters. Bottom times, beyond the no-decompression limits, can be achieved on surface-supplied dives if decompression schedules are used. The general working limit with Jack Brown mask is 60 minutes at about 18 m depth and up to 30 minutes at a depth of 27 m. The work limit for Kirby Morgan mask MK1 without come home bottle is 18 m, the maximum for MK1 without open bell is 10 minutes at 40 m, and with open bell 60 minutes at 58 m depth.

Surface-supplied air diving operations require more topside support than SCUBA diving operations. Surface-supplied diving has limited mobility due to the connection to the surface. Inspection work generally requires the diver to constantly change depth or travel around structures or obstacles. Additional support equipment, for both SCUBA and surface supplied operations, could include a recompression chamber (Figure 3.8 (a) & (b)). A chamber is required when dives exceed 100 fsw or when the no-decompression limits may be exceeded.

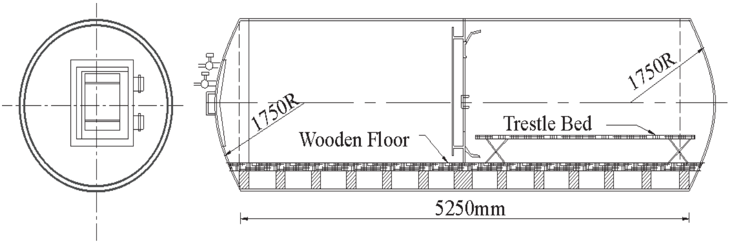

Fig. 3.8 (a) : Typical sketch of medical lock or compression chamber

Fig. 3.8 (b) : Recompression chamber

3.2.3.3 Surface Supplied Air Diving with Mixed Gas

The use of the surface supplied equipment is same as above. There are advantages using mixed gas. Nitrox will extend dive time in shallow water and Trimix or Heliox will make it possible to dive deeper than 50 meters. However, this service requires extra preparation and more equipment and personnel.

3.2.3.4 Advantages and Disadvantages of Surface Supplied Air Diving

Advantages

- Long dives or deep water diving (more than 36 m)
- Unlimited air supply
- Backup system available
- Better for low water temperature and high-effort dives

- Safe line attachment to surface
- Better for high velocity currents
- Better in polluted and turbid water.
- Does not require partner diver
- Allows direct communication for audio and video
- Topside depth monitoring is simplified.

Disadvantages

- Large size of operation
- Large boat is necessary
- Large number of equipments, e.g. Wet/dry suits, air compressors, hoses and lines etc.

3.3 Decompression

Decompression may be carried out, in water or in the medical lock on the surface. When the depth exceeds 10 m, suitable decompression arrangements shall be provided at site. It shall be carried out in accordance with the decompression tables given in IS: 4138-1977 for depths up to 35 m and for greater depths the decompression time shall be calculated by adding 5 minutes to the time for the corresponding depths as given in the (Table 3.1.)

Duration of Dive - Up to about 18 m depth, there is no limit placed on the duration of dive. For greater depths, the following may be applied:

Table:3.1- Duration of drive with respect to depth and corresponding decompression time

Depth in m	Normal Working Duration * (min)	Decompression Time (min)
18-21	95	35
21-24	75	30
24-27	65	35
27-30	55	35
30-33	45	30
33-36	40	35
36-39	35	30
39-42	30	30
42-45	25	30
45-48	25	35
48-51	20	25
51-54	20	30
54-57	20	35
57-60	15	25

* Duration of time from leaving surface to beginning of ascent.

3.4 Equipments for Diving

Air Supply Equipments - The air supply shall be fit for respiration and in adequate quantity at a suitable pressure consistent with the depth of working. In order to avoid contamination of air supply, the compressor and cylinders shall be properly maintained at all times. The compressor and the air hoses shall be suited for air used for respiration. Except in an emergency, the compressor designed for industrial use shall not be used for air supply as the efficiency of its filters is inadequate. Hose pipes previously used for industrial purposes shall not be used as these are likely to be contaminated with dirt.

Air Requirement - The minimum air supply required for a diver in normal working conditions is 45 litres per minute but may go up to 75 Iitres per minute in case of hard work. The total air output requirements may be decided by multiplying the diver's requirements by the absolute pressure in bars. For example, hard work at 30 metres depth will require 75 litres X 4 bars absolute, that is, 300 litres per minute of compressor capacity.

Air Pump - The air compressor or pump and the connected system shall be tested daily for leakage and to determine that the pressure can be maintained within the system, at the full working pressure of the dive, after the pump or the compressor has stopped.

A hand pump shall turn without undue friction, and deliver the required quantum of air against high pressure. The water jackets fitted round the cylinders shall be kept fitted with water to ensure cooling. The water shall be changed as soon as, it warms up.

The gauges shall be tested every six months, or earlier whenever an error is suspected.

Power driven compressors should always be used where more than one diver is employed or where continuous diving is called for. The capacity of the compressor shall be such that it can supply at least two divers in the maximum depth envisaged. The compressor shall always supply its air through a receiver, the capacity of which shall be such that the diver can be brought to the surface in safety in the event of a breakdown of the compressor. It shall ensure that the minimum air requirment shall meet. There shall be a separate receiver to supply air to each diver. In addition, it is recommended that the diver carries on his back two cylinders filled with compressed air, which he may avail of for bailing out of water, in the event of failure of air supply from the surface. The intake of the air compressor shall be away from the sources of any smoke or harmful gases and the filter used shall be replaced as and when required.

The air shall be cooled to ambient temperature, dried and filtered to remove any possible impurities and moisture.

Exposure Suits - An exposure suit is usually necessary to protect and insulate the diver from water temperature, because in water if the body rapidly loose heat and diver become chilled after prolonged exposure.

For underwater inspections, two kinds of exposure suits are commonly used, the wet suit and the dry suit. In warm waters, generally above 50 degrees Fahrenheit, a wet suit will provide adequate thermal protection. The suit is intended to be tight fitting and constructed of neoprene. The wet suit allows a thin layer of water between the suit and the diver’s skin. This layer of water, which is warmed by body heat, acts as insulation to keep the diver warm. A full wet suit consists of a jacket, pants, boots, gloves, and hood.

A variable volume dry suit is an extremely effective suit in cold water. Dry suits are also used extensively in polluted waters. The dry suit normally requires the diver to wear more weight than is worn with a standard wet suit, due to the volume of air in the suit.

Diving Dress - When in regular use, dresses shall be hung up at night over a jackstay to drain. These shall not be spread out in the sun. Special care shall be taken when the dress is to be maintained in between uses at long intervals. Any salt shall be washed and the dress dried before storage in a cool place in the dark. Repairs to the dress shall be promptly carried out according to the manufacturer's instructions.

Face Mask - The face mask protects a diver’s nose and eyes from the water. The air pocket within the mask allows the eye to focus on underwater images. Masks which have corrective lenses are also available.

Buoyancy Compensator - This is also called as personal flotation device. The inflatable flotation device maintains the diver at the surface in a face-up position at different depths. Proper use of the BC reduces the effort of vertical movement. It is a system of one or two rubberized air bags protected by an outer shell. Most often it is in the form of a vest, although there are also “horse collar” style buoyancy compensators.

Reserve Breathing Gas Supply - Each SCUBA diver should have a diver-carried reserve breathing-gas supply that consists either of a manual reserve (J-valve) for the primary air cylinder, or an independent reserve cylinder that has a separate regulator. The independent reserve should be of sufficient size to meet the emergency air volume requirements of the planned dive.

Weight Belt - A diver uses a weight belt to help control buoyancy. The most popular weights are molded lead which fit onto a nylon web belt equipped with a quick-release mechanism. The amount of weight worn by the diver depends on natural buoyancy and the buoyancy of the equipment that is worn. For a diver wearing a wet suit, ten to twenty pounds of weight is commonly worn. With a dry suit as much as fifty pounds of weight may be required in order to become negatively buoyant.

Swim Fins - Swim fins increase the propulsive force generated by the legs while swimming underwater. Swimming efficiency is greatly increased with a proper pair of fins.

Knife - The diver’s knife is used primarily as a tool and is available for emergencies, such as entanglement. Typically, the knife is made of corrosion-resistant metal, usually stainless steel, and has a serrated edge for sawing through larger and stronger lines.

Wristwatch - A watch or bottom-timer is a very important piece of equipment for diving. A diver uses it to stay within the no-decompression limits, to control decompression dives or to monitor rates of ascent.

Depth Gauge - Depth gauges measure the pressures created by the column of water above the diver and are calibrated to indicate a direct reading of depth in feet of water. Accurate depth readings are essential when diving in order to stay within no-decompression limits or to locate decompression stops if outside the no-decompression limits.

Submersible Pressure Gauge - A submersible cylinder pressure gauge provides the diver with a continuous indication of the amount of air remaining in the air cylinder.

Dive Lights - Dive lights are waterproof, pressure-proof, underwater flashlights. They can be very useful where natural light does not penetrate the water to the dive depths, but they are of limited usefulness in muddy or dirty water where there is significant turbidity.

Dive Computer - A dive computer continuously monitors bottom time and water depth. This device is especially useful in inspection work because the diver does not spend long periods of time at any one depth. It should not be used, however, without a full understanding of its capabilities and limitations.

Communication - In a hard-wire system, the diver has a microphone and speaker connected by a cable to a surface transmitter-receiver.(Fig 3.9, Fig 3.10, Fig 3.11). This is used regularly in surface-supplied diving and can be used when a SCUBA diver utilizing a full face mask is tended with a strength/communication line. Wireless systems are available for use with SCUBA diving equipment. The advantage of a wireless system is that it allows the diver greater mobility. Figure 3.9 shows a commercial SCUBA diver using a wireless system.

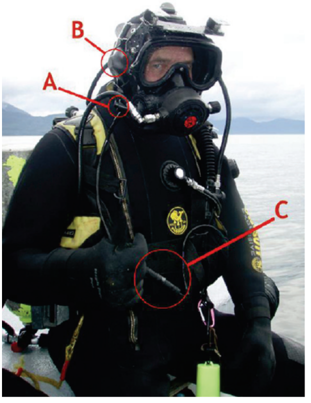

Fig. 3.9 : Driver with wireless communication system.

(A) microphone (B) Earphone (C) transceiver

Fig. 3.10 : Communication box system

Fig. 3.11 : Full face lightweight driving mask with communication system

Divers' communication device have to work under most unfavorable conditions. The helmet is always damp and there is a possibility of moisture affecting the system. Care, attention and gentle handling are essential to maintain reliable communication. All cable connections shall be checked daily to rectify loose connections.

Breathing Apparatus - Surface-Supplied breathing equipment are of two types- free flow and demand. Both types allow the diver to breathe through the mouth or the nose.

Free flow system - In this system air is delivered to a helmet continuously and then exhausted through an open valve to the surrounding water. The helmet has a tendency to float because of contineous air flow, therefore this type of helmet need to be secured through jocking harness.

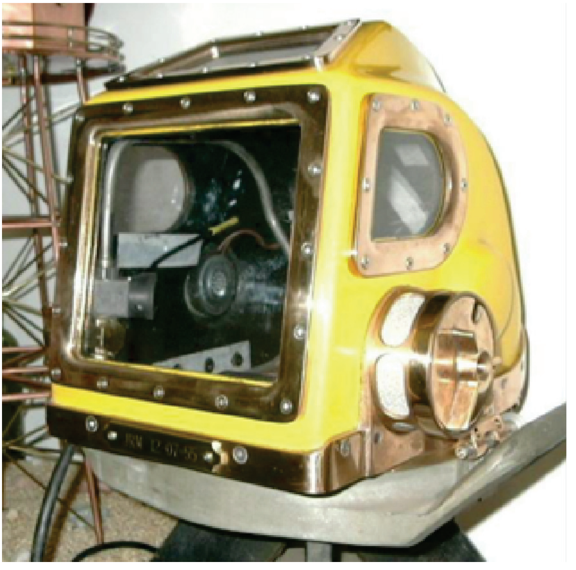

Fig. 3.12 MK 12 free-flow helmet

Demand masks - Demand masks combine a regulator, similar to the SCUBA regulator's second stage, with a “face mask” in one unit. Air is suppled to the regulator via a side block, a one way valve attacthed to mask is connected to a primary and a backup air source. (Fig. 3.7 and 3.9).

Both the helmet and the band mask generally have a movable nose pad to assist the diver in equalizing pressure in ears and sinuses. More weight will be required by a diver in a helmet because of the volume of air inside it. Jocking harnesses are not necessary with the demand helmets.

Helmet - The non-return inlet valve through which air from the pump enters the helmet shall be inspected daily. Damage to the screw threads and bearing surfaces are the main points to guard against any damage. After use, the helmet shall be wiped out, firstly with a cloth dampened in fresh water and then with a dry cloth so as to get rid of salt and dampness. The visors shall be inspected daily and any cracked ones replaced. Spare glasses shall be maintained at the site.

Air pipe - Before bringing in use any length of air-pipe, it shall be ensured that it can withstand the intended air pressure with a factor of safety of, at least two, and is composed of materials acceptable for such use.

Backup Air Sources - When a surface-supplied dive is conducted deeper than 100 fsw or outside the no-decompression limits, it is required that a diver carry a reserve breathing gas supply independent of primary system. This reserve is typically high pressure tank containg air for having suitable connection with helmet for air supply.

Tenders - Each diver must be continually tended while in the water. Tenders are responsible for ensuring that the planned dive profile is followed and for maintaining the dive station. All components of the surface-supplied dive systems, including communications, compressors, pressure gauges, backup systems, as well as the diver, are to be continuously monitored during each dive operation. As a minimum, a tender should be trained in the topside requirements of surface-supplied diving.

Ladder - The Ladder for getting in and out of the water shall have the railing carried up, at least, one metre above the top rung so that when the diver has his feet on the top rung, he has the support to steady himself.

Medical Lock - Where the maximum operating depth exceeds 20 m, a suitably constructed medical lock shall be provided and maintained and used solely for the treatment of persons working in compressed air. The medical lock and its use shall conform to the provisions of IS: 4138-1977. (Fig. 3.8 (a) & Fig. 3.8 (b)).

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CHAPTER - 4

UNDERWATER INSPECTION PROGRAMS

4.1 Introduction

Under water inspection program of a bridge substructure depends on type and extent of damage expected, inspection intensity level and frequency of inspection. It is a good practice to schedule underwater inspection immediately after monsoon. It is best to schedule underwater inspection during that period of the year when the conditions are most favourable, such as during low water or low pollution Level or good underwater visibility. The dive should be timed for the period when the tide is stable for the bridges located in the backwaters. The sub-structure of the bridges which are normally under water should be inspected by adopting suitable methods which may include engaging of divers and special equipments.

4.2 Inspection Type and Frequency

Routine underwater inspection shall be carried out more frequently to ascertain no obvious damage. Through inspection aimed at finding latent defect should be carried out in a detailed manner but at a larger interval or as the situation demands. However, special inspections based on need shall be done as and when situation warrants. The level of intensity of inspection shall vary depending upon the situation and interval at which inspection is being done.

4.2.1 Level of Inspections

The resources and preparation needed to do the work distinguish the level of inspection. Also the level of inspection determines the type of damage/defect that is detectable. Depending upon intensity and scale there are three Levels of underwater bridge inspections. The three levels of inspections are:

Level I : Visual, tactile inspection

Level II : Detailed inspection with partial cleaning

Level III : Highly detailed inspection with non- destructive testing

Level I Inspection : Level I inspection is a visual inspection on entire underwater substructure of the structure to determine obvious major damages/ problems due to over stress, severe corrosion, decay of material due to age, removal of bed sediments, biological growth and attack and external damage etc. This inspection is performed to determine the physical and functional condition of the structure, identifying changes from previously recorded conditions. This type of inspection does not involve cleaning of any structural element and can, therefore, be conducted much more rapidly than other types of inspections.

Although Level I inspection is referred as a “Swim-by” inspection, it must be detailed enough to detect obvious major damage or deterioration. A Level I inspection is normally conducted over the total (100%) exterior surface of the underwater structure, involving a visual and tactile inspection with limited probing of the substructure and adjacent stream bed. The results of the Level I inspection can indicate the need for Level II and Level III inspections and aid in determining the extent and selecting the location of more detailed inspections. The Level I inspection should be carried out by an experienced diver guided by an experienced team leader.

Following results are expected from the inspections:

- Water depth sounding and scour around piers and abutments.
- Verification of the continuity of the piers in full length.
- Registration of spalling.
- Registration of corrosion.
- Registration of cracks larger than 0.2mm.
- Registration of severe damage in general.

The report of a Level I inspection should comprise of the following:

- Method and extent of investigation.
- Background material.
- Recording of deficiencies/important aspects requiring notice of higher authority.
- Assign condition rating number of the underwater bridge components.
- Need for further inspections (Level II or III)

Photos and video recordings may be done as required but secific requirement, if any, for photo/video recording should be ascertained by Chief Bridge Engineer of the Railway.

Level II Inspection : Level II inspection is a detailed visual inspection where detailed investigations of selected components or sub components, or critical areas of structure, directed towards detecting and describing damaged or deteriorated areas that may be hidden by surface fouling, are carried out. The Level II inspection may required to detect any deficiency not readily apparent during Level I inspection. The Level II inspection should also be carried out on those underwater elements where problems/deteriorations were noted during Level I inspection. This type of inspection will generally involve prior or concurrent cleaning of part of the structural element. The marine growth, like algae / barnacles / sea grass / snails / oysters etc. if any, must be cleaned for surface inspection. Figure 4.1 shows a diver cleaning surface of concrete pier before doing underwater inspection. Since cleaning is time consuming, it is generally restricted to areas that are critical or which may be typical of the entire structure. The amount and thoroughness of cleaning to be performed are governed by what is necessary to determine the general condition of the overall structure. One or more of the following conditions may dictate the need for a Level II inspection.

- Inconclusive results from a Level I inspection
- Critical structures whose loss would have significant impact on life or property
- Unique structures whose structural performance is uncertain
- Prior evidence of distress

- Adverse environmental conditions such as brackish and polluted water.

Fig. 4.1 Diver cleaning submerged concrete surface with hand scraper

The Level II inspection should be carried out by an experienced diver guided by an experienced team leader. The result of the Level II inspection is a recording of damage in the selected areas. The damage should be measured and the extent and severity of the damage should be documented.

A Level II inspection is typically performed on at least 20% of all underwater elements, which should include areas near the low water line, near the mud line, and midway between the low water line and mud line. Cleaning of the substructure components is to be performed at these three different water depths. The bands shall normally be located in the splash zone (low waterline), the mud line (bottom of river) and at construction joints or other structural details. If no joints exist the area could be placed midway between the low waterline and mud line. On pile structure, 25 cm high bands should be cleaned at designated locations. On large faced elements, such as piers and abutments, 30 cm by 30 cm areas should be cleaned at 3 levels on each face of the structure. Deficient areas should be measured using simple instruments such as calipers and measuring scale and extent and severity of the damage documented.

When selecting the areas for cleaning one should not only concentrate on damaged and suspicious areas, but should also include apparently undamaged areas. The thoroughness of cleaning should be governed by what is necessary to identify the condition of the underlying material. A clear water box and water jet cleaning equipment may be used if necessary. During the inspection, damage or deterioration (spalling, corrosion, cracks, etc.) or corrosion should be detected and measured, and the extent and severity of the damage should be documented.

Following results are expected from inspection:

- Registration of spalling.
- Registration of corrosion.
- Registration of cracks.
- Registration of severe damage in general.

The report of a Level II inspection should comprise of the following:

- Method and extent of investigation.
- Background material.

- Recording of Deficiencies/important aspects requiring notice of higher authority.
- Assign condition rating number of the underwater bridge components.
- Need for further inspections (Level III)
- Photos and video recordings

Level III Inspection : The level of inspection to be used for a particular task is usually decided early in the planning phase. However, depending upon visibility, marine growth, and extent of deterioration, this may be adjusted as the inspection proceeds. Level III inspection is primarily designed to provide data that can be used to perform structural assessment. A Level III inspection is a highly detailed inspection of a critical structure or structural element or a member where extensive repair or possible replacement is contemplated. Level III inspection will require considerably more experience and training than Level I or Level II inspections and should be accompanied by qualified engineering or testing personnel. An experienced engineer skilled in inspection procedure and techniques must perform the structural assessment. The underwater inspection may be accomplished by a qualified engineering diver or by a qualified and certified diver; supervised by an engineer.

The scope of Level III inspection can also be required after unusual occurrence and may vary substantially by the type and severity of event. Inspection must be sufficient to determine the need for emergency load restriction or closure of bridge to traffic and to assess the Level of effort necessary to repair the damage. If measurable damage has occurred, inspections must evaluate section loss, misalignment of members, and loss of foundation support if any.

On the basis of the visual underwater inspection (Level I and II inspections) and prior knowledge the substructure may be divided into homogeneous areas. A homogenous area is defined as an area where the present level of deterioration and parameters affecting the deterioration of the substructure exhibits only a random variation. Consider for example a bridge pier in saline water. The chloride surface concentration will be large in the tidal and splash zones. The chloride surface concentration will decrease with increasing distance from the mean water level. In this case it makes no sense to compare results from different piers if the tests are not performed at the same distance from the mean water level. To overcome this problem the piers may be divided into homogenous areas.

A Level III inspection is carried out to determine in detail the type, extent and cause of damage. Furthermore, the Level III inspection should evaluate the future development of damage. In this way, the Level III inspection forms the necessary basis for the detailed assessment of the damage and the preparation of the rehabilitation design. A Level III inspection is a highly detailed inspection of critical components or components where extensive repair or possible replacement is contemplated. During the Level III inspection hidden or interior damage must be detected, loss of cross sectional area must be detected and the material homogeneity must be evaluated. Fig. 4.2 shows a diver measuring thickness of steel member using ultrasonic thickness measuring device. The

Level III inspection includes extensive cleaning, detailed measurements and selected non-destructive and partially destructive testing techniques such as ultrasonic, sample coring or boring, in-situ hardness testing etc..

Fig. 4.2 Steel pile with an ultrasonic thickness measuring device

The tests are planned using all available information from the drawings, previous underwater inspections of the bridge, underwater inspections of similar bridges and the knowledge and experience of the persons performing the underwater inspection. On this basis a "hypothesis" concerning the cause of damage, the total damaged area and the condition of the damaged area may be formulated. If the test results do not confirm the hypothesis regarding the cause of damage, the hypothesis must be revised. It may be necessary to perform supplementary tests to confirm the revised hypothesis.

4.3 Inspection Frequency

Underwater inspections based on frequencies can be of three types:

4.3.1 Routine Inspection

This is an underwater visual/feel inspection. This inspection is often characterized as a “swim by” inspection. These inspections are normally performed following new construction, modifications, or repair to establish as-built or base line structural conditions and generally become the benchmark for assessing the results of all future inspections. The basic purpose is to detect obvious damages or problems. This inspection should be of Level I. This inspection shall be carried out once in a year. This is the maximum interval at which all underwater elements of a bridge, even if it is in sound condition, must be inspected. Any problems identified during the inspection may necessitate going in for Detail Inspection.

Routine inspection determine the physical and functional condition of the structure, identifying changes from the previously recorded conditions. Routine inspections should be performed on a cyclical basis and are a proactive approach to maintenance. A routine inspection should normally include:

- A Level I inspection on 100% of the underwater portion of the structure to determine obvious problems
- A Level II inspection on 20% of underwater units selected as determined by the Level I inspection
- Sounding to be made in a grid pattern about each pier and upstream and downstream of a bridge to detect areas of scour. Local scour to be determined with probes in the vicinity of piers and abutments.

4.3.2 Detail Inspection

This inspection is more detailed and directed towards obtaining limited measurements of damaged or deteriorated areas that may be hidden by marine growth. The marine growth needs to be cleaned for surface inspection and such cleaning is restricted to sample areas of the entire underwater structures. In addition to this, Detail Inspection shall also be done on those structures where problems have been identified/ encountered during Routine Inspection. This inspection should be of Level II and shall be carried out once in five year. This is the maximum interval at which all underwater elements of a bridge, even if it is in sound condition, must be inspected. During this inspection, when there is an apparent damage to the bridge or any problem is visualised/ identified which may necessitate further investigation, Level III inspection should be carried out. However, sectional Sr.DEN/DEN should first ascertain the necessity of carrying out Level III inspection before instructing to carry out this inspection. Detailed inspection involve in-depth inspection of one or more members below the water level to detect any deficiencies not readily apparent using routine inspection procedures. One or more of the following conditions may dictate the need for an in-depth inspection:

- Inconclusive results from a routine inspection
- Critical structures whose loss would have significant impact on life or property
- Unique structures whose structural performance is uncertain
- Prior evidence of distress

- Adverse environmental conditions such as brackish and polluted water.

RDSO Report No. BS-96 “Guidelines for Underwater Inspection of Bridges” lays down that 20% of underwater units (such as piers/abutments) for each bridge, selected randomly, should be inspected every year. The random selection should be made in a way that entire structure is covered in five years. The detailed inspection should also be carried out on those underwater elements where problems/deteriorations were noted during routine inspection.

Detailed inspection typically includes Level II inspection over extensive areas and Level III inspection of limited area. Non-destructive testing may be performed and the inspection may also include partially destructive testing methods, such as extracting samples for laboratory analysis and testing and probing.

4.3.3 Special Inspection

Sometimes referred to as post-event inspections, damage inspections are typically unscheduled inspections aimed at rapidly assessing the stability of a structure in the event of structural damage resulting from environmental or man inflicted causes. Often an interim inspection is scheduled, at the discretion of the engineer, before taking up detailed inspection. An interim inspection is used to monitor a particular known or suspected deficiency e.g. foundation settlement or scour.

The scope of special inspection can vary substantially by the type and severity of event. Inspection must be sufficient to determine the need for emergency load restriction or closure of bridge to traffic and to assess the level of effort necessary to repair the damage. If measurable damage has occurred, inspections must evaluate section loss, misalignment of members, and loss of foundation support if any. Situations that may warrant a damage inspection include:

- After unusual floods – bridges located in streams, rivers and other waterways with known or suspected scour potential.
- After vessel impact, unless it is obvious that no damage has occurred.
- Build-up of debris at piers or abutments – this material build up effectively widens the unit and may cause scouring currents or increase the depth of scour.
- In case of settlements or other evidence of excessive scour.
- Evidence of deterioration or movement – many underwater deficiencies only become apparent above water when the distress extends above the water line or is manifested by lateral movement or settlement.
- Significant earthquake – bridges also need to be inspected after an earthquake where structural damage is expected.

This inspection should initially be of Level I. However, higher level of inspection can be planned if required. Table 4.1 summarises the type of material damage that is detectable with the three types of inspections.

Table 4.1 Capability of each inspection level for detecting damage

Level	Purpose	Detectable Defects		
		Concrete	Masonry	Steel
I	General visual to confirm as- built condition and detect severe damage	Major spalling and cracking, Disintegration of material, Cavitation, Severe reinforcement corrosion	Cracked joints, Fall out masonry, Impact damage	Extensive corrosion, Severe mechanical damage
II	To detect surface defects normally obscured by marine growth	Surface cracking and Rust staining, crumbling, Exposed rebar	Hollow masonry, Deep loss of mortar	Moderate mechanical damage, Major corrosion pitting
III	To detect hidden and imminent damage	Internal voids, Change in material strength, Beginning of corrosion of rebar, Quality of existing concrete, Thickness of material.	Decrease in material strength	Internal cracks

■ ■ ■

CHAPTER - 5

UNDERWATER INSPECTION PROCEDURES

5.1 Introduction

Under-water bridge inspection, especially the initial inspection, requires careful planning to ensure that work is performed effectively and economically. Prior site reconnaissance can reduce the cost by leading to selection of methods and equipment best suited to the work.

5.2 Planning an Underwater Inspection

Planning for underwater inspection is important because of

- Unknown factors which may be discovered during the diving
- The difficulty in verifying the thoroughness of the inspection
- The cost of conducting underwater inspection.

The above factors are most influential for first time underwater inspection, which set a benchmark for further inspections. The effectiveness of an underwater inspection depends on the agency’s ability to properly consider all factors:

- Method of underwater inspection
- Diving inspection intensity level
- Type of inspection
- Qualification of diver/inspecting team

With these factors considered, one may opt for a lower level of inspection. Depending on the conditions and type of damage found, a higher level of inspection may then be necessary to determine the actual bridge condition. It may also be possible that different levels may be required at various locations on the same bridge.

It is best to schedule underwater inspection during that period of the year when the conditions are most favourable, such as during low water or low pollution level or good underwater visibility. It is also a good practice to schedule underwater inspection immediately after a storm.

5.3 Preparation

5.3.1 Review of Available Records

Before taking up the underwater inspection, a detailed review of drawings and past report should be carried out for

- Types of members in the system
- Types of materials to be encountered
- Type and extent of repairs carried out in past
- Results of last underwater inspection
- Accident or damage caused to the structure

Based on the above review, the nature and extent of inspection required should be worked out. If necessary, sketches may be prepared for documentation of inspection items and defects.

5.3.2 Availability of Tools and Equipment

The engineer-in-charge, before taking up the inspection, should list out the equipments required for the inspection and ensure that they are properly working. The following equipment would generally be necessary.

- Boats with oars, motor and life preservers
- Diving gears
- Portable flashlight
- Surface cleaning tools, e.g. brushes, scrapers
- Easy-to-read measuring tape
- Knife, hand scraper and hammer
- Sounding gear for determining depth
- Other measuring devices
- Recording devices such as still and video cameras, Plexiglas, and grease pencil.
- Safety equipments

In addition to above, specialized equipments may also be kept ready for non-destructive testing of material. At occasions, partially destructive testing equipments and equipments for taking samples e.g. core cutting equipment may also be required.

5.3.3 Communication

Two-way voice communication is absolutely desired and can be accomplished by using either hard wire or radio systems. The hard-wire systems are typically used and are extremely reliable in their simplicity, but the newer wide-band radio systems are a definite improvement over the older AM and FM systems and may be preferred in certain cases.

Close circuit television is generally used for transmitting video to the surface, which can then be scrutinised by the engineer at site who can give necessary direction to the diver. However, transmitting video to the surface works well only as long as the visibility is accommodating.

5.4 Method Selection Criteria

The diver's work environment is inherently hostile; they often work in dark and cold isolation. A bridge inspector cannot properly conduct an underwater inspection if the diver's sole concern is survival. A diver must feel safe and be comfortable while working in order to do an accurate and effective job.

The dangers presented by waterways, such as high flow velocities, limited underwater visibility, potential for entanglement, and poor water quality also contribute to the hostile nature of the diver's work environment. Divers are particularly and uniquely exposed to a variety of pressure-decompression related illnesses and injuries and physiological hazards such as pressure, temperature extremes, oxygen deficiency, nitrogen narcosis etc.

The inadequate ventilation of the diver's mask or helmet results into carbon dioxide poisoning. Therefore, special care must be taken when locating the intake of a diving air source compressor to avoid contamination of air with exhaust of the compressor.

Breathing air under high partial pressures can cause oxygen poisoning which dependents upon both the partial pressure and the exposure time.

When air is breathed under pressure inert nitrogen and other gases diffuse into the tissues of the body; diffusion depends upon the depth and duration of the dive. When the diver ascends rapidly, the nitrogen will not be dissipated and gas bubbles can form in the diver's tissue and blood resulting in what is commonly known decompression sickness. For this reason, a diver may require to decompress in stages by slowly ascending and spending time at intermediate depths or in a recompression chamber, thereby allowing sufficient time for the nitrogen and other gases to safely come out of solution.

Because of the potential for nitrogen narcosis and to reduce the risk of decompression sickness, other breathing media, such as Heliox—a mixture of oxygen and helium, or Nitrox—a mixture of air with increased oxygen percentages may also be used. Mixed-gas dive stations are more costly to set up and operate, and they require specially trained dive personnel. Most bridge inspections are conducted at depths where air can be used as the breathing medium.

The majority of bridge inspections dives are of short duration or at shallow depth; therefore, decompression stops or recompression are not normally needed. Such dives are referred to as no-decompression dives.

A number of factors influence the proper underwater inspection method. Depth of water alone should not be the sole criteria in determining whether a bridge can be inspected by wading or whether it requires the use of diving equipment. Some of the factors are:

- Water depth
- Current velocity
- Underwater visibility
- Substructure configuration
- Streambed condition (softness, mud, "quick" conditions. and slippery rocks)
- Debris

Where detailed inspections are required to be carried out, surface supplied air diving is more suited as it provides longer time for detailed investigations. Since, in this method, communication is available with the diver, it is possible for an onsite engineer to give direction to the diver.

5.5 Diving Operation

5.5.1 Divers

Use of experienced divers trained and screened by a reputed commercial diving school is critical for successful underwater inspection. Divers must not only be proficient in commercial diving techniques in order to gain access to submerged structural elements, they must also possess a first hand knowledge of a wide array of deterioration and their causes for the purpose of quantifying the damage. They should be able to interpret and report what is observed. Therefore, the divers employed must have certification as a Scuba diver by a reliable certification agency, preferably a government agency.

5.5.2 Diver Qualification

The requisite qualification for divers and diving supervisors are given in IS : 10291 –1982, which stipulates that the diver:

- Should be at least 18 years of age.
- Should be certified as being fit for diving by a qualified medical practitioner within the previous six months.
- Should be satisfactorily tested to the maximum pressure he is to work in diving dress in water, or to an equivalent pressure in a compression chamber.
- Should have thorough knowledge of diving signals (IS : 10291).
- Should be competent to use helmet, diving equipments etc.
- Should be able to conduct a circular search in the bottom under conditions of no visibility and in at least 0.6m depth of mud or soft silt.
- Should be able to work on platform suspended under water.

5.5.3 Signaller (observer)

The signaler or observer are persons kept on the surface and are in communication with the divers through line (divers rope) or otherwise. He shall he medically fit and mentally alert. He shall have been certified by competent authority for having knowledge of first aid artificial respiration.

5.5.4 Standard Line Signals

A stout long line shall be used for signals. The line shall be laid over the right shoulder of user from the rear and under the left arm clear of all parts of other equipment and the end of the line shall be secured round the belt at the back and over the standing part of the line, so that the user can be pulled out when in difficulties. Various signals shown in Table 5.1 shall have the meaning as indicated against each:

TABLE 5.1 Standard signals and their meanings

Sr. No.	Signal	Meaning
1	One pull on the line	User - I am alright, stop lowering me. Attendant - Are you alright? I am stopping lowering you.
2	Two pulls on the line	User - Payout more line and lower me further. Attendant - I am paying out more line or I am lowering you.
3	Three pulls on the line	User- Take in slack line or pull me up. Attendant- I am taking in slack line, or I am pulling you up.

Sr. No.	Signal	Meaning
4	Succession of pulls	User - Danger, help me out. Attendant - Danger, I am pulling you out.

5.5.5 Diving Supervisor

A competent supervisor shall he present at all times when diving operations are in progress. He shall be familiar with IS :10291 and shall take charge of the diving operations. He shall also be fully familiar with the decompression procedures including therapeutic decompression in recompression chamber (see IS: 4138-1977). It is essential that he has previous experience as a diver.

5.5.6 Divers in a Team

One team of divers should have minimum three members. This is a requirement of safe working. The idea is while a minimum two-member team is carrying out the dive, a third member is ready for the dive in case of any emergency.

5.5.7 Safety Precautions

Every employer of workmen undertaking diving operations shall comply with the requirements of IS: 4138-1977 in so far as they affect anyone employed by him.

- The employer shall arrange for any medical examination required by the code, and
- The diver's fitness register containing details of certificates of fitness shall be kept by the employer.

The working agency should have its own diving safety manual, which should be strictly followed. This manual should include:

- Safety procedures and checklist for diving operations
- Assignment and responsibilities of dive team members
- Equipment procedures and checklist
- Emergency procedures in case of equipment failures, adverse environmental conditions, diver illness or injury.

Before taking up diving operation, the supervisor must :

- Ensure that all persons connected with the diving operations under his supervision comply with the requirements of relevant IS code (s).
- Ensure the safety of all personnel under his supervision.
- Arrangements such as control point shall be established on the surface before commencement of diving operations to take care of emergencies.
- A lifeline is provided for use of diver and arrangements shall be made for an effective signaling between the diver and the signal attendant.
- Adequate number of competent persons such as signalmen and stand-by divers shall be employed in attendance upon him to render assistance in emergency.

- A stand-by diver provided with sufficient equipment shall be available and in hazardous conditions, he shall be fully dressed to ensure diver's safety.
- Each diving operation is thoroughly planned.
- Ensure that sufficient number of signalmen and stand by divers are present at the site during the whole of the operation.
- Allocate duties of the diving crews during diving operations.
- All the diving equipments shall be physically examined before each use to ensure that they are in working condition.

A diver shall not be permitted to commence work on empty stomach or within 2 hours of the consumption of a substantial meal. He shall not dive so long as he is under the influence of alcohol or intoxicating drugs consumed by him and if such effects are visible the supervisor shall prohibit him from diving.

While operating at night two red lights fixed approximately 3m apart horizontally and visible all round shall be displayed at the surface control point. While diving operations are in progress whether in day time or in night, no power driven vessel shall be operated and no underwater explosion shall be carried out in the vicinity.

5.6 Cleaning

Before any structure can be inspected, it is necessary to expose the surface material of the structure. Wherever there is marine growth or incrustation on the surface of the structure, cleaning of the same, may be in a limited area, will be required. The best approach is to restrict cleaning to small zones, which are:

- Structurally critical areas
- Areas known to frequently deteriorate for that specific structural configuration
- Areas randomly selected to statistically lower the probability of overlooking damage

Bridge Inspector's Training Manual of FHWA, USA recommends a 15 to 30 cm bands or squares depending on the size and shape of the structure. Highest priority should be placed on locations near the low water line and connecting elements. If feasible, location at the mud line, and midway between the mud line and low water line should also be included. For large elements, squares around the perimeter should be chosen at effective intervals.

Light cleaning can be done with a diver's knife or with hand held tools such as a chipping hammer or a scraper. Cleaning of thick, hard growth will require pneumatic or hydraulic powered chippers, grinders and brushes. Tough cleaning jobs on concrete and steel may require high-pressure blaster.

Details on cleaning tools are included in Chapter 7 of this book.

5.7 Scour Investigation

Scour is probably the most critical item to be aware of when performing an underwater inspection of pier/abutment or protection work of a bridge. The most important assessment of scour is how much of the pier or abutment or protection work is exposed when compared to plans and typical designs. Therefore, inspection for scour should be carried out near pier / abutment's base at bed level on the upstream side and adjacent to it.

Local scour is detectable by divers since this type of scour is characterised by holes near piers/protection works. Divers should routinely check for such scour holes. A typical approach is to take depth measurements around the substructure, both directly adjacent and at concentric intervals. Measurement should be taken at 10 cm increments from upstream to downstream end. Water depth and height of scoured level to normal mud line should be measured and recorded. It should be noted that divers operate in low current situations. Sediments often refill the scour holes during these periods. However, since this refilled sediment is usually soft, a diver using a probing rod can often detect soft areas indicating scour refilling.

Diver's role is primarily to point out a potential scour problem. The diver can use any one of the following methods to measure the scour :

- Diver investigations
- Sounding /sensing devices

5.7.1 Diver's Investigations

The dive team should also conduct a scour Investigation at the bridge sites including:

i) Inspect the channel bottom and sides for scour. Diver should detect undermine and scour holes, small diameter but deep scour holes around piles.

ii) Cross sections of the channel bottom should be taken and compared with as-built plans or previously taken cross sections to detect lateral channel movement or deepening (see Fig. 5.1)

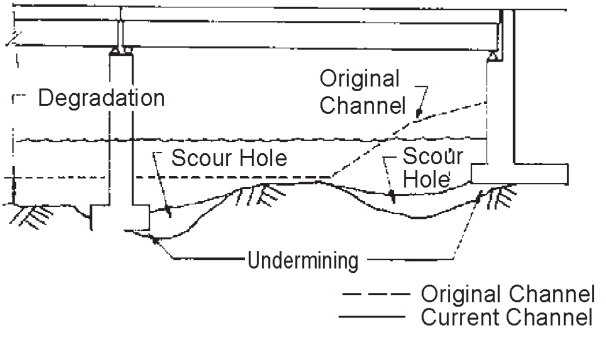

Fig. 5.1 Channel cross section

iii) Soundings should be made in a grid pattern(see Fig.5.2) about each pier and upstream and downstream of the bridge, developing contour elevations of channel bottom, to detect areas of scour.

Permanent reference point markers should be placed on each abutment/pier. Data obtained from the soundings should be correlated with the original plans (if available) of the bridge foundations and tied to these markers for reference during future underwater inspections.

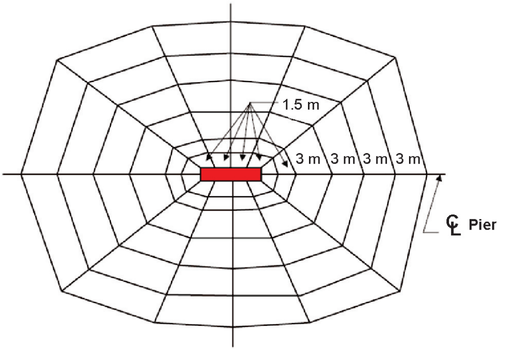

Fig. 5.2 Pier sounding grid

iv) Local scour and undermining should be determined with probes in the vicinity of piers and abutments. In streams carrying large amounts of sediment, reliable scour depth measurements may be difficult at low flow due to scour hole backfilling. Properties of soil helps in determining back filling of scour holes so diver should collect soil samples.

Divers should take photographs of the bottom showing scour at different locations along the stream and around the structure for thorough evaluation of scour by the engineer.

5.7.2 Sounding-Sensing Devices

Although sounding - sensing devices can be used independently of diving, they are commonly part of an underwater inspection. For details see Chapter 6. With the exception of poles and lead lines, sounding-sensing devices depend on some type of signaling system. While these systems are quite effective, yet they can be misinterpreted. Therefore, an on-site diver can investigate questionable readings and more fully determine the channel bottom conditions.

5.8 Inspection of Masonry Substructures

5.8.1 Inspection Procedure

Brick or stone masonry substructures typically develop problems at joints between pieces of brick or stone, mostly due to loss of fill from behind the structure due to current action. Sometimes falling of loose masonry also creates unsafe condition. Inspection of masonry structures may be carried out as under:

- Begin the inspection at the water line, checking for excessive weathering and abrasion deterioration, and loss of mortar from the joint.
- Inspect below the waterline, taking note of general condition of the pier/abutment and paying particular attention to the joints between each stone.
- If there are significant gaps between stones/ bricks or stones/bricks are missing, note the location, depth and length of missing masonry.
- Any crack in the masonry should be measured using a ruler. Length and breadth of the crack should be recorded on a Plexiglas plate.
- Continue to the bottom of the structure and note any undermining or scouring of the material under the structure.
- At any missing stone/brick or undermining, probe the cavity to estimate the extent of void behind or below the structure.

- Take photographs and video to capture the defects for analysis and evaluation by the engineer.

After returning to the surface, all the information gathered should be recorded in the predetermined format for further analysis and planning of maintenance work.

5.8.2 Equipments and Tools Required

Since the underwater inspection of stone masonry substructures involve only a cursory inspection of the joints between stones and the general condition of the wall and its foundation, only a few tools are required. A sounding hammer is generally used to assess the voids below the surface. A ruler may be used to determine the width and depth of cracks and open joints, as well as the size of missing stones or pieces of stone. A length of small diameter rebars or other suitable probe can be used to check the voids in the fill behind or below the wall. A Plexiglas slate and a grease pencil are used underwater to record any pertinent information, or the information is communicated to topside personnel via hardwire. Small hand tools, such as wire brushes and scrapers are also useful to clear off cracks and joints.

5.9 Inspection of Concrete Substructures

5.9.1 Inspection Procedure

Details of problems and deterioration in underwater concrete substructures have been discussed in Chapter 2 earlier in this book.

The underwater inspection of a pier/abutment should include all pier/abutment surfaces between the high waterline and the mud line. The entire pier surface may be divided into suitable number of segments along the perimeter, each covering a height of 1 to 1.5 m. A typical arrangement is shown in Fig. 5.3. This facilitates identification of location of defects.

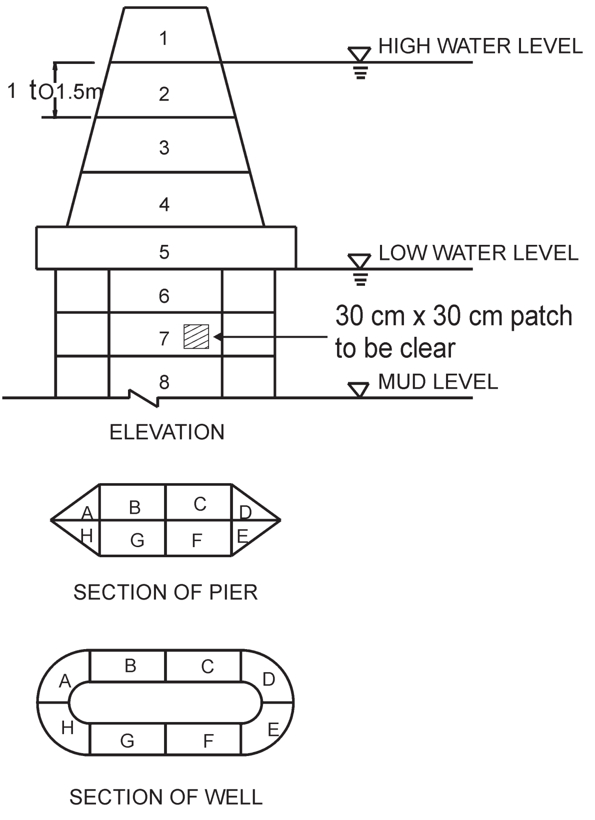

Fig. 5.3 Numbering of segments

Inspection of pier/abutment may then be carried out as under:

i. Conduct visual inspection of the entire surface using up and down sweeping motion. If the surface is covered with marine growth, one of the segments as marked in Fig. 5.3 should be thoroughly cleaned and examined particularly just below the waterline, mid point between waterline and mud line, and at mud line.

ii. Visually inspect this area for cracks, surface spalling, cavitation, mechanical damage, exposed reinforcing steel. Diver should be alert for any change in appearance of the concrete surface.

iii. Sound the cleaned area with a hammer to detect any loose layers of concrete/hollow spots in the structure. A sharp ringing noise indicates sound concrete. A soft surface will be detected not only by a sound change but also by a change in the rebound or feel of the hammer. A thud or hollow sound indicates a delaminated layer of concrete or internal voids.

iv. Descend, visually inspecting the structure and inspect in greater detail the base of the structure. Note down any signs of undermining by wave and current action. Record the water depth with any observation of damage on a Plexiglas plate.

v. Cracks found on the surface of the concrete structure should be given careful attention. Sketches should be made to show the length and direction of the cracks. Still and video photograph should be taken as they are helpful in later decision making.

5.9.2 Equipments and Tools Required

To perform a thorough inspection, the marine growth on the structure must be removed. A "Barnacle Buster" or pneumatic chipping gun is an efficient method of removing marine growth from concrete surfaces. Various types of high-pressure water jet cleaning systems are also effective. Exercise care in the use of these methods because they may further damage a deteriorating concrete structure. If minimal marine growth is found in the splash/tidal area, small hand tools, such as wire brushes and scrapers are sufficient. A hammer for sounding and an accurate water-depth gauge will be required. Record observations on a Plexiglas slate with a grease pencil. Use underwater still/ video camera for permanent visual documentation.

5.9.3 Level III: Non-Destructive Inspection

If there is evidence of significant deterioration, then a Level III inspection, involving either non-destructive or destructive tests, may be required. Some of the NDT equipments that can be used for underwater examination of concrete are:

- Rebound Hammer
- Ultrasonic system
- Magnetic Rebar Locator

Each instrument consists of an underwater sensor connected to a topside deck unit through an umbilical cable. The deck unit contains the signal conditioning electronics and data acquisition system. To operate the instrument, the diver has to position the underwater sensor on a previously cleaned portion of the structure surface, and person topside operates the data acquisition system in order to collect and store the data.

Detailed information on underwater non-destructive equipments is included in Chapter 6 of the book.

5.10 Inspection of Steel/Cast Iron Substructures

5.10.1 Inspection Procedure

Corrosion is the principal cause of deterioration in steel waterfront substructures. On bare un-protected steel pilings, corrosion is often most severe just above the high tide line with another zone of severe attack just below the low tide line. The most vulnerable area in rivers is area at waterline where air and moisture cause rust formation. Submerged steel is also subjected to galvanic corrosion.

Underwater Inspection of steel/cast iron structures may be carried out as under:

i. Start the inspection at splash/tidal zone and proceed to 30 cm below the mean low water level. This is where most mechanical and corrosion damage is normally found.

ii. Inspect general condition of steel/cast iron. If there is marine growth, clean all marine growth from a 30 cm square section of pile and inspect for rust, scale and any pitting.

iii. Sound the surface with a hammer to detect any scaled steel or hollow areas.

iv. In case of cast iron, check for soft steel with knife or knocking by hammer.

v. Descend, visually inspecting the structure and sounding with a hammer where there is minimal marine growth.

vi. Record other visual observations such as coating condition (peeling, blistering, erosion). Closely inspect splices for loss of weld material and looseness.

vii. Record the extent corrosion, structural damage, or any other significant observation, using callipers and scales to measure the thickness of steel flanges, webs, and plates, and ultrasonic meters to measure the thickness of steel pipe piles and sheet piling.

viii. Take still/video photographs showing general condition of the structure. Also take close up photographs of damaged areas.

5.10.2 Equipments and Tools Required

To ensure thorough inspection, the area must be cleared of all marine growth. Hand tools such as wire brushes and scrappers are sufficient for smaller jobs. For larger area, high-pressure water jets are most effective method. Sounding of structure can be done with a small hammer or pickaxe. Callipers and scales are used to determine thickness of steel flanges, webs and plates. Visual documentation can be recorded using underwater camera.

5.10.3 Level III: Non-Destructive Inspection

Some of the structural defects in steel structures may not be visible during visual inspection. In that event more detailed non-destructive techniques (NDT) may be required under a Level III inspection. Following equipments may be used for NDT testing underwater.

- Ultrasonic flaw detection for thickness measurements
- Underwater magnetic particle testing for surface and sub- surface cracks
- Radiography for internal defects

Details on underwater non-destructive testing of steel structures are presented in the next chapter.

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CHAPTER - 6

UNDERWATER NON-DESTRUCTIVE TESTING

6.1 Introduction

Generally, visual inspections will allow detection and documentation of most forms of deterioration of structures; some types of structural defect may not be detectable during visual inspection. Underwater non-destructive techniques (NDT) are now available for testing material condition underwater. However, performing underwater NDT can cause a decrease in reliability as compared with above-water testing. There are factors that influence the results, such as environmental and working conditions, qualification of personnel, inspection procedures, and capacity and performance of the equipment. If all these factors are resolved, it is possible to achieve a reliable test.

The most common underwater tests are the following:

6.2 Sounding - Sensing Devices

Sounding devices are effective in checking scour in the stream bed adjacent to a bridge.

Common types of sounding - sensing devices are described in the following para.

6.2.1 Black & White Fathometer

Most commonly used sounding device is black & white fathometer (Fig 6.1). The units are compact and easy to use. They consist of a transducer, which is suspended in the water, a sending/receiving device, and a recording chart, which displays the depth on paper. High frequency sound waves, generally in the range of 200 kHz, emitted from the transducer travel through the water until they strike the channel bottom and are reflected back to the transducer. The fathometer measures the time it takes the sound waves to return to the transducer, and converts that time to the depths of water, which are displayed on a graphic recorder in the form of a continuous plot of the channel bottom.

Fig. 6.1 Black and white paper chart Fathometer

Advantages of the black & white Fathometer are:

- Inexpensive
- Effective

Disadvantages include the following:

- False readings can occasionally occur due to heavy drift or turbulence.
- The strip chart moves at a constant rate and does not record a horizontal scale; unless the boat can be kept at a constant speed, the scale becomes distorted.
- Fathometers may also fail to detect refilled scour during calm water.

6.2.2 Dual Frequency and Colour Fathometer

Dual Frequency and Colour Fathometers can be used to detect refill in the scoured area since more than one frequency is utilised. With Colour Fathometers, materials having different densities are displayed in different colours. A video tape recording becomes necessary to get a hard copy of the display.

6.2.3 Fathometer with Theodolite

The horizontal scale problem in use of Fathometer can be solved by using equipment, which combines a Fathometer with a total station theodolite. The theodolite is set up on shore, it tracks and records the coordinates of the transducer, and automatically records depths at specified increments using a microprocessor. The data can be plotted on a topographic map.

6.2.4 Fixed Instrumentation

It is possible to monitor local scour at pier or abutment using fixed instrumentation as an alternative to the sounding and scour sensing devices. With fixed instrumentation, local scour can be continuously monitored on real time basis, unaffected by washing back of silts and sands.

The instrument consists of a steel rod inside a conduit attached to the pier or abutment (Fig. 6.2). The rod acts as a probe, resting on the stream bed supporting the pier/abutment. As local scour occurs the soil is washed away and the rod drops which can be measured.

Fig. 6.2 Arrangement showing fixed instrumentation for scour measurement

6.2.5 Ground Penetrating Radar

Ground penetrating radars (GPR) and low frequency sound are also used in scour survey. These are good in shallow water but not very effective in salty, brackish water.

GPR survey system transmits radio frequency electromagnetic pulses into the water and bed sediments and receives energy reflected back from surface and sub surface reflectors. The reflectors can be any sub surface contact between water and geological material or geological materials with different physical and material properties. Man made materials such as concrete and steel also can be a sub surface reflector.

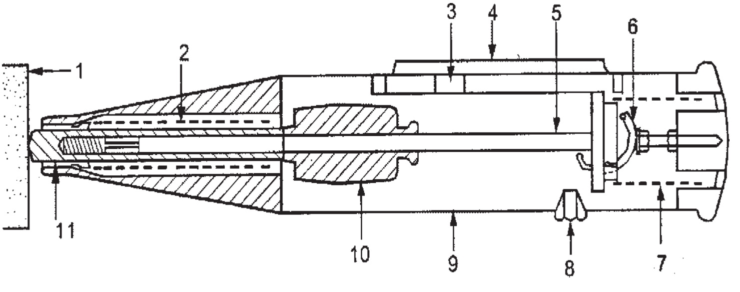
All depths to existing and new scour holes and bed bottom and sub-bed bottom reflectors are approximate. These depths are based upon estimated ground penetrating radar two way travel time for water, saturated sands, fill and bed rock (Table 6.1).

Table 6.1 Approximate ground-penetrating radar two-way travel time for selected materials

Material	Approximate two way travel time (nanosecond per m)
Water	59
Saturated Sand	33
Fill	21
Bed rock	16

6.3 Rebound Hammer

The underwater rebound hammer system is a surface hardness tester that can be used to obtain a general condition assessment of concrete. The system consists of an underwater rebound hammer, an umbilical cable, and a topside data acquisition unit (DAU). The rebound hammer is mounted in a waterproof housing which contains an electrical pick up to sense the position of the rebound mechanism. The umbilical cable connects the underwater rebound hammer to the DAU that contains the signal conditioning electronics and data acquisition system. Various components of a rebound hammer are shown in Fig. 6.3 (a).



1. Concrete surface
2. Impact spring
3. Rider on guide rod
4. Window and scale
5. Hammer guide
6. Release catch
7. Compressive spring
8. Locking button
9. Housing
10. Hammer mass
11. Plunger

Fig. 6.3 (a) Components of a rebound hammer

The rebound hammer correlates the rebound height of a spring driven mass after it impacts the surface of the concrete. The spring driven mass slides on a guide rod within the tubular housing (Fig. 6.3 (b)).

Fig. 6.3 (b) Water proof rebound hammer

When the impact plunger is pressed firmly against the concrete surface, a trigger releases the spring-loaded mass causing it to impact the plunger and transfers the energy to the concrete surface. The mass then rebounds and the rebound height is correlated to the surface hardness of the concrete. A general calibration chart relates the rebound number to the cube compressive strength for the underwater rebound hammer.

6.3.1 System Limitations

The following characteristics of concrete can affect the correlation of the rebound number with the actual surface hardness and should be taken care of for better results.

i. High rebound numbers are generally obtained for smoother surfaces and the scatter in the data tends to be less. Minimising the data scatter increases the confidence in the test results. Therefore, underwater concrete surfaces must be thoroughly cleaned and smoothened with a carborundum stone or similar abrasive before tests are conducted.

ii. Water saturated concrete tends to show rebound readings lower than for the same concrete tested dry. This may affect the comparison of data taken above and below waterline. An assessment of reduction in rebound number in an underwater test should be evaluated, and necessary correction should be applied to rebound number.

iii. Type of aggregate and cement affects the correlation of the rebound numbers with actual compressive strength of the concrete under test. A calibration curve is required for each particular concrete mix to assure accuracy.

Because of these limitations, the estimation of concrete compressive strength obtained with a rebound hammer may vary upto ± 20% from the actual strength. The rebound hammer is primarily useful for checking surface compressive strength or surface hardness and uniformity of concrete within a structure. It can also be used to compare one concrete structure element against another if they are reasonably similar.

6.4 Magnetic Rebar Locator

The Magnetic rebar locator is an instrument that detects the disturbances in a magnetic flux field caused by the presence of magnetic material. The magnitude of this disturbance is used to determine the location and orientation of rebar in concrete structures and to measure the amount of concrete cover over the rebar. The system consists of an underwater test probe, an umbilical cable, and a topside data acquisition unit (DAU) including printer.

The test probe consists of two coils mounted on a U-shaped magnetic core. A magnetic field is produced in one coil and the disturbance-induced magnetic field in the rebar is measured in the other coil. The magnitude of the induced current is affected by both the diameter of the rebar and its distance from the coils. Therefore, if either of the parameters is known, the other can be determined. By scanning with the probe until a peak reading is obtained, the location of the rebar can also be determined. A maximum deflection of the meter needle will occur when the axis of the probe poles are parallel to and directly over the axis of a reinforcing bar, thus indicating orientation.

The underwater rebar locator is calibrated for rebar that varies from No.3 to No.16 in size. The meter can be used to measure the depth of concrete cover over rebar in the range of 5 to 200 mm thick, or conversely, it can measure the diameter of the rebar. The best accuracy (± 10 percent) is obtained for concrete cover less than 100 mm thick.

6.4.1 System Limitations

The presence of other metallic objects in the vicinity where the measurements are being made can affect the operation of the rebar locator. For example, in heavily reinforced structures, the effect of nearby rebar cannot be eliminated and accurate depth readings are difficult or impossible. If the separation of two parallel rebars is at least three times the thickness of the concrete cover, this effect can be neglected. The presence of rebar perpendicular to the axis of the underwater probe has less effect on the measurement of concrete than that of parallel rebar, and in most instances it can be ignored.

6.5 Ultrasonic System for Concrete Elements

Ultrasonic methods can be used underwater for overall assessment of the strength of concrete based on sound velocity measurements through a large volume of structural element. It can also be used to detect and locate flaws and discontinuity in concrete elements. It is, however, recommended that the underwater ultrasonic system be used primarily for checking the uniformity of concrete from one test location to another in a given structure. If the data consistently indicates poor or very poor quality concrete, core samples must be taken and standard compression test performed to confirm the results.

The system consists of two different underwater transducer holders for direct and indirect sound velocity measurements. An umbilical cable connects either the direct or indirect transducer holder to the topside DAU. The DAU contains most of the signal conditioning electronics and data acquisition system.

In ultrasonic testing, an electric pulse is generated in the test instrument and transmitted to a transducer that converts the electric pulse into mechanical vibration. The vibrations are transmitted into the object being tested. A portion of this energy is reflected to the receiving transducer, where it is reconverted to electrical energy and sent to the DAU. Sound velocity is calculated by measuring the time required for transmission of sound wave over a known path length. Table 6.2 presents suggested condition grading for concrete based on pulse velocity measurements.

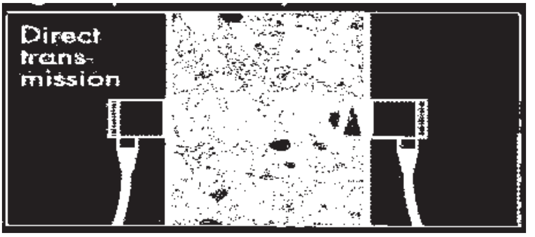
Table 6.2 Criterion for concrete quality grading

Pulse Velocity (km/sec)	Concrete quality grading
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

Three types of transmission through the testing element is possible, namely:

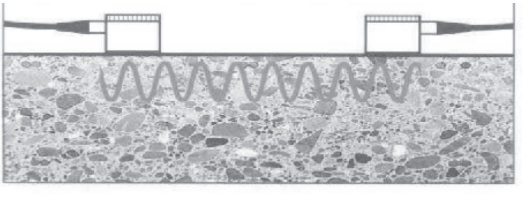
- Direct transmission
- Semi direct transmission
- Indirect transmission

Direct transmission is used to examine structures wherever opposing surfaces are accessible; for example concrete piles. The indirect transmission is used when only one surface is accessible. Fig. 6.4 shows the three types of transmission through the element. The direct transmission is most preferred as it provides maximum sensitivity with a well-defined path length.



a) Direct Transmission

b) Semi-direct transmission



c) Indirect transmission

Fig. 6.4   Types of transmission

6.5.1   System Limitations

Though ultrasonic pulse velocity method is most widely used method for non-destructive evaluation of in-situ concrete, the results obtained with the ultrasonic test systems are affected by following factors which influence the quality of the data.

i. Cleanliness of surface - Sound energy transmission is greatly affected by marine growth on the surface of the concrete element. Ultrasonics require a clean bare surface for accurate results. Therefore, concrete surface should be thoroughly cleaned before performing the test.

ii. Concrete surface finish - The smoothness of the surface under test is important to ensure proper acoustical contact between the transducer and the concrete surface. A coupling agent, such as silicon grease, must be placed between the transducer and concrete surface to ensure transmission of maximum energy. If a coupling agent is not used, the transmitted signal will be severely attenuated which results in large errors in the measurement of transit time.

iii. Reinforcing Steel - The sound velocity measurement taken parallel to the reinforcing bars embedded in the concrete will be markedly higher because sound velocity in steel is 1.2 to 1.9 times the velocity in concrete. The effect is small when the axis of the rebar is perpendicular to the direction of sound propagation and the correction factors are of the order of only 1 to 4% depending on the quality of concrete. It is, therefore, recommended that sound transmission paths should be chosen, based on available drawings that avoid the influence of the rebar. If drawings are not available, rein forcement locator equipments may be used to verify the presence and orientation of embedded rebars. (Fig. 6.5)

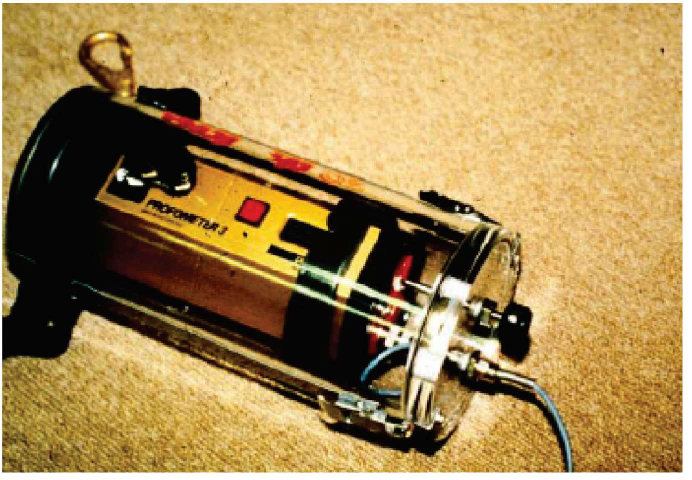


Fig. 6.5 Rebar locator

iii. Signal detection threshold - The signal detection threshold of the ultrasonic system can cause erroneous transit time data to be recorded. This happens when the amplitude of the first peak of the received signal is below the threshold triggering level of the system. When the instrument detects a following peak, this causes an apparent transit time increase of one-half wavelength or more.

6.6 Ultrasonic Thickness Measurement

Ultrasonic thickness meters measure the thickness of steel by passing an ultrasonic wave through the member. Thickness measurements are obtained because certain types of ultrasonic waves travel at a constant speed through a material, because they travel in straight line, and because a portion of the wave is reflected when it meets end interference. The difference in time between the detection of the front surface and back surface echoes is correlated to the thickness of the material. Transducer is placed on one side only, and the thickness is displayed on LED readout. Totally submergible or surface display units are available. Ultrasonic thickness meters available in the market can measure the thickness of the steel through coating up to 6 mm. For use in turbid water, thickness meters with topside repeaters can be used.

Ultrasonic thickness measurements require thorough removal of marine growth. Measurement can be unreliable if the surface on which the instrument is placed is highly pitted. The applicability of use of ultrasonic thickness meters on cast iron has yet not been confirmed. Presence of random graphite spicks in cast iron reflects sound waves, which leads to erroneous data.

6.7 Underwater Magnetic Particle Testing

Underwater magnetic particle testing (UWMT) is a non-destructive testing suited for detection of surface cracks or discontinuities in magnetic materials underwater. Magnetic particles are attracted to flux leakages at the surface of magnetised materials forming a ridge of magnetic particles around the surface cracks.

In operation, magnetic element is magnetised using an electromagnetic yoke specially designed for underwater use. Wherever surface discontinuities exist, with the yoke's field of influence, magnetic flux will leak from the surface of the part. Slurry of magnetic particles are attracted to, and aligned with the leaking magnetic flux. The particles are brightly coloured and form a visible indication corresponding to the location of discontinuities at or very near the part surface.

Equipments required for conducting UWMT are:
Inspection Equipment:

- Electronic yoke with power cable
- Ground fault interrupter
- White light source
- Magnetic particle applicator
- Magnetic field applicator

Surface preparation Equipments:

- Diver Staging (as required)
- Hydraulic hand held grinder or high pressure water jet

Recording Equipments:

- Stereo and or still camera (optional)
- Video and monitoring system (optional)
- Measuring devices

6.7.1 Limitations

As with any non-destructive test method, UWMT has some limitations as under:

i. Underwater magnetic particle testing has limited surface capability. It is considered to be strictly a method for detecting and measuring surface discontinuities. It is not an approved method for detection of flaws below the surface.

ii. UWMT method can only be applied to ferromagnetic materials. For most applications, a simple check with a magnet is sufficient to determine suitability for UWMT.

6.8 Radiography

Radiographic non-destructive examination of components is based on the phenomenon that materials absorb radiation energy as it passes through them. The amount of energy absorbed depends on several factors, the main ones being the density of the material and the path length in that material. As a rough guide, greater the density of the material and longer the path length, the greater the radiation absorption.

In this method, x-rays and gamma rays are used to detect those features that have an appreciable thickness in a direction parallel to the radiation beam. Discontinuities, which have measurable thickness in all directions, can be detected as long as they are not too small in relation to the section thickness. Radiography is more effective when the flaws are not planar.

The radioactive isotope emitting x-rays or gamma rays is secured to the work site and the films in a light proof and watertight cassette is secured on the opposite side. The source is so close to one surface that it does not register on the film, and only the far wall is recorded. Multiple exposures are required in order to achieve all round coverage.

Divers are employed to place the source in its secured and safe condition, as well as the film cassette. After securing the source and the cassette at desired location, diver is withdrawn to a safe location. Source is exposed for the correct time by remote control. On completion of the exposure, the source is secured into its safe condition by remote control. Once this has been verified by remote control video camera, the diver is sent to move the source to the next exposure position. This procedure is used for each exposure until total coverage has been obtained.

6.8.1 Limitations

i. Radiography is a costly and time consuming method, which requires extensive safety measures to be adopted at site.

ii. Radiography may miss cracks, which are not parallel to the radiation beam or are in thick sections.

Computerised Tomography (CT), which is again based on radiography, is a recent and more advanced method. With this, voids can be located, steel locations can be pinpointed and sections can be indicated accurately.

6.9 Dynamic or Vibration Tests

Tests of this type, also known as sonic integrity test, involve subjecting the element to a single impulsive blow or cyclic load, and measuring the response of the element. This response is measured in terms of decaying response. All other things being equal, the response of the element will depend on the stillness of the element and the naturally inherent damping, both of which are changed by the presence of flaws. Therefore, if there was a change in response between two tests, a close investigation should be carried out to establish a cause.

The system generally employs accelerometers to detect the vibration signal. The accelerometers are mounted on the structure to a depth of 30 m below the surface, and the frequency analysis required to compare the vibration signature at various times is carried out by computer.

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CHAPTER - 7

INSPECTION EQUIPMENTS

7.1 Access Equipments

Short span bridges can often be accessed from riverbank or shore. However, many bridges with longer span will require a boat for access. Typically a 3 m or longer vessel can safely handle the equipment and crew. Occasionally, access is made from the bridge itself.

7.2 Diving Equipments

Generally two types of diving, (i) SCUBA diving and (ii) surface supplied air diving, is employed in underwater inspection of bridges. In SCUBA diving, air supply is provided by the pressure tank carried by the diver. Surface supplied air diving equipment includes a compressor, which collects and pumps air into a volume tank for storage. The compressed air is regulated to the diver through a hose, which passes through an air filter. The hose is part of a tether, which includes a safety line, communication line and Pneumofathometer hose. The pneumofathometer provides depth measurements to the surface. A reserve air tank may also be carried by the diver for emergency.

In addition to above, following personal equipments are required with the diver:

- Exposure suit (wet or dry)
- Face mask or helmet
- Breathing apparatus
- Weight belt
- Swim fins
- Knife
- Wrist watch
- Buoyancy compensator (a floatation device capable of maintaining a diver face up at the surface)
- Depth gauge
- Pressure gauge

For detail please see Chapter 3.

7.3 Surface Cleaning Tools

To perform a thorough inspection, the marine growth on the structure must be removed. This can be done by various means, depending on surface support. There are basically four modes of cleaning which are described below.

(a) Hand tools : Hand tools include scrapers, wire brushes, chain and wire ropes. Tools of this type are suited where cleaning is confined to smaller areas. They are unlikely to cause any damage to the structure itself. The disadvantages are that they are slow to use; some hard foulings can not be removed; and prolonged use leads to diver fatigue.

(b) Pneumatic tools : These are more efficient than hand tools and cause less diver fatigue. The disadvantages are that below about 20 m, they are grossly inefficient; needle guns can cause notches and thus cause damage to the structure; and grinders can be both difficult to control and may remove lot of material if not properly controlled. The use of these tools on concrete is limited.

(c) Hydraulic tools : Hydraulic tools include grinders, rotary brushes and scrubbers. The advantages of hydraulic tools are the same as those of pneumatic tools, with the added advantage of no depth restriction. The disadvantages are that they are quite heavy and hoses are stiff and awkward to handle.

(d) Water jets : These tools are widely used and produce a bright metal finish in one operation. Grit entrainment is available and makes the tool even more efficient. The main disadvantages are operator safety and the fact that unskilled operators can cause damage by scouring the surface of the material to be inspected. The use of water jets on concrete should be tightly controlled.

7.4 Inspection Tools

A number of inspects tools are available. The dive team should have access to the appropriate tools and equipments as warranted by the type of inspection being conducted. Inspection tools and equipments include:

i) Handheld tools such as flash lights, rulers, and tape measures for documenting areas; small or large hammers or pick axes for performing soundings of the structural member; callipers and scales for determining thickness of steel flanges, webs and plates or diameters of piling; and chipping tools for prodding the surface of the concrete to determine the depth of deterioration.

ii) Mechanical devices including a Schmidt Test Hammer for measuring concrete surface hardness, and rotary coring equipment for taking core samples from concrete structures.

iii) Electrical equipment such as Rebar Scanner for scanning of rebars; underwater sonic and ultrasonic equipment for detecting voids in concrete, and thickness measurement of steel; Underwater Magnetic Particle Testing to locate and define surface discontinuities in magnetic materials.

7.5 Underwater Photography and Video Equipments

Still photographs and video records facilitate in-depth documentation of underwater inspection. Video systems can provide pictorial representation of existing conditions, transmit visual data to topside personnel for analysis and interpretation, and provide a permanent record of the inspection process. The photography system used in underwater inspection includes still-photography equipment, video recording system, video imaging system and any accessories. Fig. 7.1 Shows diver using digital camera in water proof housing.

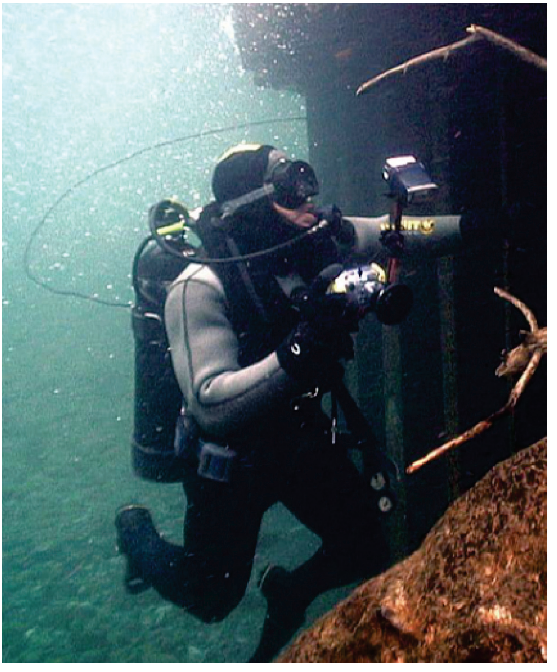

Fig. 7.1 Digital camera in waterproof housing

7.5.1 Still Photography Equipments

Still photography equipment includes cameras and lighting. Most above water cameras ranging from the "instamatic" type to sophisticated 35 mm cameras can be used underwater in waterproof cases. There are also waterproof 35 mm cameras designed specifically for underwater photography. These cameras usually include specially equipped lens and electronic flashes to compensate for the underwater environment.

Cameras come with a variety of lens and flash units.

Wide-angle lenses are preferably used where visibility is limited and camera is required to be placed close to the object. Fig. 7.2 shows vanious water proof camera housing

Fig. 7.2 Various waterproof camera housing

Suspended particles often scater the light reaching the object and can reflect light back into the lens. When visibility is low, clear water boxes can be used. The boxes are made of clear plastic and can be filled with clean water. By placing the box against the object area, the dirty water is displaced and the camera shot can be taken through the clear water.

7.5.2 Video Equipments

Video equipments are available either as self contained, submergible units (Fig. 7.3), or as submergible cameras having cable connections to the surface monitor and controls. The latter type allows a surface operator to direct shooting while the diver concentrates on aligning the camera only. The operator can view the monitor, control the lighting and focussing and communicate with the diver to obtain optimum image.

Fig. 7.3 Self-contained submergible video camera

An extension of video camera is a Remotely Operated Vehicle (ROV), where the diver is eliminated and the camera is mounted on a surface controlled propulsion system (Fig. 7.4). However, its effectiveness diminishes substantially in stream velocities greater than 1.5 knots and turbid water.

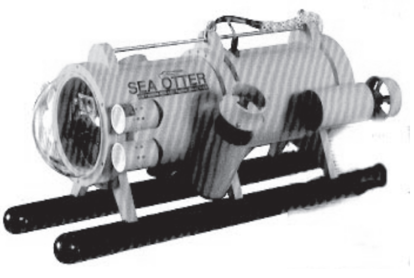

Fig. 7.4 Remote Operated Vehicle (ROV)

7.6 Surface Communication

It is not necessary to have voice communication in all situations, particularly for shallow dives where the diver can readily return to report any findings. However, on deep dives, there are several advantages provided to the underwater inspection by the use of direct two-way communication.

i) It allows the diver to immediately describe observations and location for simultaneous recording by a note taker on the surface.

ii) The diver can take guidance from the engineer on the surface for further investigation.

iii) Areas of concern can be more clearly and efficiently defined.

iv) The surface communication allows an engineer at the surface to discuss observations with a non-engineer diver, to direct attention to specific zones, and to have follow-up inspection with specific measurements according to the type of damage found.

v) As the diver proceeds with inspection, a note taker can follow drawings, verify their validity, note damages on the drawings at the proper location and track the progress of the diver.

vi) Diver can inform the surface personnel about any impending danger or problem.

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CHAPTER - 8

SPECIAL CONSIDERATIONS FOR UNDERWATER INSPECTION

8.1 Introduction

Once a diver enters the water, there environment changes completely. Visibility decreases and is often reduced to near zero due to muddy water and depth. The diver not only has reduced perceptual capabilities but is less mobile as well. Manoeuvrability is essential for underwater bridge inspections. In many cases, artificial lighting is required. In addition to above, certain special situations are encountered, which require special consideration.

8.2 Working environment

The diver's work environment is inherently hostile. Divers often work in dark, cold isolation and are exposed to a variety of pressure-decompression related illnesses and injuries. The dangers presented by waterways, such as high flow velocities, limited underwater visibility, potential for entanglement, and poor water quality contribute to the hostile nature of the diver's work environment. Divers must rely completely on external life support systems while working under severe limitations such as diminished sensory and perceptual capabilities; interference with cognitive capabilities; and psychomotor skills. Reduced physical working capacity and physiological and psychological stress also limit diver effectiveness. Divers are particularly and uniquely exposed to physiological hazards such as pressure, temperature extremes, oxygen deficiency, and nitrogen narcosis.

To work effectively, the diver must adapt to the environment, be familiar with the diving equipment, and select methods appropriate for the task. A bridge inspector cannot properly conduct an underwater inspection if the diver's sole concern is survival. A diver must feel safe and be comfortable while working in order to do an accurate and effective job.

Air is the most commonly used breathing medium for diving. When air is breathed under pressure, as in diving situations, inert nitrogen and other gases diffuse into the tissues of the body. The amount of nitrogen absorbed increases with the depth and duration of the dive. When the diver ascends, the nitrogen comes out of solution. If the ascent rate is too rapid, the nitrogen will not be dissipated and gas bubbles can form in the diver's tissue and blood. These bubbles tend to collect at the body's joints resulting in what is commonly known as the "bends" or, more correctly referred to as, decompression sickness. For this reason, a diver's time and depth in the water must be carefully monitored.

Combinations of deep dives and dives of long duration may require the diver to decompress in stages by slowly ascending and spending time at intermediate depths or in a recompression chamber, thereby allowing sufficient time for the nitrogen and other gases to safely come out of body fluids. The majority of bridge inspections dives are of short duration or at shallow depth; therefore, decompression stops or recompression are not normally needed. Such dives are referred to as no-decompression dives.

Although decompression is not normally a concern within the limits as shown in Table-1, an amount of nitrogen remains in the diver's tissues after every dive. For repetitive dives, the diver must consider the effects of residual nitrogen in evaluating the adjusted no-compression times for subsequent dives and assessing the need for planned decompression.

Breathing air under pressure can cause nitrogen narcosis, a feeling of euphoria sometimes referred to as "rapture of the deep." At depths below approximately 100 feet, most divers feel the early lightheaded effects associated with nitrogen narcosis. Beyond 200 feet, few divers can work effectively while breathing air due to the effect of nitrogen narcosis.

The diver's greatest threat is loss of supply of the breathing gas, but another threat is inadequate ventilation of the diver's mask or helmet resulting in carbon dioxide poisoning. Many times contamination of exhaust fumes from internal combustion engines in a diver's air supply can cause carbon monoxide poisoning, special care must be taken while locating the intake of a diving air source compressor.

Breathing air under high partial pressures can cause oxygen poisoning. Partial pressures of oxygen in excess of those encountered at normal atmospheric conditions may be toxic to the body. Oxygen toxicity is dependent upon both the partial pressure and the exposure time. In the range of 0.2 to 0.6 atmospheres (atm) of oxygen, no toxicity is detectable. From approximately 0.6 to 1.6 atm of oxygen, with exposure times from hours to days, lung toxicity may occur. At pressures greater than 1.6 atm of oxygen, central nervous system oxygen toxicity occurs before lung toxicity produces symptomatic damage. The air diver seldom encounters oxygen partial pressures greater than 1.6 atm since it represents a depth of over 200 fsw. The greatest opportunity for exposure to oxygen poisoning is during recompression treatment or surface decompression using oxygen.

Because of the potential for nitrogen narcosis and to reduce the risk of decompression sickness, other breathing media, such as Heliox a mixture of oxygen and helium, or Nitrox a mixture of air with increased oxygen percentages may also be used. Mixed-gas dive stations are more costly to set up and operate, and they require specially trained dive personnel. Safety standards also require the presence of a recompression chamber for any type of mixed gas diving. Most bridge inspections are conducted at depths where air can be used as the breathing medium.

8.3 Dealing with Current

Most waterways have low flow periods when current will not hinder an inspection. Diving inspections should be planned with this consideration in mind. Divers can work in current below 1.5 knots with relatively little hindrance.

As current increases, special precautions are required. The simplest is to use bottom anchors to tether the diver. In swifter current, shielding devices and special anchor systems may be required.

8.4 Dealing with Drift and Debris

The drift and debris are sometimes carried with water during high floods. This mostly consists of logs and limbs of trees, which are usually, matted/woven either against or within the substructure elements. Often this debris is located on the lower parts of the substructure and cannot be detected from the surface. The build-up can be so thick as to prevent access to major portions of the underwater substructure.

Since they are often hidden, drift and debris problems present the bridge owner with an unknown cost factor. The removal of the drift and debris must be provided for if an inspection of the underwater structure is to proceed. While in many cases it can be removed by the inspection divers, heavy equipment such as a hoist or underwater cutting devices, are sometimes required.

Generally such build-up occurs in repetitive patterns. If previous underwater inspections have been conducted, its presence can be estimated based on past history. Also, certain rivers and regions tend to have a history of drift problems, while others do not. Knowledge of this record can help predict the likelihood of drift. A separate drift removal team, working ahead of the dive inspection team, could possibly be utilised.

Divers must also have a safety concern about the build-up of debris near a bridge. Occasionally, debris can be quite extensive and can lead to entanglements or sudden shifts which might entrap the diver.

8.5 Physical Limitations

Dark and hostile environment can result in a reduced physical working capacity. The diver is also totally dependent on external life support systems, which adds psychological stress. Things that can be done intuitively above water must be conscientiously planned and executed step-by-step underwater. For example, maintaining orientation and location during an underwater inspection requires continual attention. Distractions are plentiful and range from living organisms, such as fish, snakes and crustaceans, to environmental conditions, such as cold, high current and debris.

8.6 Decompression Sickness

Since the majority of bridge inspections are in relatively shallow water and of short duration, decompression problems rarely occur. However, multiple dives have a cumulative effect and the no-decompression time limit decreases rapidly at greater depths. There is no limit placed on the duration of diver up to 18m depths but for greater depths, decompression should be carried out as specified in IS :10291-1982. However, suitable decompression arrangements must be provided at site when depth of diving exceeds 10 m. Divers should routinely track their time and depth as a safety precaution.

8.7 Videography in Turbid Water

Turbid water condition poses problems in taking good and clear photographs and video recording. Suspended particle matters in turbid water impair the transmission of light. The performance of camera in such conditions is critically dependent on the quality and arrangement of the lighting used to eliminate the subject.

If the suspended particle matter forms an optical barrier between the object and camera, a clear box, filled with clean water, between camera and the object may be used for better results (Fig. 8.1). However, applicability of this arrangement is limited to specific locations in smaller areas. In conditions where turbidity is sufficient to impair light transmission, but not so bad as to form a complete optical barrier, then the camera choice and lighting arrangement can be critical to the quality of the result.

Fig. 8.1 Underwater inspection camera with clear water chamber

8.7.1 Problems in Turbid Water

There are three main problems, which limit the viewing performance of an underwater camera. These are:

- Absorption
- Refraction
- Reflection

Absorption reduces the amount of illuminating light that reaches the object from the light source. It also reduces the amount of light reaching the camera from the object. This combined absorption of light limits the maximum distance between the camera and the object. The viewing range is proportional to the power of the light source, and the light sensitivity of the camera used.

The process of refraction causes dispersion of light from the light source across a larger area than would occur in clear water, thus reducing the intensity of the light beam. The light coming back from the subject to camera is also reduced and scattered in a similar fashion causing loss of contrast and image detail in the video signal.

Reflection is probably the most critical factor for the performance of cameras in turbid water. The suspended particles in the path of illuminating light reflect a portion of the illuminating light directly back into the camera. This backscatter, can often be limiting factor in the use of underwater visual imaging system in turbid water. The illuminating light reflected back from the suspended particles tends to “swamp” the imaging light from the subject.

8.7.2 Remedial Measures

Absorption : The process of absorption of light can be overcome by using higher powered lighting, or by using more light sensitive cameras or both combined.

Refraction : There is little that can be done to overcome the effects of refraction. Image definition and contrast in turbid water condition will never be as good as in clear water condition. The use of image enhancement techniques to artificially sharpen up the image can be of some benefit, but these do not significantly improve the amount of information that the image provides.

Reflection : The problem of reflection can be minimised by carefully placing the flash away from the axis of the camera and at angle to provide reasonable coverage of the subject as shown in Fig. 8.2.

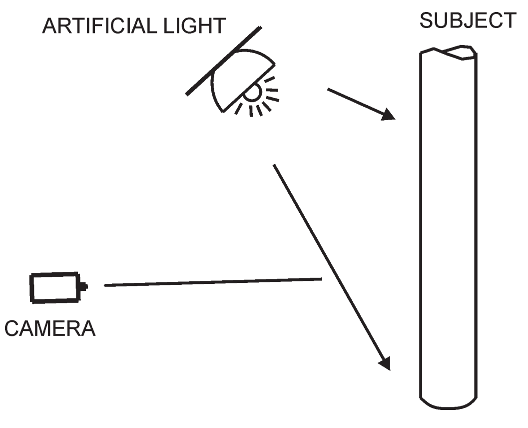

Fig. 8.2 Lighting arrangement to avoid reflection

8.7.3 Use of Scattered Lighting

In this arrangement, a very high powered, tight beam spot light (beam angle less than 10^0) is used. The lamp is directed near but not at the object. The object is illuminated by scattered light from the high power lamp beam along the light path (Fig. 8.3). Because the illuminating light is scattered and diffused, the effect of backscatter tends to be much reduced as there is little directly reflected light.

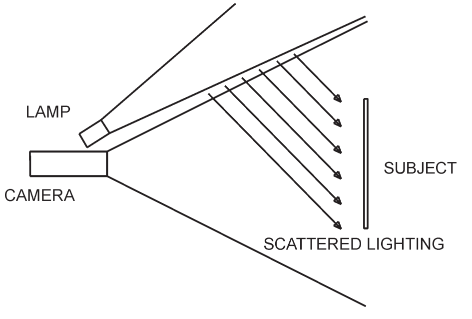

Fig 8.3 Arrangement for scattered lighting

Advantages

- Less severe backscatter than direct illumination
- Not very critical to alignment

Disadvantages

- Needs very high power
- Uneven object illumination
- Relies on turbidity to work. Non suitable in clear water
- Not suitable for close-up inspection as there will not be enough scatter.

■ ■ ■

CHAPTER - 9

DOCUMENTATION AND REPORTING

9.1 Documentation

Because of efforts in conducting underwater inspections, combined with the time between inspections, it is particularly important to carefully document the findings. On-site recording of all conditions is essential.

Sketches : It is recommended that sketches be used as much as possible; providing enough detail is critical since it is difficult to go back to check items once diving is completed. Drawings should be prepared for the following:

- Elevation showing dimensions and scour, cracks, unstable conditions, etc.
- Sections showing degree of scour, spalling etc at different locations.
- Plans showing inspection areas, inspected sections.
- Sketches showing details of various damages to the structure.

Logs : In addition to sketches, a written log is often kept describing the inspection.

Tape recordings : When significant damage is encountered, a tape recording of the diver's observations can also prove helpful.

Underwater photographs and videotapes : When appropriate, damaged areas should be documented with still photography and closed circuit television. Still photography provides the necessary high definition required for detailed analysis, while video, though having a less sharp image, provides a continuous view of events that can be monitored by surface engineers and recorded for later study. All photographs should be numbered, dated and labelled with a brief description of the subject. A slate or other designation indicating the subject should appear in the photograph. When a colour photography is used, a colour chart should be attached to the slate to indicate colour distortions. Videotapes should be provided with a title and lead-in, describing what is on the tape.

9.2 Reporting

For each inspection, a report is prepared. The report includes an evaluation of the assessed conditions and recommendations for further action. The report should provide sufficient technical detail to support the assessment and recommendations.

The report shall include the following:

- Identification and description of all major damages and deterioration in the structure element-wise.

- Estimate of the extent of minor damages and deterioration.
- Assessment of the general physical condition.
- Cause of damage/deterioration if known.
- Water depths at each structural element.
- Recommendations for types of maintenance and repairs required.
- Recommendations for types and frequencies of future underwater inspections.
- Water visibility, tidal range, water current and any other pertinent environmental conditions.

Since underwater inspections are specialised, a report format such as one presented in Table 9.1 is recommended. The objective of the guideline is to facilitate the writing of comprehensive, standardised, and usable reports.

Table 9.1 Format for inspection reports

Report cover
→ Title page
→ Executive summary
→ Table of contents
→ List of figures
→ List of photographs/videotapes
→ List of tables

Section 1	**Introduction**
1.1	Background/Objective
1.2	Location and details of structure
Section 2	**Inspected structural element**
2.1	Name of structural element
2.2	Description of the element
2.3	Observed inspection condition
2.4	Structural condition assessment
2.5	Recommendations
Repeat the above as necessary for each element	
Appendices	
A	Inspecting Agency and key personnel
B	Inspection procedure/Level
C	Pertinent background information
D	References

9.3 Case History : Underwater Inspection and Repair Br. No.132 on Chalakkudy River in TVC Division of Southern Railway.

9.3.1 Introduction

Underwater inspection of Br.No.132 Up & Dn on Chalakkudy river was regularly inspected by external agencies since 2004 in Trivandrum division of Southern Railway. The objective of these inspections were to provide a general description and assessment of the underwater condition of the bridge. The scope of work was:

1. Underwater inspection of Piers
2. Underwater cleaning of marine growth to assess the condition of the Piers
3. Underwater Videography of the Piers and abutments
4. Measurement of damages
5. Submit written report with evidence of photos and videos.

Data/information were taken as per underwater inspection, available technical drawing and railway engineer's assistance.

9.3.2 Bridge Details

Name of Bridge	132 UP & DN
Location	64/3-5, Chalakkudy River
Category	Well foundation steel girder bridge
Bridge Span	6 x 18.30m
No. of Pier Inspected	04
Inspection Date	14-02-2014 & 21-02-2014
Client	Southern Railway, Trivandrum Division - India

9.3.3 Instrument Details

CCTV System	Outland U/W CCTV system : UMG 10214 Sl.No.L1009-15164U
Diving System	UK Standard (IMCA) Diver Umbilical : Cortland fibron BX Sl.No.:002239X07XI Diving Helmet : KMB 28B, Serial Number 12170B LR approved.
Communication system	Amron Radio : Serial Number 2810A-811 LR approved.
Cylinders	Faber Cylinders – UDINE ITALY LR approved

9.3.4 Case History

The available records suggests that for the first time in year 2004 while doing under water inspections cracks were seen in well foundations of a Pier. The Pier was founded on two wells with common well cap. Left well below Pier No.2 was observed with vertical as well as horizontal cracks and also having small honey combs. Right well of Pier No. 2 was having vertical cracks from top to bottom and cutting edges was eroded and unsupported for about a length 5.74m (max. gap was 33cm). Both the well of Pier No. 3 & 4 also exhibited horizontal and vertical cracks as well as honey comb. Wells at Pier No. 4 was also observed with eroded and unsupported cutting edge for about a length of 5.5m (max.gap 45cm.)

Subsequent to this inspection bridge was placed under speed restriction of 20kmph and repair works of foundation of Pier No. 2&4 were carried out with external agency. Underwater inspection was again carried out in year 2005 which revealed that the repair was standing well. After that speed restriction was relaxed and normal speed was restored.

In 2006, again under water inspection was carried out which showed that the combined jacketing at Pier No.2 was standing well. At Pier No.3 some loss of mortar and honey comb was noticed at both the wells. At Pier No.4 small honey comb as well as vertical hairline crack was noticed on left well. At Pier No.5 loss of mortar and small honey comb was noticed. However, these conditions were considered normal and no further action was taken.

In 2011, under water inspection was again done and following observation was made:

A) Pier No. 2 having combined jacketing exhibited serious damages of the jacketing in the following manner. Spalling of Concrete with reinforced rod exposed around the well at bottom side. Measurements from bottom are as follows:

i) East side height 55 cm to 1.60 m Depth 50 cm to 1.80 m

ii) North side height 30 cm to 75 cm Depth 40 cm to 1.15 m

iii) West side height 45 cm to 70 cm Depth 45 cm to 1.25 m

iv) South side height 40 cm to 68 cm Depth 28 cm to 1.20 m.

Spalling of concrete also noticed at the following spots at north and south side above the bottom damage.

v) North side height 15 cm x Depth 10 cm length 1.10 m

vi) South side height 25 cm x Depth 20 cm length 1.50 m.

B) Pier no. 3 did not exhibit any defect.

C) Pier no. 4 exhibited cavities as follows:

i) P4 LH Well - Cavities noticed at South side length 1.70 m x height 22 cm x depth 73 cm and length

50 cm x height 15 cm x depth 10 cm.

ii) P4 RH Well - Cavities & spalling of concrete noticed at south north east side for length 11.50m x height 65 to 25 cm x depth varies from 1.5 m to 85 cm.

D) Pier No. 5 exhibited cavities and spalling of concrete as follows:

i) P5 LH Well - Leaching of concrete and honey comb noticed at east side.

ii) P5 RH Well - Leaching of concrete at west side. Small cavities at east side noticed.

From above inspection it was seen that the repair done to Pier No. 2 could with stood for about 6 years and now need extensive repairs. Pier 4 also requires major repairs; so speed restriction of 20 kmph was imposed. However, repairs to other foundation survives. To ascertain the condition the bridge, it was again inspected during 2012 by departmental diver and damage to foundations of Pier No. 2 and Pier No. 4 was confirmed. Subsequently, an agency was finalised in 2014 to carry out repair works. A sample report of damaged portion of Pier No. 2 is given in following para.

9.3.5 Survey Report Pier No. 2

The pier consists of elongated hexagonal shape supported by steel girder bridge rested on the concrete well foundation and it is situated on the splash zone. In general, average water depth was observed 3.20 m and inspection was carried out all the area below water level. The entire pier was cleaned and thoroughly inspected. The circumference of well is 36.70m (It seems that the well was constructed as twin wells and subsequently connected together and now appears to be like a single well). Sketches showing top view and elevation including observation of defects are shown in Figure 9.1 and 9.2 respectively.

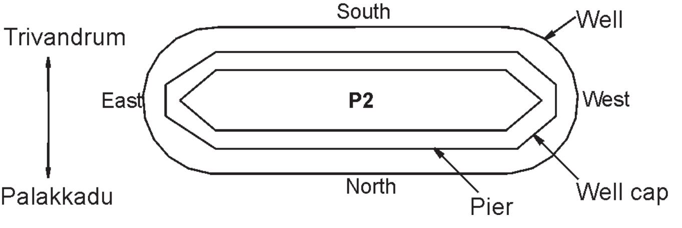

Fig. 9.1 Bridge number 132 (P2) top view

9.3.5.1 Findings

- Serious damage noted, only one fourth portion of the well is touching the river bed.
- Damage area all-round the pier about 1.5m Height x 24m Length x 3m Depth.
- Steel reinforcement bars are exposed.

9.3.5.2 Recommendation

Serious damages noted. Repair Pier No. 2 immediately.

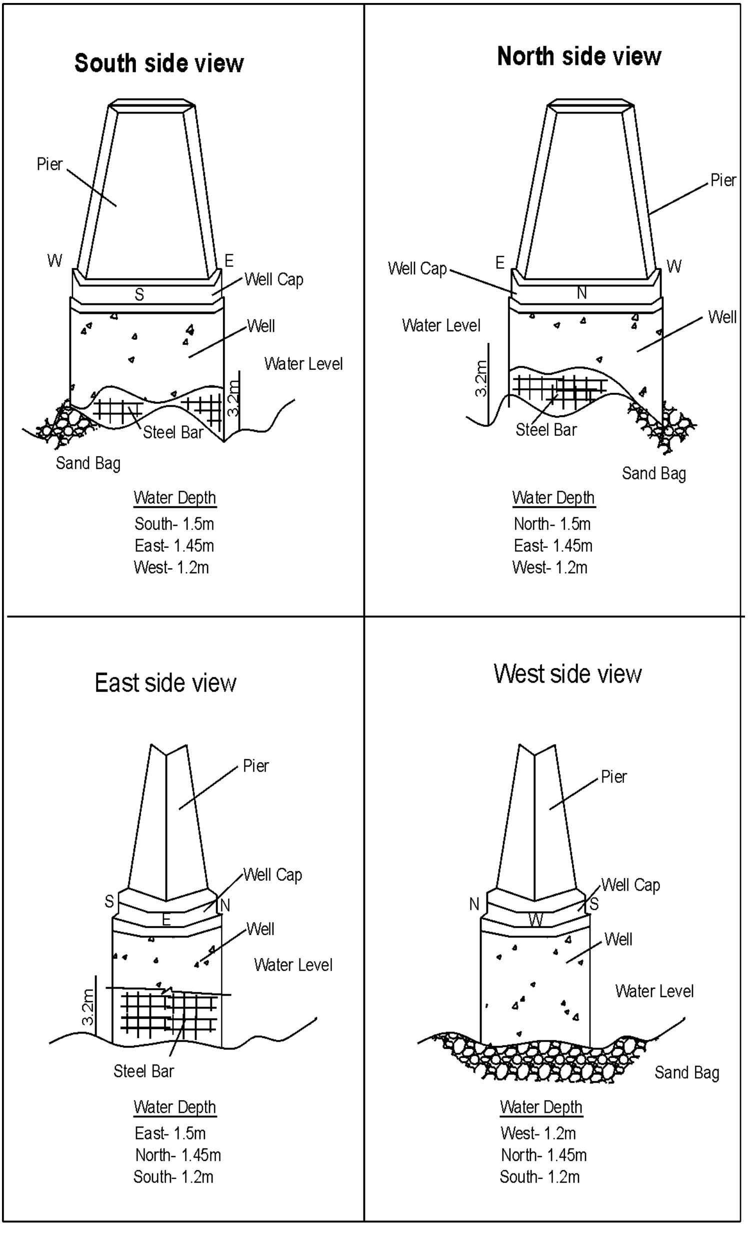

Fig. 9.2 Bridge no. 132 (P2) elevation

9.3.6 Repair activities:

After inspections an agency was fixed to carry out extensive repair work. This times, under water repair was avoided and repair was planned in dry condition by creating a cofferdam. As per Southern railway's drg.no. CBE/VI/206/2014 (attached on page no 165, Annexure - II) the modus operandi is as follows:

Fig. 9.3 Repair work in progress

9.3.6.1 Modus operandi

Impose nonstop 20kmph speed restriction with necessary speed indicators. Keep ready materials for coffer dam etc.

Detailed repair procedure was divided into three stages, Pier wise procedure is discussed in the following para

Stage I - Providing cofferdam and temporary packing of unsupported well kerb. Erect cofferdam with Earthern bund (or to suit site conditions) around the existing well foundation as shown. (Caution- no earth shall be removed around the well for erecting cofferdam.) Bailout the water inside the coffer dam. Fill up with boulders/ sand bags around the well steining in the unsupported kerb portion to have sufficient packing. Inspect the well and assess the unsupported area to be repaired.

Stage II - Anchoring the unsupported kerb into the rock by dowelling and concreting in stages of limited unsupported length. Remove the temporary boulders packing only to the limited length of 600mm along kerb and excavate upto the top of hard rock. Drill holes by chiselling and provide sufficient dowel rods and grout with cement mortar. (Caution - the behaviour of well shall be monitored for the tilt etc. during the course of the work). Pressurised pumping of concreting is done for the eroded portion duly ensuring the concrete packing inside the bottom plug encasing and also ensuring of the exposed reinforcement of steining portion. Concreting shall be done as per actual requiredment. Complete the work in all respects. Remove the confferdam arrangements.

The above operations in stage I & II are to be done for Pier No. 2 and Pier No. 4 seperatly to complete the work.

Stage III- Boulder crates are to be provided to make up the original bed level. Keep ready boulders crates of suitable size filled with boulders of such size and weight as per specifications and directed by the engineer in charge. Provide the crates in position over the scoured bed to make up the original bed level as shown in the drawing.

9.4 Case Study on Bridge no. 209 on River Sunkosh in Juri-Srirampur section of APDJ Division of NF Railway

9.4.1 Introduction

North-east Frontier Railway conducted under water inspection of Bridge No.209(7x45.72m) on River Sunkosh in Permanent Way section Juri- Srirampur of APDJ Division during 2007. This bridge is founded on 9.1 meter dia well and constructed in 1963. During under water inspection Pier No.4, 5 & 6 (perennially under water) was detected with cracks, blow holes etc.

Based on under water inspection estimate was prepared and repair works was carried out by an agency. During repair the external surface of crack was sealed using solvent free epoxy based putty SIKAGARD 694 F(I). This material has excellent property of moisture intensive repair. SIKAGURD(694) is solvent free epoxy based resin (KT/373 and confirming IS: 3907).It is available in two parts and these are mixed until become uniform grey in colour. Its pot life is 20 minute at 30^0C. As per IS:9162 its compressive strength after one should not be less than 40 N/mm2. This shall be applied by glove protected hand, spatula or Trowel.

The deeper crack is filled using high density epoxy based injection risen SIKADUR (53UF), which cures without shrinkage and its high density ensure water replacement. SIKADUR(53UF) is solvent free epoxy based injectable resin. This is available in two parts.

These shall be mixed by mechanical means for at least 3 minutes to obtain smooth reddish brown liquid of uniform consistency. After one day curing its crushing strength shall be 40 N/mm^2 (IS:1962) at 30^0C

Brief description of work is given below; however details may be collected from NF Rly.

Note: The proportion of above chemicals shall be decided in consultation with manufacturer.

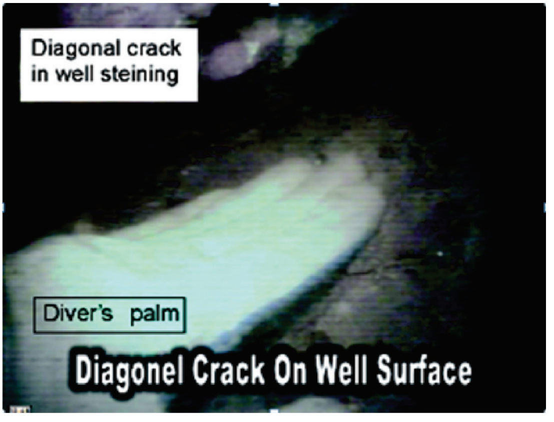

Fig. 9.4 Diagonal crack in well steining

9.4.2 Equipment Details

Following equipments are used:

a) Pneumatic drilling device

b) Pneumatic chisel

c) Wire brush

d) Pressure injection equipments with control valve & pressure gauge

e) CCTV system with DVD recorder & monitor

f) Underwater camera & lighting system

g) Air compressor of pressure up to $10kg/mm^2$

h) 8mm dia. Polythene pipe

i) Polythene container for mixing epoxy formulation

j) Portable generator

k) Weigh balance

l) Flexible pressure hose pipe

m) Mixing spindle

9.4.3 Repair Procedure:

Initial activities

i) Demarcate the chainage around the well cap/ pier

ii) Assemble the CCTV system, DVD recorder, monitor, etc.

iii) Make ready the divers with diving suit with video camera, light, etc.

iv) Make survey over the well surface by videography to locate the Cracks, blow holes, etc, & record through DVD recorder,

v) mark chainage at outer ring at RL-0 at bed level as shown in Fig. 9.5

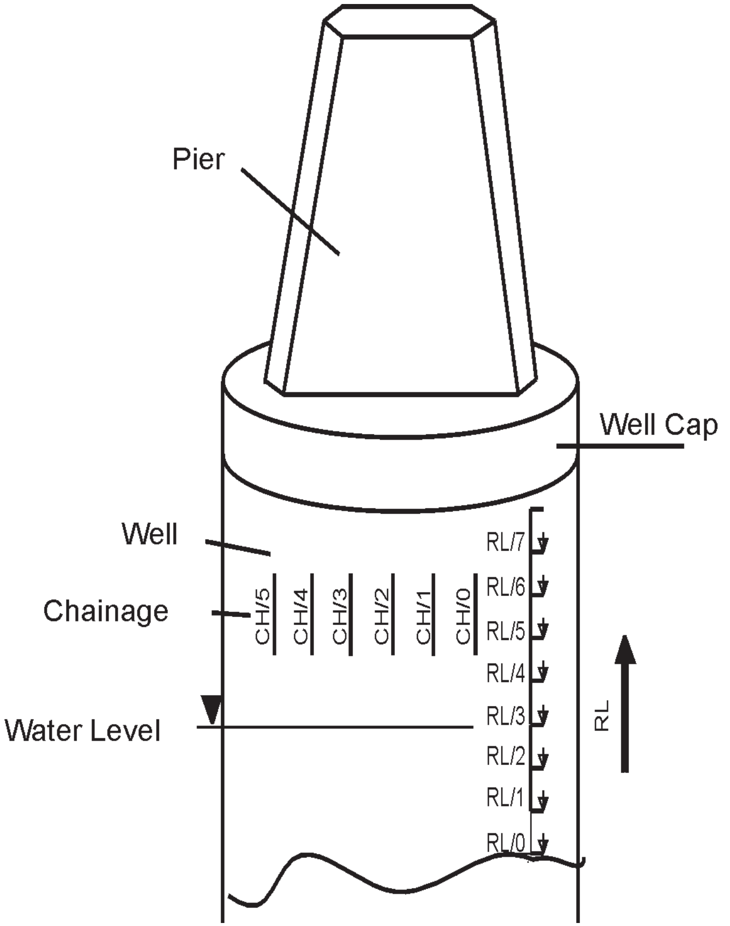

Fig. 9.5 Chainage and RL marking, 1m c/c at outer ring of well

Cleaning & preparation of surface

i) Cleaning the located defective surface by wire brush.

ii) 5mm deep 'V' grooves are cut along the cracks by pneumatic chisel

iii) Holes for fixing nipples are to be drilled along the 'V' grooveby pneumatic drill

Application of epoxy putty for fixing of nipples.

i) Mix the two part of epoxy putty SIKAGURD 694 F(I) as per specification.

ii) Let the divers to go down the water with mixed putty, spatula trowel, etc.

iii) Seal the cracks by mixed epoxy putty, by spatula / trowel after cleaning the cracks ensuring the crack free from any loose particles.

iv) Fix the nipples in the holes drilled along the 'V' groove. Fig. 9.6 (a), (b).

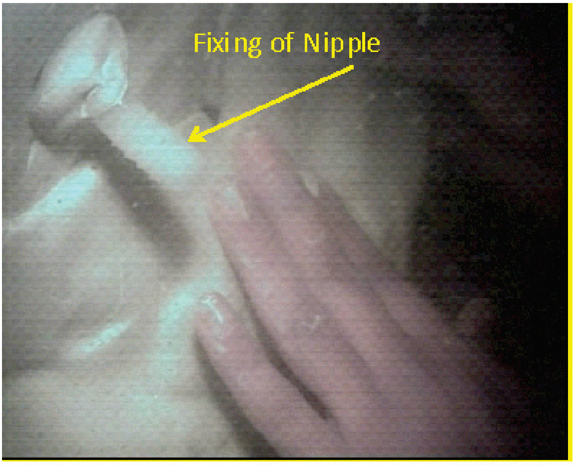

Fig. 9.6 (a)

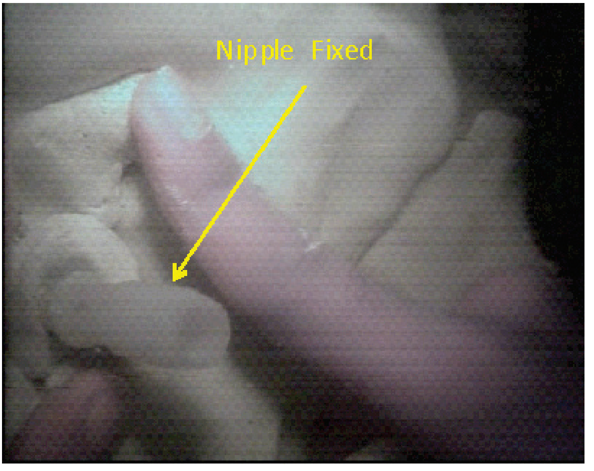

Fig. 9.6 (b)

Grouting

i) Mix two part of SIKADUR (53UF) as per specification to prepare grout.

ii) Let the divers to go down into the water with injection nozzle, camera, light, mixed epoxy putty and grout.

iii) The grout material was injected under pressure through injection port (nipples) using injection pump. The grouting material supplied from equipment installed on land / boat with regulating valve, required pressure is giving by air compressor, thus solution material are going down through the flexible pressure hose pipe to the injection gun with the diver /applicator.

iv) Grouting is started from bottom most nipple and as soon as injecting resin works out of the next injection port, the 1st one to be sealed by epoxy putty. Fig. 9.7 (a) and (b).

Fig. 9.7 (a) Injection Grouting

Injection process is continues from next port. For horizontal cracks, the process starts from one end to other till to complete the last port is used. For vertical cracks the process starts from lowest port and continued upward.

Fig. 9.7 (b)

Videography

Videography of the total operation under water is done & recorded in DVD recorder.

Precaution

i) Utmost effort for quality control to get the satisfactory output

ii) Care should be taken at the time of using the mixture as it should be used within 15 min of preparation of materials

iii) Videography of survey & execution of work should be taken

iv) Record measurement in MB is completely based on the videography.

■ ■ ■

Annexture - I

List of Underwater Inspection Agencies

S.N.	Name	Address & Email
1.	M/s Infrastructure Engineers inc.	211, 12th Street, St.Cloud FL 34769, USA Ph –407-957-1650 Email : dresser@infrastrucure engineers.com
2.	M/s Marine Engineering System Co. Inc	5030 Old Kings Road NW, Jacksonville, FL32254 USA, Email : MescoDive@aol.com
3.	M/s Mainstream Commercial Divers Inc.	322 C, C.Lowry Drive, P.O.Box No.1426, Murray K.Y.42071, mainstream USA, Ph 270-753-9654 Email : info@ divers.com
4.	M/s W J Castle & Associates	P.O.Box 586, Lum berton NJ 08048, USA Ph-609-261-2268 Fax-609-261-3422 Email: bcastle @jcastlegroup.com
5.	M/s Wilbur Smith Associates	Santosh V.Krishnan; India Country Manager ; # B-009, Sobha Sapphire S.N.15 Sahakar Nagar P.O. Bangalore 560 092, India Ph & Fax-080-23636293 santoshvk@wilbursmith.com
6.	M/s L &T Ramboll	339/340, Anna Salai, Nandanam Chennai – 600035. Phone – 044-24331181 ltramboll@vsnl.com
7.	M/s Enviro Infra Tech	A – 320, Ganinath Nikunj, Plot No.1 Sector 5 Dwarks, New Delhi – 110045 Phone-011-5087214

S.N.	Name	Address & Email
8.	M/s Jwalpa Enterprise Pvt. Ltd.	140, Vanasthali, Mandir Lane, Ballupur, Dehradun-248001, Uttaranchal Ph-0135-752942
9.	M/s Advanced Construction Technologies Pvt. Ltd. In association with Disco Tech. Dubai	19, Cenotaph Road, Teynampet, Chennai – 600 018 Fax.044-24342272 Email : dubai@dicotech.com
10.	M/s Sea Swift Enterprises	B-11, Fashqua Shopping Centre, Station Road, Santa Cruz (W) Mumbai – 400 054 Ph-022-6041333/43 Fax-022-6056697 Email : Seaswift@vsnl.com
11.	M/s United Divers Pvt. Ltd.	201, SAIDEEP 2 nd floor, NG Acharya Marg, Chembur, Mumbai – 71 Fax-022-5565636 Email : United_divers @vsnl.com
12.	M/s S.J.Group Consulting Civil Engineers	196 Jawahar Nagar, Goregaon(W) Mumbai 400 062, Ph-022-8732517 Fax-022-8759710 Email : sjgroup@vsnl.com
13.	M/s Sverdrup Civil Inc	242, Okhla Industrial Estate Phase III, New Delhi – 110 020 Ph-011-6319901, Fax –011-6319907
14.	M/s Construma	2nd Floor, Pinky Plaza, 5th Road, Khar, Mumbai-400 052, Ph-022-26487415, Fax-022-26463181 Email : ccpltd@bom3.vsnl.net

S.N.	Name	Address & Email
15.	M/s Aqua Space Diving Services	39/4024/B Sreekandath Road, - Ernakulam Cochin-682016, Kerala, Ph-369981, Fax-0484-323424
16.	M/s Intertech Sales Corporation	Shagun, S-27 Rajouri Garden, New Delhi –110 027 Ph-011-5104288, Fax-011-546320 Email : interec@ bol.net.in
17.	M/s Sea Lion Diving Services	E 1/5, Municipal Complex, Stadium Road, Visakhapatnam-530001 Ph – 0891-2726148
18.	M/s Dynasoure Concrete Treatment Pvt. Ltd.	419, New Sonal Service Industrial Estate, Link Road, Malad West, Mumbai - 400064 Ph – 022-28821668
19.	M/s B.V. Construction	Shop No. 25, APHB,Vidya Nagar, - Hyderabad-44.
20.	M/s Hyderabad Telivisions, Panjagutta, Hyderabad	Plot No.9, Janata Flats, Kanti Shikara Complex. Panjagutta, Hyderabad-82.

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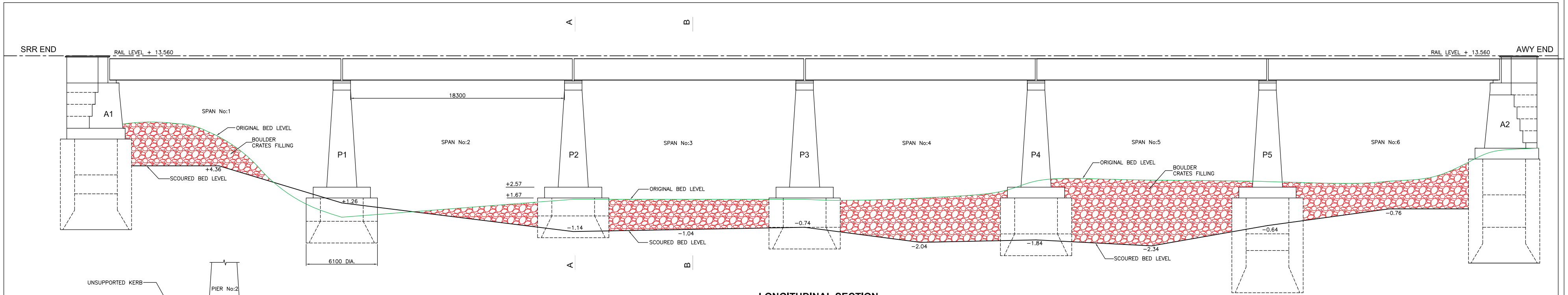
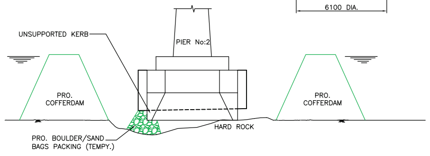
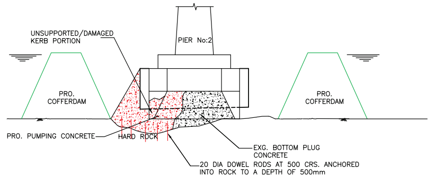


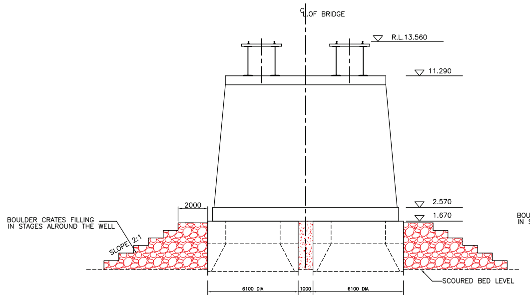
LONGITUDINAL SECTION



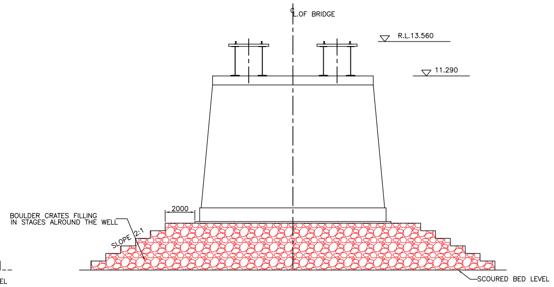
STAGE I
PROVIDING COFFERDAM AND TEMPORARY PACKING OF UNSUPPORTED WELL KERB



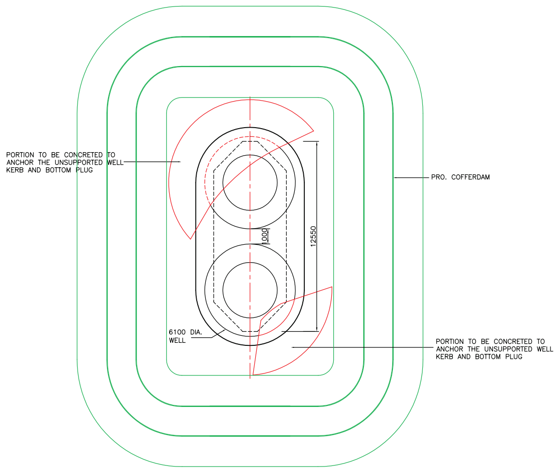
STAGE II ANCHORING THE UNSUPPORTED KERB INTO THE ROCK BY DOWELLING AND CONCRETING IN STAGES OF LIMITED UNSUPPORTED LENGTH



SECTION ON A-A
CROSS SECTION OF PIER NO.2 (TYPICAL)



SECTION ON B-B
CROSS SECTION AT MID SPAN OF SPAN NO. 3



PLAN SHOWING THE COFFERDAM ARRANGEMENTS

MODUS OPERANDI:

PRELIMINARY

IMPOSE NON STOP 20KMPH SPEED RESTRICTIONS WITH NECCESSARY SPEED INDICATORS.

KEEP READY MATERIALS FOR COFFER DAM ETC.,

IN PIER P2

STAGE I PROVIDING COFFERDAM AND TEMPORARY PACKING OF UNSUPPORTED WELL KERB

ERECT COFFERDAM WITH EARTHERN BUND (OR TO SUIT SITE CONDITIONS) ALROUND THE EXISTING WELL FOUNDATION AS SHOWN.
(CAUTION ;- NO EARTH SHALL BE REMOVED AROUND THE WELL FOR ERECTING COFFERDAM.)

BAILOUT WATER INSIDE THE COFFER DAM. FILL UP WITH BOULDERS/SAND BAGS AROUND THE WELL STEINING IN THE UNSUPPORTED KERB PORTION TO HAVE SUFFICIENT PACKING.

INSPECT THE WELL AND ASSESS THE UNSUPPORTED AREA TO BE REPAIRED.

STAGE II ANCHORING THE UNSUPPORTED KERB INTO THE ROCK BY DOWELLING AND CONCRETING IN STAGES OF LIMITED UNSUPPORTED LENGTH

REMOVE THE TEMPORARY BOULDERS PACKING ONLY TO THE LIMITED LENGTH OF 600mm ALONG KERB AND EXCAVATE UPTO THE TOP OF HARD ROCK.

DRILL HOLES BY CHISELLING AND PROVIDE SUFFICIENT DOWEL RODS AND GROUT WITH CEMENT MORTAR.
(CAUTION ;- THE BEHAVIOUR OF WELL SHALL BE MONITORED FOR THE TILT ETC., DURING THE COURSE OF THE WORK)

PROVIDE PRESSURE PUMPING CONCRETING THE PORTION DULY ENSURING THE CONCRETE PACKING INSIDE THE BOTTOM PLUG AS POSSIBLE INCLUDING ENCASING THE REINFORCEMENT EXPOSED IN STEINING PORTION.

CONCRETING SHALL BE DONE WHEREVER FOUND REQUIRED.

COMPLETE THE WORK IN ALL RESPECTS.

REMOVE THE COFFERDAM ARRANGEMENTS.

IN PIER P4

REPEAT THE ABOVE OPERATIONS IN STAGE I & II FOR PIER P4 ALSO AND COMPLETE THE WORKS.

STAGE III PROVIDING BOULDER CRATES TO MAKE UP THE ORIGINAL BED LEVEL

KEEP READY BOULDER CRATES OF SUITABLE SIZE FILLED WITH BOULDERS OF SUCH SIZE AND WEIGHT AS PER SPECIFICATIONS AND DIRECTED BY THE ENGINEER IN CHARGE.

PROVIDE THE CRATES IN POSITION OVER THE SCOURED BED TO MAKE UP THE ORIGINAL BED LEVEL AS SHOWN.

NOTES

1. ALL MEASUREMENTS ARE IN MILLIMETRES.
2. FOR COMPLETION PLAN REFER DRG. No. CN 105-80/1(COM).
3. THIS SKETCH IS PREPARED BASED ON THE INSPECTION NOTE No. 3/2014 OF DY.CE/BR LINE ON 11/3/2014.
4. BOULDERS TO BE USED SHALL BE OF SUCH SIZE AND WEIGHT AS PER SPECIFICATIONS AND DIRECTED BY THE ENGINEER-IN-CHARGE.
5. PACKING OF BOULDERS SHALL BE DONE WELL AS DIRECTED BY THE ENGINEER-IN-CHARGE.
6. MINIMUM GRADE OF CONCRETE SHALL BE OF M20 GRADE CONTROLLED CONCRETE WITH WEIGH BATCHING.
7. 20mm DIA. DOWEL RODS SHALL BE ANCHORED INTO ROCK FOR A DEPTH OF 500 mm AND AT A SPACING OF 500 CRS.

DGN MADE		TRIVANDRUM DIVISION	SOUTHERN RAILWAY	
DGN CKD				
DRG CAD	S.NEELA	SRR-ERS SECTION BRIDGE No.132 AT Km 64/200-400 (6x18.30 G) ACROSS THE CHALAKUDI RIVER PROPOSED ANCHORING OF EXISTING WELLS IN PIER NO 2 &4 AND PROPOSED BOULDER CRATES FILLING	DETAILS OF ANCHORING AND BOULDER CRATES	
DRG CKD			ABE/III	
JE/I/DRG			BE	
SE/DRG			DY.CE/Br./L	
SE/DGN			DY.CE/Br.	
SCALE - 1:100,200			CBE	
CASE No.			DRG. NO.	CBE/V1/206/2014

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