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# *CONCRETE BRIDGE MAINTENANCE*

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*A Thesis Submitted to School of Graduate Studies of Addis Ababa University presented in partial fulfillment of the requirements for the Degree of Master of Science (School of Civil And Environmental Engineering)*

Addis Ababa University

Addis Ababa, Ethiopia

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## Addis Ababa University

## School of Graduate studies

This is to certify that the thesis prepared by Bayu Getachew, entitled: ***Concrete Bridge maintenance*** and submitted in partial fulfillment of the requirements for the degree of Degree of Master of Science *(School of Civil And Environmental Engineering)* complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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# DECLARATION

I, the undersigned, hereby declare that this thesis titled "**concrete bridge maintenance**" is my original work carried out under the supervision of Dr. Asnake Adamu. It has not been presented as a thesis in any other university and all source of material used for this thesis are duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

| Dr. Asnake Adamu | __________________ | __________________ |
|---|---|---|
| Advisor | Signature | Date |

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Bayu Getachew

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# ABSTRACT

So far, the usual practice in Ethiopia to maintain concrete structures is simply plastering and masking the defects (ugly looking) without considering the structural aspect of the structure. But such activities should not be called maintenance unless the overall condition of the concrete structure is regained through the task accomplished. When the defects or a failure of the concrete structure is a bit exaggerated, demolishing and reconstruction was the best option and was practiced so far.

In concrete bridge failures, reconstruction of the structure instead of rehabilitation for every defect or failure is very difficult in terms of money and construction. That is the amount of money involved for reconstruction of bridge is much and very expensive. In addition closing of the road may interrupt traffic flow, which has significant impact on the economy of the country especially when the bridge is on the federal road. So rehabilitation or maintenance of concrete bridges become very crucial and mandatory to stop failure of bridges before reaching their design period and to avoid unnecessary expense to construct a new bridge instead of maintaining and lengthen the service life of the bridge.

Proper design and construction does not mean that the bridge will serve about its design life. Because lack of inspection and controlling with minor rehabilitation may make the bridge to fail before serving to its maximum capacity. So monitoring, inspection, and maintenance of every concrete bridge have to be done starting from construction day before failure, which leads to erection or construction of a very expensive new bridge.

Unlike the practice we used to do before, concrete bridge rehabilitation techniques, materials and procedures are burning and crucial issue now a day, being many of the bridges are reaching about their design life and need rehabilitation before failure. Considering the urgency of the issue, the universities in particular and the country in general with the respective parties have to think of the problem and participate on provision of possible solutions. Although not satisfactory or to the requirement of the country, Ethiopian Road Authority (ERA) in collaboration with Japan International Cooperation Agency (JICA) has maintained some bridges within the last five to eight years.

Concrete bridge maintenance is not an easy task, because regaining the overall condition especially the structural strength of concrete bridge by simple plastering is difficult. So the use of different admixtures (modifying agents), additives (fine mineral powers) and epoxies is mandatory following the procedures and specifications given by the suppliers. At this time there are many suppliers for the construction company involved in maintenance or construction.

Considering the importance of concrete bridge rehabilitation on a national base currently, this study has done to address the basic defects, causes of defects, materials for maintenance and possible techniques and procedures of rehabilitation. It has also given some idea about rehabilitation, so that the respective sectors and researchers can have an assignment on the issue for further investigation and work.

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# 1 INTRODUCTION

This study addresses the increasing needs of skill upgrading trainings on bridge maintenance which is not available in universities or higher technical institutions learning in the country. Conducting this research study is found necessary in order to make simple application of the methods considering the local condition by incorporating international maintenance methods and materials that can be available in the country. In addition, it is intended to make it friendly applicable and usable for contractors, consultants, and other interested users.

This research outlines simple guide and procedure (including identification and selection of materials available) for practicing engineers involving in the repair and maintenance of concrete bridges, and could be useful reference document for researchers and students interested in the subject.

The study shall focus on maintenance of concrete bridges which is dominant defect type occurring in constructed concrete works.

Since bridge structures suffer various kinds of deterioration and defects, many kinds of rehabilitation and strengthening methods have been considered.

In the light of the above, this thesis shall address the following,

- ❖ Defects of concrete structure
- ❖ Causes of defects
- ❖ Material selection and Repairing methods

## 1.1 Background

In 60 years of Ethiopian Roads Authority history, never before as today the need for bridge asset management and maintenance has acquired attention. This calls for careful assessments of the long stayed problems and provision of an urgent action to establishing bridge database, updating, and inspection, prioritization for rehabilitation or maintenance.

Many bridges in Ethiopia have attained about design period, as most are constructed 40-70 years ago. Others have suffered abuse by unscrupulous (ignorant) transporters who overload or move over-height containers. As a result, the structures exhibit cracks and deterioration leaving the steel rebar in most cases exposed to aggressive climatic conditions.

Exposed rebar consequently rust and this could easily result in premature failure of the structure. Even in cases where failure does not occur, the safe use of the structure cannot be guaranteed.

Often under these circumstances, the first and the simplest option is to demolish and reconstruct the structure. However demolition and replacing is very expensive. Besides, there is great inconvenience to road users due to closure of the road while undertaking new construction.

Thus, maintaining and rehabilitation of existing bridges is a better option provided the relevant strength requirements are satisfied. In this aspect tackling the problems, a number of construction chemicals suppliers advertise wide variety of concrete repair products to meet the needs of all kinds of repair situations, indicating availability for use.

A concrete structure is expected to retain the required levels of its functions during the intended service life. Thus, concrete structure shall retain structural performance over the required levels with adequate reliability during the design service life. Consequently, in order to keep the performance always above and to its required level, the adequate maintenance should be indispensable or necessary for most concrete structures.

The basic policies of the bridge maintenance consist of the following concepts. **[1]**

1) The maintenance procedure consists of initial inspection, deterioration prediction, inspection evaluation, judgment, remedial measures, and recording.
2) Maintenance in the structure’s service life need be considered from planning/design to the end of service life
3) Performance based concept is introduced in accordance with the international trend of Codes.
4) Categories of maintenance are defined, with considering engineers activities, which includes various repair option with respect to durability, cost effective, and causes minimum disruption to traffic, in addition to complying with the increasingly stringent environmental regulation.

Bridge rehabilitation can be much more involving than designing and constructing a new bridge. Due to the fact that lack of experience in bridge maintenance works, many professionals tend to recommend bridge replacement. This option calls usually for tremendous amount of budget and interruption of traffic flow and should be the last option.

Currently as an output of BMS bridge prioritization, significant numbers of bridges are proposed for improvement after conducting a detailed investigation. Following this effort, ERA, has allocated considerable amount of budget dedicated to bridge improvement works.

## 1.2 Objective of The Study

The objective of this research is:

- ❖ To identify the basic and most common defects of concrete structures, in general and our country in particular.

- To identify the causes of their defects.
- To propose methods of selecting suitable material and recommendations of maintenance procedure.

## 1.3 Scope of The Thesis

The thesis encompasses concrete bridges from failure to maintenance. But the special attention of the thesis is towards the materials and procedures for maintenance.

In this thesis you will find

- Different parts of concrete bridges
- Defects of different parts and causes of defects
- Maintenance techniques or procedures of defect maintenance.
- Materials involved for maintenance

So, this thesis attempts to address procedures of concrete bridge maintenance with materials involved on national bases.

## 1.4 What is In This Thesis

The thesis has five chapters, which each section representing distinct phase of an overall bridge maintenance program.

- Chapter one addresses introductory and background information on the maintenance of bridges as well as the scope and objective of the thesis.
- Inventory procedure and corresponding inspections for defects are very important for maintenance; in this regard inventory, inspection and causes of defects are dealt in chapter two.
- The materials involved for maintenance are addressed in chapter three.
- The basic concern of this thesis is to give ideas about maintenance and rehabilitation of concrete bridges, which is discussed in chapter four.
- Finally conclusions and possible recommendations are covered in chapter five.

# 2 REVIEW OF BRIDGE DEFECTS AND THEIR CAUSES

## 2.1 Inventory of Bridges

### 2.1.1 Inventory of Bridges

Bridge inventory is a procedure where data and general information about a bridge is gathered which is essentially not subjected to change unless a mistake exist in the first data entry. As a minimum the following information are recorded for each bridge. **[4]**

1) ***Structure number*****:** The official number assigned to the structure by the bridge owner
2) ***Name:*** The full name of the bridge. Other common names by which it is known may be placed in parenthesis following the official names

3a) ***Year built*****:** Year of original construction

3b) ***Year of reconstruction:*** The years during which major reconstruction or widening occurred

4) ***Highway system*****:** State whether or not the bridge is located on Federal Aid System. Describe the types of Federal Aid System and show the route number where applicable.
5) ***Location*****:** Location of the bridge must be sufficiently described so that it can be readily spotted on a map or found in the field. Normally the bridge should be located by route number, county and log mile.
6) ***Description of structure*****:** Briefly give all relevant data concerning the type of structure. Include the type of super structure for both main and approach spans, the type of piers and type of abutment along with their foundations. If the bridge is on piles, the type of piles should be stated. If data is available, indicate type soil up on which footings are founded, maximum bearing pressures, and pile capacities.
7) ***Skew*****:** The skew angle is the angle between the center line of a pier and a line normal to the road way center line. Normally the skew angle will be taken from the plans and it is to be recorded to the nearest degree. If no plans are available, the angle should be measured, computed or estimated. If the skew angle is zero degree, it should so stated.
8) ***Spans:*** The number of spans and the span lengths are to be listed. These shall be listed in the same direction as the log mile. Spans crossing state highways will be normal listed from left to right looking in the same direction as the log mile for the route under the bridge. Span length should be recorded and be noted whether the measurement is center to center(c/c) or clear open

distance (clr.) between piers, bents or abutments. Measurements should be along the center line of the bridge.

9) ***Structure length*****:** This should be the overall length and shall be the length of road way which is supported on the bridge structure. This normally be the length from paving notch to paving notch or between back faces of back walls measured along the center line
10) ***Bridge road way width*****:** This shall be most restrictive of the clear width(s) between curbs railings, or other restrictions for the road way on the bridge. On divided road ways, the road way width will be taken as the traveled way between shoulder, but, also, the shoulder and median width will be given.
11) ***Deck width*****:** The out to out width of bridge to be nearest tenth of meter.
12) ***Clearances*****:** A vertical and horizontal clearance diagram should be made for each structure which restricts the vertical clearance over the highway, such as over crossings underpasses, and through truss bridge.

    The minimum number of vertical measurements shown on the diagram will be at each edge of the traveled way and the minimum vertical clearance within the traveled way.

    The report will state the minimum road way clearance. This will included each road way on divided highway.
13) ***Wearing surface and deck protective system*****:** The type and thickness of wearing surface and the type of deck protective system should be noted.
14) ***Curb or sidewalk widths*****:** The width of left and right curb or sidewalks to the nearest tenth of meter. If only one is present, the side walk should be noted thus “1@1.5m(east).” Sidewalks on both sides are noted thus “2@1.5”. If there are no sidewalks note “None”.
15) ***Railing and parapets*****:** List the type and material of the railing and /or parapet .the dimensions of the railing and/or parapet should also be recorded.
16) ***Bridge Approach Alignment*****:** Note whether the bridge is tangent or on a curve. If the bridge is on a curve, state the radius of the curve if plans are available for this information. On the older roads and bridges, a comparison of the alignment with the general alignment of the road should be made. Note if there are any posted speed restriction.
17) ***Lanes on and under the structure:*** State the number of the traffic lanes carried by structure and begin crossed by the structure.
18) ***Average daily traffic and average daily truck traffic*****:** State the ADT and ADTT, if known along with the date of record. This information should be updated at intervals of approximately 5 years.
19) ***Design load*****:** The live loading for which the bridge was designed should be stated if it is known. A structure widened or otherwise altered so that different portions have different live load designs is to have each live loading specified. If the design live loading is not known, this should be so indicated.
20) ***Feature intersected*****:** List facilities over which the structure crosses in addition to the main obstacle. For example a bridge with the name “wet-water river” Obviously carries traffic over the river; it may also cross over a rail road or other roads, etc.

21) ***Plane and dimension*:** State what planes are available, where they are filed and, if they are as built when plane are available, dimensions and size of structural components should be checked. When plane are not on file, sufficient drawings should be prepared during field investigations to permit an adequate structural analysis of the entire structure, where practical.

22)***Critical features:*** Special structural details or situations, such as scour critical location, fracture critical members, fatigue-prone details, pins and hangers, cathode protection and weathering steel should be emphasized and highlighted for special attention during field inspections.

#### 2.1.1.1 Revised Inventory Data

When a bridge is significantly altered by widening lengthening, or by some other manner which extensively modifies the structure, the bridge inventory data should be updated to reflect the change made to be bridge. The bridge inventory data should also be updated to reflect change in wearing surface, railings and others similar items.

### 2.1.2 Defect Inspection

#### 2.1.2.1 General

**(A). Purpose of Inspection**

Bridge inspection is an action to assess correctly the bridge conditions in a standardized manner and is the most important element in the Bridge Management Cycle that is the systematic maintenance process of inspection, assessment, selection of measures, prioritization and repair to keep bridges in satisfactory levels. The purpose of bridge inspection is not simply to collect the latest information about the present bridge conditions but, more importantly, it should be understood that the inspection is to provide essential information for Bridge Management Cycle. The road administration sometimes must take the critical decisions such as closure and re construction of the bridge based on the inspection results.

Bridges can't keep good conditions forever. Bridges start deteriorating soon after their completion because of the actions of weather, traffic and other various causes. If the bridge inspections are not carried out at all lots, bridges would collapse frequently across the country and would invite social and political troubles without doubt. One bridge collapse can cause casualties and require considerable amount of money and time to reconstruct the new bridge. It is important to understand that a bridge consists of lots of members and elements that have different durability in nature due to the difference of materials, locations, and sensitivities against weather and loads. This indicates that in order to keep the appropriate functions of bridges expected in design, appropriate maintenance is essential in response to the actual deteriorations. Service life of a bridge is usually expected as long as fifty years and longer.

To do bridge inspection in the standardized manner can provide:

- Basic information to assess the safety of bridges
- Data and information to all the activities of Bridge Management Cycle
- Information on any potential trouble spots
- Information on a consistent maintenance strategy

- Information on the effect of any changes in traffic loads
- Information on the behavior of repair and new strengthening techniques
- Hard facts on the results of new constructions and measures

Therefore, bridge inspections should be conducted correctly by qualified inspectors who have good knowledge about bridge design, construction and maintenance.

**(B). Work Flow of Inspection**

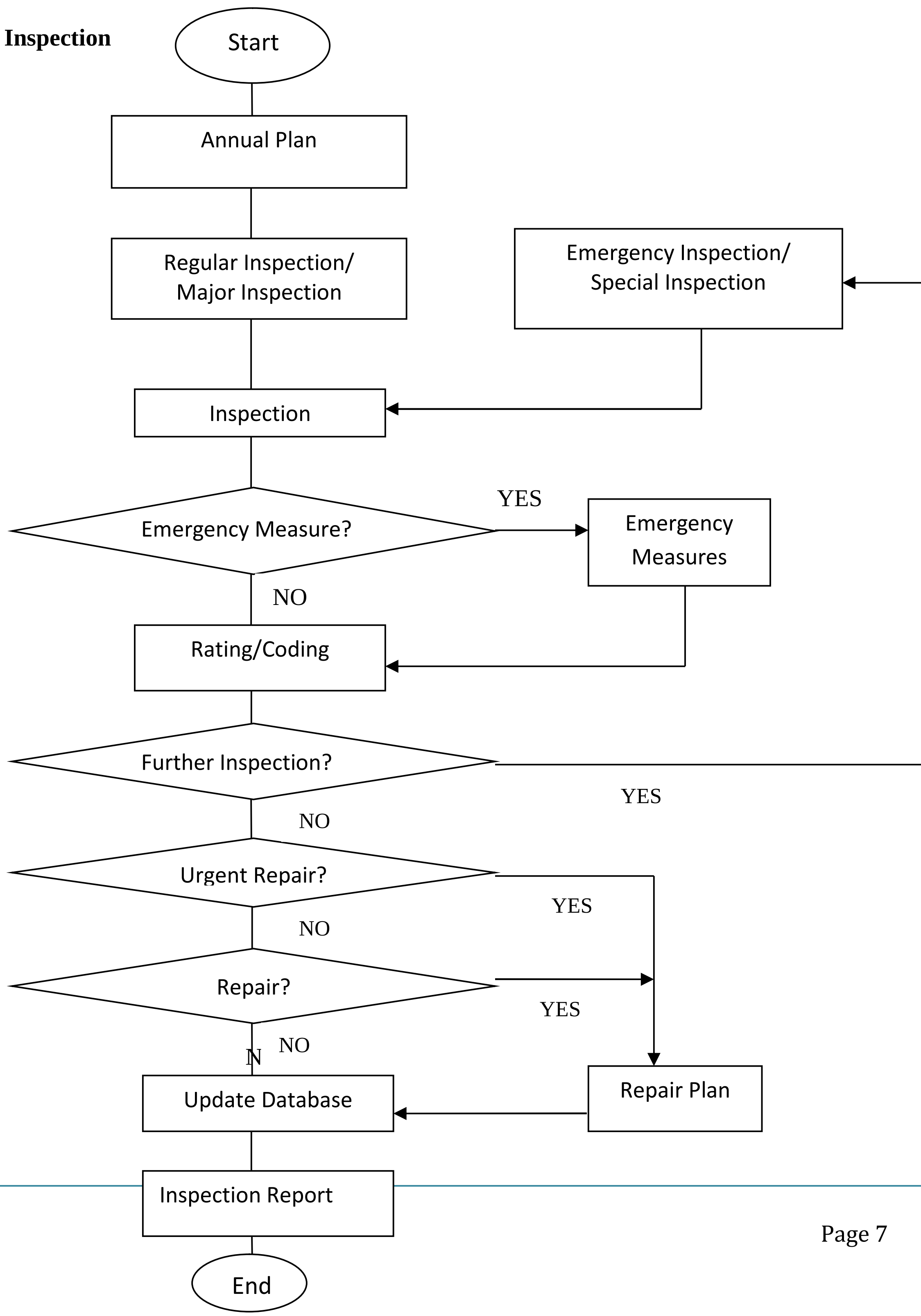

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Figure 2.1.3(b): Work flow chart for inspection

**(C). Classification of Inspection**

Bridge inspections are classified into three types in terms of purposes and frequencies as shown in the following table.

| Classification | Type | Purpose | Frequency | Method | Inspector |
|---|---|---|---|---|---|
| Regular Inspection | Periodic Superficial | Assessing traffic safety and structural safety. Finding major defects | Once a year | Visual from ground level. Report on check list | Road inspector, or bridge inspector |
| Major Inspections | Periodic Detail | Assessing conditions of all structural components. | Once in three years | Visual with equipment. Detailed report with damage ratings. | Bridge inspector or bridge engineer. |
| Emergency Inspections | Non Periodic (during an emergency) | Assessing traffic safety and structural safety. | When needed | Visual | Bridge inspector or bridge engineer. |

- **Regular Inspection**

The regular inspection is a planned, periodic and superficial inspection to confirm the structural safety and safe traffic condition as frequently as possible. It is also expected that the regular inspections can detect the major/serious defects and damages as soon as possible. The inspections are to be carried out by not only bridge inspection staff but also road inspection personnel.

Inspectors must develop the annual plan for the regular inspection work to cover all bridges in the District to meet the frequency requirement of once a year.

- **Major Inspection**

The major inspection is a planned, periodic inspection to be conducted once in every three years by close visual inspection method. The results of the major inspection are core information of the Bridge Management System and bridge inspectors of the District must conduct the major inspections.

Inspectors must develop the annual plan for the major inspection work to cover one third of the bridges in the District to meet the frequency requirement of the bridge once every three years.

- **Emergency Inspection**

The emergency inspection shall b e conducted when needed. After natural disasters and severe traffic accidents the emergency inspection may be needed. The purpose of this inspection is to provide information on structural safety and safe traffic condition. If needed, bridge inspectors must do the emergency inspection without delay so as to judge necessity of emergency measures.

#### 2.1.2.2 Standard Procedures of Inspection

Sometimes inspectors may follow the different procedures due to actual traffic conditions and seasonal conditions. Before going out for inspection, the inspector shall check the availability of past inspection records using BMS and obtain the necessary information on the target bridges. Inspectors shall bring the necessary equipment to manage the appropriate inspections. Thus, a standard inspection procedure is as shown below.

1. Arrive at the target bridge
2. Park at the safe space with necessary traffic safety measures
3. Check the location data and name of the bridge using the required BMS data
4. Check the GPS indication
5. Examine the entire carriageway condition form the abutment side(s)
6. Examine the approach road section
7. Examine the expansion joint
8. Examine the pavement
9. Examine the parapet and railing
10. Examine the drainage inlets
11. Examine the surrounding land condition
12. Move down to underneath the bridge (channel, opening)
13. Examine the abutments
14. Examine the bearing(s) at the abutment(s)
15. Examine the piers
16. Examine the bearing(s) at the piers
17. Examine the high water level
18. Examine the river condition (river bank, sedimentation)
19. Examine the girder(s)
20. Examine the deck
21. Take the pictures of defects/damages
22. Check all the inspection records are correctly filled in the standard form
23. Leave the bridge

### 2.1.2.3 Defects and Damage

The table below shows the typical defects/ damages frequently observed in bridges in Ethiopia

| ***Bridge Type*** | ***Component*** | ***Defects/Damages*** | ***Principal Causes*** |
|---|---|---|---|
| | Girder | Flexural Crack | Excessive Load |
| | | Shear Crack | Excessive Load, Poor Design |
| Concrete Bridge | | Spalling, Delamination | Insufficient Cover, Excessive Load |
| | | Re-bar Exposure | Insufficient cover, Re-bar Corrosion, Concrete Deterioration |
| | | Material Deterioration | Poor Construction |
| | | Honeycomb | Poor Construction |
| | | Water Leakage | Excessive Load, Poor Design |
| | Deck Slab | Flexural Crack | Excessive Load, Poor Design |
| | | Spalling, Delamination | Insufficient Cover, Excessive Load |
| | | Re-bar Exposure | Insufficient cover, Re-bar Corrosion, Concrete Deterioration |
| | | Material Deterioration | Poor Construction |
| | | Honeycomb | Poor Construction |
| | | Water Leakage | Excessive Load, Poor Design |
| | Bearing | Break Failure | Poor Design, Poor Construction, Abrasion |
| | | Dislocation | Poor Design, Poor Construction |
| | | Abnormal Restraint | Poor Design, |
| | Expansion Joint | Abrasion | Aging |
| | | Distortion | Aging |
| | Pier, Abutment | Crack | Poor Construction |
| | | Spalling, Delamination | Insufficient Cover |
| | | Re-bar Expose | Insufficient cover, Re-bar Corrosion, Concrete Deterioration |
| | | Material Deterioration | Poor Construction |
| | | Settlement, inclination | Poor Design, Poor Construction, Earth Pressure |
| | | Scouring | Poor Design |
| | Pavement | Abrasion, Pothole | Aging |
| | | Rutting | Aging, Overloading |
| | | Cracking | Aging, Overloading |
| | Parapet, Guardrail | Deformation | Vehicle Collision |
| | | Break Failure | Vehicle Collision |
| | Clearance | Sedimentation | Poor Planning, Lack of Maintenance |
| Steel Bridge | Girder/Truss | Break, Failure | Excessive Load, Collision |
| | | Deformation | Collision |
| | | Crack | Fatigue, Excessive Load |
| | | Bolt Missing | Material Problem, Excessive Load |
| | | Corrosion | Aging |
| | | Wearing | Aging |
| | | Paint Peel Off | Aging |
| Masonry Arch | Arch Rib, Barrel | Crack | Excessive Load, Poor Design |
| | | Spalling, Delamination | Concrete Deterioration |
| | | Dislocation of Block | Excessive Load, Settlement of Foundation |
| | | Material Deterioration | Poor Construction |
| | Spandrel | Missing of Stones | Poor Construction |
| | | Deterioration of pointing | Aging |
| | | Crack | Excessive Load, Aging, Settlement of Foundation |

| | | | |
|---|---|---|---|
| | | Bulging | Excessive Load, Aging, Settlement of Foundation |
| | Foundation | Scouring | Poor Design |
| | Parapet, Guardrail | Deformation | Vehicle Collision |
| | | Break Failure | Vehicle Collision |

#### 2.1.2.4 Superstructure

Inspectors shall examine the defects/damages of girders, deck slab, and other transverse beams, deterioration of materials, straightness and flatness of members, abnormal noise and vibration, and deflection of girders.

#### 2.1.2.5 Substructure

Inspectors shall examine the settlement and inclination of substructures, defects/damages of materials, deterioration of materials, bulging and missing of masonry materials, and scouring.

#### 2.1.2.6 Miscellaneous Structural Elements

**A-Ancillary**

Inspectors shall examine the defects/damages of pavement, expansion joints, drainage, railings/parapets, and bearings.

**B-Approach**

Inspectors shall examine the settlement of backfill behind the abutments, displacement and erosion of embankment, and surrounding land condition.

#### 2.1.2.7 Channel, Inlet and Outlet

Inspectors shall examine the water level, sedimentation of rocks and sand, other debris, vegetation, rip-raps, and condition of levee.

### 2.1.3 Defects Rating System

Every defect and damage found shall be rated based on the following rating system. Because the rating system reflects the specific conditions and desirable interventions taken into account. Inspectors shall strictly follow the rating (ranking) description given in the table below **[1]**

| Rating (Ranking) | Condition | Desirable Intervention |
|---|---|---|
| A | Serious/major damages, defects, and deterioration causing reduction of load carrying capacity | Urgent repair |
| B | Major Damages, defects, and deterioration affecting durability (reduction in durability) | Repair but not urgent |
| C | Minor/no damages, defects and deterioration | Routine maintenance |

## Damage Rating for Concrete [1]

| Damage | Rank “A” | Rank “B” | Rank “C” |
|---|---|---|---|
| | Single crack width of more than | Single crack width of more than 3mm | Single crack width of more |

| | | | |
|---|---|---|---|
| Cracking | 5 mm or multiple cracks width of more than 3 mm, together with water leakage. In bearing area, single crack width of more than 3mm and multiple crack width of 1mm which causes reduction in loading capacity. | or multiple cracks width of more than 1mm, together with slight water leakage. In bearing area, single crack width of more than 1mm and multiple crack width of less than 1mm which causes reduction in durability. | than 1mm or multiple crack width of more than 1mm. In bearing area single crack width of less than 1mm with no water leakage. |
| Peel Off | Serious peel off which affects the safety of third parties due to a possibility of concrete falling down. Total area is more than 900 cm2. | Wide range of peel off due to rebar corrosion, which causes a reduction in loading capacity. Total area is between 900 -400 cm2. | Small range of peel off due to external forces which affects the durability of the deck slab. Total area is between 400 – 100 cm2. |
| Rebar Exposure | Serious and wide range of rebar exposure together with corrosion which causes a reduction in loading capacity. | Partial rebar exposure with corrosion due to expansion or rebar, peel off or honeycomb, which causes negative effect on loading capacity. | Partial rebar exposure without corrosion, which affects the durability of the deck slab. |
| Honeycomb | Wide range of honeycomb with very serious damage to the rebar, which causes the closure of the bridge | Wide range of honeycomb with seriously corroded rebar, which causes a reduction in loading capacity. | Wide range of honeycomb, which affects the durability of the deck slab. |
| Void | Wide range of voids with serious and continuous water leakage, multiple voids volume of more than 10x10x10Cm, which causes the closure of the bridge | Wide range of voids with serious water leakage, multiple voids volume of 600 -1000 cm3, which causes a reduction in loading capacity. | Wide range of voids, which affect the durability of the deck slab. Volume of less than 600cm3 |
| Water Leakage | Serious and wide range of water leakage through cracks or voids which may progress and cause a reduction in loading capacity, together with leaching free lime or salt. | Serious and wide range of water leakage through cracks or voids which cause a reduction in the durability, together with leaching free lime or salt. | Localized or partial water leakage, which has negative effects on the deck slab. |
| Deformation | Outstanding deformation, which affects the loading capacity due to buckling or partial yielding. | Partial deformation on Primary members such as girder or cross-girder. | Partial deformation on secondary members such as girder or cross – girder. |
| Corrosion | Major corrosion, which affects the loading capacity by reducing cross sectional area on primary member | Partial but wide range corrosion on primary member on such as girder or cross –girder, which affects the durability. | Partial corrosion secondary members. |
| Wearing | Major wearing in almost all range on bridge components, which affects the durability of primary and secondary members. | Wearing in wide range on bridge components, which affects the durability of primary members. | Wearing in wide range on bridge components, which affects the durability of secondary members. |
| Bolt Missing | Missing or falling out of bolts in more than 3 pieces on a primary member joints. | Missing or falling out of bolts in more than 3 pieces on a secondary member joints. | Missing or loosening of bolt in more than one piece on joints. |
| Paint Peel Off | Peel off of paint almost all of area, which affects the steel durability, together with serious corrosion. | Peel off of paint less wide range, which affects the steel durability, together with corrosion. | Peel off paint in wide range, which affects the steel durability, but without corrosion. |

## 2.2 Defects of Concrete Structures

Defects of concrete structures can occur in different stage of life span due to internal or external reasons. Any type of defect can be classified as undesired occurrence that leads to minor or major problem shortly to deterioration.

Deterioration is the process that adversely affects the performance of a structure over time due to defects and damages occurred by naturally occurring chemical, physical or biological actions, repeated actions such as those causing fatigues, normal or severe environmental influences, and wear due to use, abuse, and others.

Here, the initial defect basically should be repaired at construction stage. The instantaneous damage does not change much in their degree with time after they arise. Therefore, in general, they may be treated promptly as emergency treatment. On the other hand, since the rate of performance degradation of structure due to deterioration would change apparently with time, the deterioration mechanism should be identified as much as possible and appropriate actions concerning the prediction of deterioration and evaluation/judgment of performance degradations should be carried out. Therefore, the deterioration should be mainly dealt with as the target for the maintenance activities.

### 2.2.1 Cracking

Concrete is by nature a brittle material, so reinforced concrete structures are destined to suffer cracking. Cracking cannot be prevented completely with present techniques. Not all types of concrete cracking, however, pose problems; some are detrimental to structures but others are not. Damaging cracking includes those types that cause water leakage due to cracking throughout the member, excessive deflection, aesthetic concerns and defect to the durability of structure.

Cracks in concrete may described in a variety of ways. Some of the more common ways are in terms of surface appearance, depth of cracking, width of cracking, current state of activity, and structural nature of the crack.

Cracking can be an important indicator of deterioration taking place in concrete and possible corrosion of reinforcement steel depending on the size, extent and location of the cracks.

Cracks of concrete are classified as structural or non-structural cracks.

**Phenomenon**: - Generally, cracking represents the deterioration of concrete. Surface appearance which is pattern or map cracks and individual cracks can give the first indications.

Individual cracks indicate tension in the direction perpendicular to the cracking.

Depth cracking is a self explanatory as may be surface, shallow, deep and through type. Active or dormant state of cracks, width of cracks, and structural nature of crack (Structural or non structural) can be listed as different types of it.

Cracking after reinforcement corrosion owing to the increase of corrosion of reinforcement and cracking before reinforcement corrosion that induces the corrosion of reinforcement are different options of crack.

- **Structural Cracks**: - Are those cracks which result from insufficiency of the section to withstand the flexural, shear, settlement and other stresses developed in that section due to dead and live loads applied upon it. Structural cracks are caused by load stress and are divided into flexure and shear cracks.
    - ***Flexural cracks*** are vertical and start in the maximum tension zone and proceed toward the compression zone.

Plate 2.2.1a: Flexural crack

- ***Shear cracks*** are found near the bearing area. It begins at the bottom of the member and extends diagonally upward. Structural cracks will usually be substantial in width, and the opening may tend to increase as a result of continuous loading and creep of the concrete.

**Plate 2.2.1b: Shear crack**

- **Non-structural cracks**:-Can be referred as cracks caused by temperature, shrinkage and mass concrete cracks. These cracks are relatively minor and generally do not affect the load carrying capacity of the member. They can, however, provide openings for water and contaminants, which can lead to serious problem.

  Non structural cracks are those cracks which result from workmanship Problems, shrinkage of concrete and other minor causes.

### 2.2.2 Peel off, Delaminating, Void

Disintegration of concrete differs from spilling in that larger pieces of intact concrete are lost when spilling occurs.

Two of the most commonly used terms to describe disintegration are Scaling and dusting. Scaling is the gradual and continuing loss of surface mortar and aggregate over an area. Dusting is the development of a powdered material at the surface of hardened concrete. Dusting will usually be noted on horizontal concrete surfaces that receive a great deal of traffic.

Expansion beneath the surface of concrete, for example as a result of reinforcement corrosion, produces tensile stress, which exceed the concrete strength and areas of the concrete surface break away.

Delamination occurs when layers of concrete separate at the level of outermost layer of reinforcing bars. Delaminated areas give a hollow sound when tapped with a hammer.

The resulting depression by delaminating is called a spill. A spill is a roughly circular or overall depression in the concrete resulted from separation and removal of portion of surface concrete. Spilling means the breaking

away of concrete flake. Spilling is defined as the development of fragments, usually in the shape of flakes, detached form a layer mass. A spill is a roughly or oval depression in the concrete.
This can be protected by providing a well cleaned and painted form work surface.


**Plate 2.2.2: Peel off**

### 2.2.3 Honey Comb

Honeycomb refers to voids in concrete due to failure of the mortar to effectively fill the spaces among coarse-aggregate particles. This may be due to leakage of mortar through formwork joints which is not well prepared. It usually becomes apparent when the formwork is stripped (exposed), revealing a rough and, 'stony 'concrete surface with air voids between the coarse aggregate. Sometimes, however, a surface skin of mortar masks the extent of the defect.
Honeycombing may extend some depth into the member. Honeycombing is always an aesthetic problem, and depending on the depth and extent may reduce both the durability performance and the structural strength of the member.
Coarse aggregate with air space appear on the surface of concrete. Honeycombing occurs where the spaces between coarse aggregate particles are inadequately filled, with the result that the hardened concrete has an open structure. Honeycomb preferably shall be repaired at the construction time, before handing over the original work, with supervision.


**Plate 2.2.3: Honey comb**

Concrete surface is not smooth as desired. Spots and small voids are visible, accumulation of bigger size aggregates may also be observed. Due to pour-out of cement paste, bondage of aggregates seems very poor.
To minimize the incidence of honeycombed coarse aggregate:-

- Ensure the mix has sufficient fines to fill the voids between the coarse aggregate
- Use a mix with appropriate workability by repeatedly checking the slump test for the situation in which it is to be placed
- Ensure the concrete is fully compacted and the placing methods minimize the risk of segregation
- Ensure the reinforcement layout and the section shape will permit the concrete to flow around the reinforcement and completely fill the forms
- Check that the formwork is rigid and well braced, the joints are watertight and any penetrations through the formwork e.g. form ties, are properly sealed

### 2.2.4 Spoiling, Scaling, Wearing

Spoiling is loose of quality appearance due to many external reasons. Wear and abrasion of the concrete surface are caused by being exposed to traffic and water flow.
Wearing land abrasion is the result of external forces acting on the surface of concrete member like erosive action of sands in running water over the concrete surface.

Excessive water added at the time of delivery of concrete in order to increase the workability of concrete causes an increase in the water cement ratio of the concrete leading to a reduction in strength and durability of concrete, which can be manifested in surface defects like scaling, crazing and dusting.

Improper finishing and curing operations cause surface scaling. The materials for finishing and curing operation cause the concrete to dusting and scaling. The procedures used to prevent dusting will prevent surface scaling.

**Plate 2.2.4: Surface scaling**

## 2.3 Causes of Concrete Defects

### 2.3.1 General

Defects that appear on the surface of concrete during construction or within a relatively short time after completion, are usually caused by poor quality materials, improper mix design, lack of proper placing and curing procedures, or poor workmanship. The repair of surface defect is both difficult and costly. The best repair work will not be as good as an original properly finished surface. Every effort should be made both prior to and during construction to avoid the use of materials or construction practices that can cause surface defects.

Various causes may have contributed to the formation of a particular defect. However every effort should be made to determine the causes and ensure that the correct repair strategy is adopted. Clear factors like, natural disasters, fire, flood, vehicular collision; foundation settlement, excessive stress beyond the capacity of the designer are some of the causes of concrete defects.

Structures may be overstressed by conditions outside the control of the designer and constructor, such as overloading, change to the flow of a river, failure of adjacent structures and various natural causes.
Settlement of a structure, which was not anticipated and allowed for in design, can result in very severe damage to concrete structures. Wide cracks and crushing where members come into unintentional contact may indicate that settlement has occurred.

When settlement is suspected a structure should be carefully monitored to assess whether movement has cease or is continuing. Excessive settlement can cause complete collapse of a bridge.

Following a vehicular collision with a bridge, careful consideration of the structural effects must be carried out by an experienced structural engineer. Damage to primary elements can severely weaken a structure, or even cause collapse.

Similarly the effects of fire damage must be assessed by an experienced structural engineer. Defects such as cracks, spills, delaminating of the concrete cover, deformation of reinforcing bars and deflection of structural members can seriously affect the performance of a bridge. Extensive fire damage may necessitate replacement or strengthening of affected members.

Generally defect in concrete structures may result from many factors such as poor design and detailing, construction deficiencies, overstress or loss of section resulting from, chemical attack, settlement of the foundation, changes to the support or loading conditions caused by scour or silting, failure of bearings or expansion joints, and traffic collision defect.

Deflection due to excessive and repetitive loading is a sign of deck slab deterioration and cracks.
There are two causes of deflection:

1. Deflection induced by external force acting the concrete structure in excess of its design load. Flexural and shear cracks are generated such a factor, leading to acceleration of steel corrosion and other types of defect.
2. Fatigue is a phenomenon where cracks that have developed in concrete or reinforcement by repetitive loading lead to cover scaling and steel failure. Fatigue failure may occur if excessive loads are applied repetitively. An example is the depression of a reinforced concrete slab by repetitive wheel loads on a bridge.

Common types of causes of defects in concrete bridges can be categorized as follow:

- **Design Errors:** Common design errors which result in defects include:
    - **Incorrect concept –**which includes inappropriate structural planning (arrangement), inappropriate structural modeling, insufficient knowledge, and incorrect procedure.
    - **Calculation errors -**which include Design specification error, inadequate factor of safety; Stress analysis error, Omission of design consideration, arithmetic error and Failure to allow for the effects of creep.
- **Drawing/detailing errors** which include
    - Poor reinforcement or pre stressing detail
    - Failure to provide all of the required reinforcement
    - Inadequate checking of drawings
    - Incorrect movement joint spacing and locations
    - Poor detailing of expansion joints
    - Poor drainage details which result in leakage or clogging
    - Insufficient development length
    - Insufficient lap length
    - Inadequate data in the drawing

- Insufficient provision of sections and details
- Lack of specification of material quality and procedures

- **Construction errors:** Adequate supervision at the construction stage is essential to ensure that the works comply with the design. Many defects and problems arise can be covered up during construction by the resident engineer or responsible person.

  ***Typical construction defects are***: Incorrect concrete mix proportions, failure to adequately support the formwork resulting in movement during concerting, improper reinforcement arrangement, inadequate cleaning out during preparation for concreting, failure to provide the specified concrete cover to reinforcement, insufficient compaction of concrete, lack of curing of concrete elements, and failure during dismantling of the formwork.
- ***Poor materials* –** This includes poor quality ingredients of concrete (cement, aggregate, sand and water), poor quality concrete mix, poor quality reinforcement, and use of incorrect grade of material,
- ***Poor workmanship -*** This consists of unsuitable construction method or order of construction, inexperienced or careless workmen, temporary works failures (formwork and false work), inadequate supervision and deterioration of material caused by inadequate storage condition,
- ***External effects* –** consists of increased traffic levels or overloading, accidental damage (collision, falls, fire), natural phenomena (flood, subsidence, heave, and earthquake), influences of the bridge approaches, chemical action (sea water, polluted water, de-icing salt, airborne pollution), and failure of adjacent structures resulting from different ground conditions.

### 2.3.2 Concrete Cracking

**1. Structural Crack:** heavy traffic loads and increment of the load acting frequencies that may occur through time after the construction of the bridge structures is one of the basic causes for structural cracks on reinforced concrete members. Insufficient structural design and errors in interpreting the drawings during construction, large impact forces caused by defect of road surfaces and aging of the concrete are also main causes of the structural cracks. The structural cracks can further be classified as flexural, shear, torsion, and compression cracks based on the internal stress which brings about the cracks. The user of this study shall identify the real cause of cracks, analyze loads and quantify the magnitude of stresses and strains developed in the sections and finally arrive at amount of reinforcement that shall be applied to repair these types of cracks.

**2. Non structural crack:** there are several causes of non structural cracks which develop on reinforced concrete bridge components. Among those causes, the most common ones are shrinkage of concrete due to lack of proper curing mechanism, defect on concrete surface during formwork removal, absence of proper expansion joints, and other similar workmanship problems.

General Cause of cracks

- Lack of curing and quick removal of form, etc
- Variation of temperature and moisture
- External forces of bending moment, shearing force and fatigue
- Differential settlement of foundation
- Corrosion of rebar for lack of covering, chloride damage and carbonation, etc.

### 2.3.3 Concrete Peel off, Delaminating, Void

However thickness of concrete cover is generally indicated in the drawings: the cover could become insufficient due to inadequate setting of spacer, error of reinforcement bar arrangement and movement of bars during casting of concrete.

Insufficient cover is hardly detected at the time of casting concrete, however the reinforcement bar will gradually rust and swell and the concrete cover start to be peeled off.

**Plate 2.3.3: Rebar exposure due to peel off and delaminating**

Spill can be caused by corroding reinforcement and friction from thermal movement due to which reinforcing steel is often exposed.
The major cause of delamination is expansion of corroding reinforcing bars. This is commonly caused by intrusion of chlorides or salt. An inadequate drainage system can severely limit the life span of a concrete deck due to deterioration by leakage and corrosion of reinforcement bar which produces tensile stress exceeding the concrete strength, so that area of the concrete surface break away.

Voids formed when the concrete fails to fill area in a form, typically those under large blackouts, in very deep placements, or forms that are heavily reinforced. Voids are almost always structural defects requiring repair. Causes of honeycomb and voids include stiff or unworkable concrete, segregation, congested rebar, insufficient consolidation, and improper placing practices.

### 2.3.4 Concrete Honey Comb

Honeycomb surfaces are caused by the use of a dry mix that was not properly consolidated. The concrete mix should be designed to provide a workable mix for the type of consolidation that will be used on the job. When honeycombing occurs, don’t just add water to the mix to correct the trouble. That will decrease the strength and durability of the concrete. The mix should be redesigned to provide improved workability or the procedure for consolidating the concrete should be improved.
Honeycombing is caused either by the compaction not having been adequate to cause the mortar to fill the voids between the coarse aggregate, or by holes and gaps in the formwork allowing some of the mortar to drain out of the concrete. In some cases, the member shape and detailing/placement of the reinforcement compounds the effect of inadequate compaction.

It can be caused by segregation of material during concrete casting, insufficient compaction of concrete and it can also be caused by the loss of cement grout, leaking of cement paste, where form work is inadequately sealed.

The defect may be purely cosmetic or, depending on the location and extent of honeycombing, may be structural and require repair. For instance, honeycombing behind post-tensioning anchors may require repair so the post-tensioning forces don’t cause compressive failure of concrete in the bearing area.

Preventing honeycomb and voids starts with attention to concrete mix proportions. Proper techniques for forming, rebar placement, providing enough paste, increasing of slump, controlling setting rate**,** concrete placement and proper vibration are important activities to reduce or avoid honeycomb problems

**Provide enough paste**: Concrete not containing enough cementicious material and fine sand will be prone to segregation and won’t flow well. Consider adding a blend sand or additional Portland cement or fly ash to increase the amount of fines. Increasing the ratio of fine-to coarse aggregate will increase workability only if 5% to 10% of the sand passes the No.100 sieve.

**Increase slump**: Even with the correct amount of paste, a mix can lack workability and won’t flow into place. To improve flow, increase slump from 15 to 20 centimeters by adding a water reducer or super plasticizer. **Reduce aggregate size:** If closely spaced reinforcement or other obstacles hindering concrete flow, consider reducing coarse aggregate size.

**Control setting rate**: Slow placement rates and high ambient and concrete temperatures can cause concrete to stiffen, reducing its flow ability. Adding a retarder may help, but retarders don’t necessarily prevent slump loss. Care should be taken to protect honeycomb defect in this process.

**Forming and rebar placement**: Review reinforcement details. Closely spaced rebar, insufficient clearance between the rebar and forms, and closely spaced lap splices all interfere with concrete flow and vibration. Work with the steel detailer to minimize these problems. Provide access to forms. Narrow or tall forms prevent observation and access during concrete placement. You may have to cut placing ports into forms containing heavily reinforced sections.
Tightly seal form joints, otherwise mortar loss through form joints may cause honeycomb.

**Vibrate Properly**: Workers must be trained to vibrate concrete correctly to ensure that it flows around reinforcing steel, embedment, and blackout. Build up a head of concrete on one side of small blackouts, and vibrate the concrete until it appears on the other side. Large block outs require concrete to flow many meters laterally, so you may need to use pour pockets beneath these block outs.
Drill holes in the bottom of a block out to allow displaced air to escape.
**Avoid delays**: If the placement is not going as fast as planned, ready-mix trucks may have to wait before discharging material and the concrete will start to stiffen. You can reduce stiffening by using retarding admixtures, but a better approach is to alert the concrete producer when unavoidable placing delays occur.

### 2.3.5 Concrete Spoiling, Scaling and Wear
Some aggregates used in concrete react chemically with high alkali cements, causing disruption of the concrete. This form of deterioration or spoil is called alkali aggregate reaction, and results in extensive cracking.

Scaling, i.e., local flaking or peeling away of the near-surface portion of a concrete slab is the most common type of surface distress, especially in areas exposed to cyclic freezing and thawing, and de-icing chemicals. A comprehensive evaluation of factors responsible for concrete surface scaling disclosed that, the following may causes.
(a) Concrete materials, proportions, and properties (air content, air void system, aggregate, cement paste, aggregate-paste interface, compressive strength, water-cementations materials ratio, degree of saturation of concrete, and chemical admixtures);

(b) Construction practices (consolidation, finishing, curing, hot and cold weather protections, drainage, and surface treatments);
(c) Concrete maturity; and
(d) De-icing salts (salt type, concentration, timing of exposure ) on scaling

***Therefore,***

A) Concrete should be air-entrained for the protection of the paste during freezing. Concrete should have a good air-void system consisting of numerous fine, discrete spherical and near-spherical air voids of sizes up to 1 mm, the majority of which should be very fine.
B) Concrete should be made using well-graded, well distributed, and frost-resistant aggregates.
C) Concrete should be properly placed, finished, and cured.
D) Concrete should be matured, i.e., it should undergo a period of air-drying and should attain a compressive strength of at least 28 MPa (400 psi) prior to the first exposure to freezing and de-icing salts.

## 2.4 Other Defects and their Causes

### 2.4.1 Scouring and Erosion

Bridge scour is the removal of sediment such as sand and rocks from around bridge abutments or piers. Scour, caused by swiftly moving water, can scoop out scour holes, compromising the integrity of the bridge.

Bridge scour is one of the causes of bridge failure. It has been estimated that 60% of all bridge failures result from scour and other hydraulic related causes. It is the most common cause of highway bridge failure in some countries like the United States, where 46 of 86 major bridge failures resulted from scour near piers from 1961 to 1976. Scour failures tend to occur suddenly without prior warning and are very difficult to monitor during flood events.

Water normally flows faster around piers and abutments making them susceptible to local scour. At bridge openings, contraction scour can occur when water accelerates as it flows through an opening that is narrower than the channel upstream from the bridge. Degradation scour occurs both upstream and downstream from a bridge over large areas. Over long periods of time, this can result in lowering of the stream bed.

Bridges that cross water channels require detailed inspection of channel characteristics and the condition of substructure elements in the channel. The need for a detailed and thorough scour inspection program is a result of the catastrophic effects which can be caused by excessive scour.

If constriction in the channel is significant, the velocity of the stream can increase such that the substructure footings and/ or piles become undermined (damaged). Sharp bends or curves in the water channel also increase velocity which can create cross-currents and turbulence. Scour either occur locally at specific substructure components or over the entire structure crossing the channel.

The effects of foundation movements upon a structure will vary according to the magnitude of movements, type of settlement, and type of structure.

Movement of large magnitudes, especially when differential settlement occurs it causes distress in the structures. Large movements in a bridge will cause:

- deck joints to jam;
- slabs to crack;
- bearings to shift;
- substructures to crack,
- buckle, and possibly, even to collapse

A uniform settlement of all the foundations of a bridge will have little effect upon the structure.

Differential settlement can produce serious distress in any bridge. Where the differential settlement occurs between different substructure units, the magnitude of the defect depends on the bridge type and span length.

Stream channel instability resulting in river erosion and changing angles-of –attach can contribute to bridge scour. Debris can also have a substantial impact on bridge scour in several ways. A build- of material can reduce the size of the waterway under a bridge causing contraction scour in the channel. A build-up of debris on the abutment can increase the obstruction area and increase local scour. Debris can deflect the water flow, changing the angle of attack, increasing local scour. Debris might also shift the entire channel around the bridge causing increased water flow and scour in another location.

During flooding, although the foundations of a bridge might not suffer damage, the fill behind abutments may scour. This type of damage typically occurs with single span bridges with vertical wall abutments.

- Foundations must transfer all loads imposed on the bridge into the ground. If the foundation is not strong enough or deep enough to do this, this bridge will be destroyed. If the foundation embedment into the ground is not sufficient to account for erosion and scour that may occur over the life of the bridge, the bridge is vulnerable to collapse under design flood and wind conditions.
- Predicting the incidence, locations, and magnitude of coastal erosion and scour is difficult, and present-day bridge codes and standards do not prescribe clear-cut solutions for designers. Therefore, designers should be conservative with their foundation designs. This means foundations may need to be stronger, deeper, and higher than what has historically been used. Lessons learned from Hurricane Ike and other recent coastal storm events should be incorporated into foundation designs.

**Erosion** refers to a general lowering of the ground surface over a wide area. Erosion can occur across a wide range of timeframes where it can be

- gradual, occurring over a long period of time (many years);
- more rapid, occurring over a relatively short period of time (weeks or months); or
- episodic, occurring during a single coastal storm event over a short period of time (hours or days)

**Scour** refers to a localized loss of soil, often around a foundation element. Scour occurs when floodwater passes around obstructions in the water column. As the water flows around an object, it must change direction and accelerate. Soil can be loosened and suspended by this process or by waves striking the object, and be carried away. Pilings, pile caps, columns, walls, footings, slabs, and other objects found under bridges can lead to localized scour. Scour effects increase with increasing flow velocity and turbulence, and with increasing soil erodeability.

Scour effects are generally localized, ranging from small, shallow conical depressions in the sand around individual piles to larger and deeper depressions around individual piles. In some cases, bridges may settle due to inadequate pile embedment, coupled with some combination of erosion, scour, and soil liquefactions that leads to loss of bearing.

There is one other erosion and scour scenario to consider in foundation design- the loss of soil around or under a bridge as a result of storm surge flow being channeled or directed across a bridge site. This process usually takes place where storm surge flow is constrained between gaps in shore protection, or when return flow to the sea follows path of least resistance, such as along canals and roads.

#### 2.4.1.1 Erosion and Scour- Impacts on Foundations

Erosion and scour have several adverse impacts on coastal foundations:

- Erosion and scour reduce the embedment of the foundation into the soil, causing shallow foundations to collapse and making bridges on deep foundations more susceptible to settlement, lateral movement, or overturning from lateral loads.
- Erosion and scour increase the unbraced length of pile foundations increase the bending moment to which they are subjected, and can overstress piles.
- Erosion over a large area between a foundation and a flood scour exposes the foundation to increased lateral flood loads (I.e., greater still-water depths, possible higher wave heights, and higher flow velocities).
- Local scour around individual piles or a bridge foundation will not generally expose foundations to greater flood loads, but linear scour across a bridge site may do so.

**Bridge examination**

The examination process is normally conducted by hydrologists and hydrologic technicians, and involves a review of historical engineering information about the bridge, followed by a visual inspection. Information is recorded about the type of rock or sediment carried by the river, and the angle at which the river flows toward and away from the bridge. The area under the bridge is also inspected for holes and other evidence of scour.

According to Lacey's formula, the width of a natural channel at bank-full flow is proportional to the root of the discharge.
To determine scouring depth:

$$\mathbf{d = 0.473\ (Q/f)^{1/3}}\ \textbf{where,}$$

Where, d = normal depth of scouring below HFL
Q =d ischarge (in m3/S)
F = Lacey's silt factor, which is a function of bed material
$F = 1.76 \times \sqrt{\text{Particle size}}$

The effects of scour can change throughout the life of a structure. Accumulations of silt and debris may reduce the channel of a river or cause it to follow a different course.

Similarly the uncontrolled extraction of gravel or sand form river beds can affect the flow, causing scour at bridges further along the river. As scour can completely undermine the foundations of a bridge and thereby cause it to collapse, it is essential that its occurrence is detected at an early stage or preferably prevented.

Sometimes scour causes large holes in river beds or washes large sections of the bank away. Many bridges have been destroyed by scour. Rivers can easily damaged or destroy bridges. Usually, bridges are damaged when the river is too big to go through the waterway under the bridge, or when the river changes its path.

There are three reasons why a river may not be able to go through the waterway of a bridge:

1. A river can grow and become too big for the waterway.
2. The waterway under the bridge can be blocked by parts of old bridges, trees, fences and other debris.
3. The waterway under the bridge was not made big enough.

If there is a flood which is too big for the waterway under the bridge, the river may do 3 things:

1. Wash away the bridge.
2. Wash away the road embankment and the road, and go round the bridge.
3. Wash away the fill in front of the abutments, and scour big holes in the river bed.

If the-waterway is too small, another bridge or some culverts may be needed to carry the extra; floodwater, otherwise the river can change their path slowly or very quickly. Change of path can, after a time, cause damage to a bridge.

**2.4.1.2 Causes for Scouring**

Any type of substructure not founded on solid rock may be subject to settlement and lateral movement like piles, earth retaining structures, such as abutments and retaining walls. Foundation movements may often be detected by first looking for deviations from the proper geometry of the bridge. Change in direction and flow type of flood specifically at pier or abutment footing area evidenced by turbulence, erodes materials from under foundations. General scour occurs over a long period of time and is initiated by an alteration in channel flow patterns. This mainly caused by a change in the supply of sediments to a large area.

- **Poor Design:** Waterways should be inspected in order to determine whether any condition exists that could cause defect to the bridge or the area surrounding the bridge. In addition to inspecting the channel’s present condition, a record should be made of any significant changes that may have taken place in the channel, attributable either to natural or artificial causes.
  In stream beds susceptible to scour and degradation, a channel profile should be taken periodically, generally at 30meter intervals, extending to a few hundred meters up-stream and downstream.
  The channel change steepens the channel and increase flow velocity. The entire section may degrade.
  Events which tend to produce local scour, channel degradation, or bank erosion are of primary importance.
  Scour can cause extensive settlement which may also be uneven. Since water will carry off particles of soil in suspension, a considerable hole can be formed around piers or other similar structural objects. This condition results in a greater turbulence can be displaced.

  Stream bed or banks near the abutments or piers may be eroded due to fast water flow; undermining the unprotected soil banks. If neglected, settlement will develop and bridges’ foundation and the embankments will be washed away.
  Scour is defined as the removal and transportation of material from the bed and banks of rivers and streams as a result of the erosive action of running water.

Stream bed degradation is usually due to artificial or natural alteration in the width, alignment, or profile of the channel. These alterations which may take place at the bridge site or some distance upstream for down-stream upset the equilibrium, or regime, of the channel.
Stream bed degradation and scour seriously endanger bridges whose foundations are located in an erodible river-bed-deposit and where the foundation does not extend to a reasonable depth below that of the anticipated scour.

- **Channel Constrictions:** Typical situations which tend to lead scour problem are Sediment deposits, Pier scour, loose riprap, Lined banks, Horizontal or vertical channel constructions that creates a high velocity, flooding, protruding abutments, debris, and river bends. Most foundation movements are caused by movement of the supporting soil. Soil deformations are caused by volume changes in the soil or by a shear failure. Slope slides and bearing failures are good examples of shear failures. Where loads are not large enough to cause shear failure, Settlements may still occurs as a result of volume change.

  Substructures that are supported directly by a cohesive soil may continue to settle through a long period of time due to consolidation, which usually produces vertical settlement.

  Slope failures (embankment slides) are shear failures manifested as lateral movements of hillsides, cut slopes, or embankments. Footing or embankment loads imposing shear stresses greater than the soil shear strength are common causes of slides.
  Inadequacy of waterway results scour and streambed degradation. The geometry of the channel, the amount of debris carried during high water periods, and the adequacy of freeboard should be considered in determining waterway adequacy.

## 2.4.2 Water Leakage and Deteriorations

### 2.4.2.1 Causes of Water Leakage

An extended water leakage largely contributes to the deterioration of the bridge part prone to this specific defect. The repair technique dealt therefore enables to protect the concrete section from being continuously degraded. Water leakage under concrete may be caused due to cracks, voids, concrete porosity, absence of impermeable wearing course, defect to joint sealants, or blockage of drains.

Stopping serious and wide range of water leakage that passes through cracks or voids, which may cause a reduction in loading capacity together with leaching of free lime or salt, is an essential activity.

Wide cracks may be repaired by filling with Portland cement grout. This method is effective in stopping water leaks, but it will not structurally bond cracked section.

All defects associated with the concrete defects which were dealt previously shall be maintained as per the techniques specified before.

Bridge drainage is also an important inspection-item, since any trapped or pounded water can cause a great deal of defect to a bridge and is also a safety hazard. Therefore, an effective system of drainage that carries the water away as quick as possible is essential to the proper maintenance of the bridge.

Accumulation of debris is a principal cause for surface drainage inlet-clogging. The ponds and puddles of water that form on the bridge deck pose the problem which constitute a safety hazard and can cause extensive bridge deterioration.

Downspouts and horizontal pipe-run, which are poorly designed with inadequate slopes and sharp directional changes at the elbows, are conducive to plugging drains.

**Corrosion**: **-** drainage water often carries corrosive element that attack drainage pipes and concrete. Clogging and slow drainage accelerate deterioration of girder, side beam and internal part of deck slabs as well as rebar corrosion.

### 2.4.3 Concrete Deck – Slab and Pier Columns Deterioration and Repair Methods

#### 2.4.3.1 Causes of Deterioration

Concrete desk slab usually deteriorate due to long period water stay or leakage, poor workmanship during the original construction period or external problems like crush and bomb blasting. Water may leak through deck slab due to the following causes.
Cracks: **-** Cracks will occur on girder/beam and deck slab by the repeated and overload wheel load. Then water can pass through the slab deck and finally some parts of the concrete will peel off.
Porous construction joints honeycomb, cast-in-fittings such as drain pipe, Deterioration of concrete due to Carbonation, and Alkali reaction, etc. are other causes of leakage of water.

### 2.4.4 Rust Treatment of Concrete Reinforcing Bar

#### 2.4.4.1 Causes of Rust

Reinforcement shall be free from pit, loose rust, mill scale, paint, oil, grease, adhering earth, ice or any other materials that may impair the bond between the concrete and the reinforcement or that may cause corrosion of the reinforcement or disintegration of the concrete.
Reinforcing steel corrodes either where cracking induces the corrosion of reinforcing steel (cracking before reinforcement corrosion) or where carbonation or salt defect corrodes reinforcing steel, which then causes cracking after reinforcement corrosion.
The point when corrosion-induced cracking occurs along the reinforcement in the concrete cover is considered the deterioration limit for the cracking caused by reinforcement corrosion.
When reinforcement corrodes to a certain extent, the surrounding concrete cover tends to crack and split. The cracks are caused by internal bursting pressures developing in the concrete as a result of a net increase in volume by the formation of corrosion products. Spalling of the concrete cover will then permit the entry of water and other corrosion accelerating agents and the rate of corrosion will accelerate.
When corrodes, the prestressing steel becomes vulnerable to fracture because it has been prestressed, and so the durability of the structure is severely affected. When reinforcement corrodes, it expands causing tensile stress in the surrounding concrete which results in cracking and spalling.

Reinforcement bars in the permanent structures may be found exposed or uncovered due to concrete peel off resulting from external impact or concrete aging or formwork removal, lack of sufficient cover during construction, and concrete void or honeycomb.

If the deterioration of concrete has been caused by corrosion of reinforcement, the products of corrosion must be removed before placing the new concrete; otherwise the repair will not be effective. If the defect is due to chloride contamination, all rust shall be removed from the steel as any residual rust will be contaminated with chlorides that could restart the corrosion later.

Materials used for maintaining the concrete failures which finally attribute the reinforcement bar exposure are to be dealt with the respective concrete failures repair. Regarding the replacement of the defect reinforcement, curious investigation shall be made for determination of the defect portion. Based on the design calculations, the reinforcing of the structure can be made using steel plate bonding or carbon fiber reinforced polymer methods.

The corrosion of reinforcement may caused by carbonation and chloride attack. Carbonation or chloride attack involves the contamination (ineffectively) of protective alkaline environment provided by good quality concrete.
The presence of excessive amounts of chloride ions, originating from the use of the admixture calcium chloride, will also destroy the passive layer, which prevents corrosion.

# 3 MATERIAL FOR REPAIR

## 3.1 General

Concrete is an essential material. With a worldwide estimated consumption of between 21 and 31 billion tones of concrete in 2006, concrete is the second most consumed substance on Earth after water! A world without concrete is almost inconceivable **[17, 18, and 19]**

The principles of producing concrete and understanding the laws of concrete behavior are well enough established through long experience and extensive research to make it possible to design and erect structures that meet the recognized requirements of engineering use and safety. There is still a need for continued research, however. New questions are constantly arising, and new methods and machines for construction operations are being developed. If concrete is to meet increasingly higher expectations with regard to durability and structural efficiency, and continue in the forefront as a building material, the new requirements need to be met by ever-increasing knowledge obtained from research and experience.

Concrete sets, hardens, gains strength, and exhibits reduced permeability with the passage of time, but it is not the passage of time alone that causes these things to happen. If the concrete is kept very cold, none of this will happen. If all moisture is removed, none of this will happen.
Many or even most concretes are confronted with potential deteriorative service conditions. If the concrete has not been provided with immunity against these influences, it may well slowly deteriorate as time passes, but not simply because time passes. Concrete need not deteriorate.

## 3.2 What is Concrete Structure?

Concrete is essentially a compressive material. While it has adequate strength for most structural uses, it is best suited for relatively massive members that transmit compressive loads directly to the founding material. Although concrete has low tensile strength, reinforcing it with steel bars produces a material that is suitable for the construction of flexural members such as deck slabs, bridge girders, and the likes, etc.

Concrete is a mixture of sand, gravel and/or other aggregates (the matrix), bound together by a water-based binder, cement. Admixtures (modifying agents) and additives (fine mineral powers) are sometimes introduced to improve the characteristics of the fresh concrete, the mixing process and/or the final hardened material.

❖ **Components**

**Portland Cement-** The cement and water form a paste that coats the aggregate and sand in the mix. The paste hardens and binds the aggregates and sand together.

*The invention of cement has been credited to Joseph Aspdin, and English mason. Aspdin patented his product in 1824 and called it "Portland Cement" because it resembled the color of natural limestone found on the Isle of Portland, a peninsular in the English Channel. Portland cement was first manufactured in the United States in 1872* **[14]**

**Water-** Water is needed to react chemically with the cement (hydration) and to provide workability with the concrete. The amount of water in the mix as compared with the amount of cement is called the water cement ratio. The lower the water cement (w/c) ratio, the stronger the concrete. (Higher strength, less permeability)

**Aggregates-** sand is the fine aggregate. Gravel or crushed stone is the coarse aggregate in most mixes.

### 3.3 Concrete Repairing Material

The different materials used for maintenance can be grouped in to three categories.

(1) Cement type repairing materials: this is simply Portland cement mortar (concrete) or non-shrinkage mortar (concrete)
(2) Polymer modified cement type : this is cement modified using different polymers and fibers
(3) Resin type repairing materials: this is an epoxy or chemical used for repairing purpose

### 3.4 The Practice in Ethiopia [ 1 ]

In collaboration with Japan International Cooperation Agency [JICA], ERA has accomplished maintenance of different bridge defects. The materials used for maintenance are basically categorized in to four. These are:

- Materials used for large defects or cracks (pure cement or polymer modified cement type materials),
- Materials used for small defects or cracks (Resin type repairing materials or crack injection materials),
- Crack sealing materials so that small cracks will be ready for injection, and
- Materials for bonding

All of these are supplied by different companies in the country.

### 3.5 Materials for Repairing of Large Defects or Cracks (polymer and fiber reinforced repair mortar)

These are materials used to repair large defects, especially those falling in rank "A" and "B". We have different materials to restore seriously damaged or injured members, some of them are: **[15]**

**1. (EMACO S88C T)**

EMACO S88C T is a cementitious pre-bagged ready-to-use structural repair mortar in powder form. When mixed with the correct amount of water, it produces a thixotropic, high strength repair mortar, reinforced with acrylic polymer fibers. It possesses excellent bond characteristics to steel reinforcement and to concrete.

EMACO S88C T is shrinkage compensated which reduced risk of crack due to shrinkage and is formulated for sprayed or trowelled applications; in thickness up to 50mm in one layer by hand application. Greater thicknesses can be achieved when spray applied.

**2. Renderoc TGXtra + Polypropylene Fiber**

Shrinkage controlled polymer modified, vertical and overhead cementitious repair mortar system.
It is suitable for hand application to repairs where light to medium load bearing is required. It is applicable to general concrete and masonry repairs, voids greater than 10mm deep, repairs to honeycombing.

**3. Sika Mono Top-612**

Sika Mono Top-612 is wet sprayed/hand placed fiber reinforced repair mortar. It is a cementitious, polymer modified, low permeability, high strength mortar containing silica fume and synthetic fiber reinforcement. Excellent workability, adjustable consistency, excellent slump resistance, sprayable by the wet spray method, good mechanical strength, easily sprayed in layer thickness up to 30mm, and good resistance to water and chloride penetration are the characteristics of Sika Mono Top-612

### 3.6 Materials for Repairing of Small Defects or Cracks (crack injection material)

These are materials used to repair small defects especially for cracks having width of crack less than 5mm. It is also applicable for defects or damages which fall in rank "C". We have different materials to restore lightly damaged or injured members, some of them are: **[15]**

**1. CONCRESIVE 1315**

CONCRESIVE low-viscosity injection resins are two component crack injection fluids for sealing cracks, filling cavities and voids in concrete and stopping water ingress. They can be injected in to cracks of varying sizes (100 microns to 9mm) including cracks too fine to be filled with traditional materials. It is highly penetrative and cures to form a permanent seal. It is applicable to columns, bridge decks, floors, piers, abutments, tunnels, basements, beams, and underpasses.

**2. Nitofill EPLV**

Low viscosity solvent free epoxy resin system used for injecting cracks in concrete or masonry to form permanent bond or seal. **Nitofill EPLV** It has two components base and hardener mixed in proportion to form strong permanent bond. The advantages of **Nitofill EPLV** are:

- Low viscosity allows penetration in to the finest cracks
- Formulated for hot climates
- Suitable for structural cracks or repairs
- Excellent bond to concrete, brick and masonry
- Minimum creep under sustained load
- Resistant to wide range of chemicals
- Non-shrink, adheres with no loss of bond

**Mixing Procedures**

1) Stir each components separately to disperse settlement
2) Pour hardener in to base & mix thoroughly
3) Pour the mix in to injection gun
4) Inject in to the pipes installed starting from lower elevations
5) Bend pipe, carefully remove injection gun, tie pipe with wire
6) Wash injection gun with thinner
7) curing for 24hrs

**3. Sikadur-52 ZA**

A two part solvent free, low viscosity injection liquid based on high strength epoxy resins applicable to civil engineering buildings, industrial buildings, columns, bridges, and foundations. It has advantage of hardness but not brittleness, low viscosity, injectability, suitable for both dry and dump conditions, and high mechanical and adhesive strength.

### 3.7 Crack Sealing Materials for Injection (Epoxy resin mortar)

Materials for sealing of very small cracks (crack width less than 5mm), so that ready for application of crack filling or injection (resin type repairing) materials. Materials involved are: **[15]**

**1. CONCRESIVE2200**

It is high strength, non-flow, epoxy bedding and repair mortar. It is a two packs, fine aggregate filled, fast curing material, and ideal for a variety of bedding, gap filling and concrete repair applications. **CONCRESIVE2200** is a stiff but easily workable compound that can be applied by trowel, spatula or knife. It is impact resistance and mechanical strength is greater than that of concrete. It can be applied as a gap filling adhesive, fixing slip bricks to concrete, dowel bar anchoring, bedding tiles, repairing concrete posts in-situ, securing bolts in to walls, and repairing surface defects or to honeycombing concrete in horizontal, vertical or overhead situations.

**2. Nitomortar FC**

High strength trowel grades, epoxy resin fairing coat, repair mortar, bedding and adhesive. It is suitable for filling pinholes prior to over coating with nitocoat or nitoflor products, general reprofiling over large areas, up to 3mm depth, Sealing of surface cracks in preparation for crack injection, general purpose bedding mortar and adhesive. **Nitomortar FC** is a two component thixotropic, solvent free, compound based on epoxy resins, graded fillers and thixotropic agents. It is applied directly to concrete substrates, without primer, and cures to a surface ready for over coating. The base component is light gray coloured and the hardener black to ease identification of uniform mixing.

**Generally:**

- It is a two component thixotropic compound
-Used for sealing of surface cracks in preparation for injection
-Has strong adhesion to concrete substrate
-1 Lit of nitomortar covers 5m$^2$ with 0.2mm thickness but it's heavily dependent on the surface condition (or with 2 mm thickness – 0.5m$^2$)
- Mix proportion ( 1 can base + 1 can hardener)

**Mixing Procedures**

1) Stir each components separately to disperse settlement
2) Pour hardener in to base & mix thoroughly until uniform colour grey is obtained (it is very viscous compound which makes stirring tedious)
3) As soon as we finish mixing apply it on surface prepared using filling knives
4) Clean all equipments used using solvent

Curing

**3. Sikadur-31CF Normal**

A moisture tolerant, thixotropic, structural two part adhesive and repair mortar, based on a combination of epoxy resins and special fillers, designed for use at temperature between 10 and 30 degree centigrade. It can be used as a structural adhesive and mortar for concrete elements, hard natural stone, ceramics, bricks, masonry steel, iron, and aluminum. Easy to mix and apply, suitability for dry and damp concrete surfaces, very good adhesion to most construction materials, high strength adhesive, thixotropic (non-sag in vertical and overhead applications), hardness without shrinkage, different colour components, high initial and ultimate mechanical strength, good abrasion resistance, and impermeability to liquids and water vapour are some of the advantages of this epoxy.

## 3.8 Materials for Bonding [15]

**1. CONCRESIVE 1414**

Epoxy bonding agent for concrete repairs, bonding concrete to concrete, steel and granolithic toppings. It is a permanent epoxy adhesive for internal or external bonding and has greater tensile strength as compared to that of tensile strength of concrete. **CONCRESIVE 1414** may be applied to clean, sound and durable surfaces that is steel, glazed tiles and bricks, ceramics and quarry tiles, terrazzo tiles and floors. high strength, non shrink, moisture tolerant, durability, and resistant to chemical attack are some of the advantages of this epoxy.

**2. Nitobond EP**

Epoxy resin concrete bonding agent used to bond fresh wet cementitious material to existing cementitious surface. It is used for horizontal and vertical surfaces of roads, bridges, pavements, loading bays and factories both externally and internally. **Nitobond EP** has two components white base and green hardener mix together and applied on dry or damp substrates. The advantages of **Nitobond EP** are: exhibits high mechanical strength, positive adhesion-exceeds that of the tensile strength of the host concrete, slow cure allows time to erect steel reinforcement and formwork, and solvent free-can be used in enclosed locations.

**Generally:**

-It is a two component material (base and hardener)

-It is used for bonding existing concrete surface with the new mortar applied

-Exhibit high bonding (tensile) and mechanical strength

-Working life time – 160min (we have to apply it on the surface before this time)

-Max overlay time – 24hr (we have to apply EMACO before this time)

-1Lit of nitobond covers 3.5 – 4m$^2$

-Mix proportion (1 can base + 1 can hardener)

**Mixing Procedures**

1) Stir each components separately to disperse settlement
2) Pour hardener in to base & mix thoroughly until uniform colour is obtained
3) As soon as we finish mixing apply it on surface prepared using brush
4) Clean all equipments used using solvent

**3. SikaLatex**

Water resistant bonding agent for mortar. It is a high quality, synthetic polymer emulsion for adding to cement mortars where good adhesion and water resistance are required. It can be applicable for thin layer patching mortars, renders, floor screeds, concrete repair mortars, abrasion resistant lining, and tile fixing mortars. **Sikalatex** has greater elasticity, small shrinkage, better adhesion strength, excellent water resistance, better chemical resistance, and non-toxic.

**4. Sikadur-32 N**

Wet to dry epoxy resin bonding agent. It is a two component solvent free, moisture insensitive, medium viscosity, structural epoxy bonding agent used for bonding fresh concrete to an existing concrete or mortar substrate. It is suitable for vertical anchor bolt grouting. **Sikadur-32 N** has different advantages, some of them are: easy to mix and apply, solvent-free, excellent adhesion to concrete and a wide variety of other substrates, tensile strength far greater than concrete, and can be applied to damp substrates.

# 4 METHODS OF REPAIR AND REHABILITATION

## 4.1 General

The following four procedures are followed in almost all repair works. **[1]**

- Removal of concrete
- Surface cleaning
- Substrate preparation
- Repair material application

### 4.1.1 Removal of Concrete

When removal of part of concrete structure is required, use power driven chipping tools or hydro demolishing equipment to remove all loose or defective concrete. Avoid defect and make sound concrete to remain in place. Avoid hitting reinforcement steel with the chipping tools. Once the initial concrete is removed, use small power-driven chipping or hydro demolishing equipment to undercut all exposed reinforcement steel. Expose the entire perimeter of the steel bars for the full area of the repair provide a minimum clearance of 1cm between the exposed steel and the surrounding concrete or two times the maximum aggregate size, whichever is greater. Remove additional concreter as necessary to keep the repair area to reasonably uniform depth. The Contractor shall obtain approval of the completed concrete removal before proceeding to surface preparation.

### 4.1.2 Surface Cleaning

The area to be repaired shall be cleaned by abrasive blasting, high pressure water blasting, or other methods approved by the Engineer. All loose particles, dirt, deteriorated concrete or other substances that would impair the bond of the repair material shall be removed. Exposed reinforcement steel of concrete, rust and other contaminants shall be cleaned and this should be followed with a high pressure air blast for final cleaning.

### 4.1.3 Substrate Preparation

Unless directed or specified, use a bonding agent if cement mortar or concrete is used for the repair material.

Use either a cement scrub or epoxy as the bonding agent. Follow the manufacturer's recommendations for bonding agents if pre-packed repair material is used. Apply a cement scrub coat bonding agent to the saturated surface-dry substrate by scrubbing, brushing, or other methods approved by the Engineer immediately before placing the repair material. Apply an epoxy bonding agent in accordance with the manufacturer's recommendations. Ensure that any bonding agent used does not set or cure prematurely, creating a bond breaker.

Where saturated surface-dry (SSD) conditions are needed, pre wet the substrate by pounding water on the surface for 24 hours before placing the repair materials. If pounding is not possible, achieve SSD conditions by high-pressure water blasting 15 to 30 min. before placing the repair material. A saturated surface-dry condition is achieved when the surface remains damp is exposed to sunlight for 15min.

#### 4.1.4 Repair Material Application

Place the repair material in an approved manner ensuring that the repair material is in intimate contact with the substrate and free of voids. Follow the manufacturer's recommendations for pre packed repair materials. Place the repair materials so that the original lines and surfaces of the structure can be restored.

## 4.2 Repair Methods for Concrete Structural Cracks

### 4.2.1 General

It is common practice by contractors to hack/chisel out cracked areas and to have them repaired by application of ordinary mortar constituted with cement and sand. These kinds of repairs eventually fail due to shrinkage and lack of proper bonding between the old and the new mortar or concrete.

The purpose of the repair work is to stop progress of cracks and to maintain the original situation. Thus, typical repair systems for cracks are use of epoxy or cement based materials that can penetrate deep inside the cracked area and bond the exposed surfaces.

Epoxies are applicable to small, deep cracks. Application can be by gun injection or pouring after appropriate preparation.

Cement rich mixing systems are used for large, shallow cracks. Application can be conventionally by hand, troweling or gun-spraying. If the crack is reasonably deep repairs are undertaken through buildup.

Before sealing or injecting any materials, it is important to ascertain why and how the cracks originated and type of crack whether it is dormant or live; this will significantly affect the selection process of repair materials.

**Dormant crack:** is the one which stops its progress or no increment of crack width nor its length.

**Live crack:** is the one which continues its propagation or shows increment of crack in width and length from day to day.

All cracks should be thoroughly cleaned to ensure a strong bond develops between interfaces.

In reinforced concrete, cracks wider than about 0.3 to 0.4 mm should be sealed and filled by injection. Before deciding the most appropriate method of / material for repairing/ sealing a crack, a determination should be attempted on its cause and whether it is **active** or **dormant**.

Whether the crack is active**,** may be determined by periodic observation. A crack resulting from a rare load-application, and which has ceased to propagate, can be repaired (if it is wider than about 0.3 to 0.4 mm) by pressure –injection with suitable epoxy- formulation so that the integrity is restored and any adverse influence on the service life of the structure is eliminated or minimized.

**Dormant cracks,** in excess of about 0.3 to 0.4 mm wide, must be cleaned, seald and then filled, by epoxy-injection for widths up to about 1mm, and fine cement grout for wider cracks.

**Where live cracks**, width exceeds about 0.3 to 0.4 mm, “V-groove’ should be made along the crack, the groove and the cracks cleaned by a dry air-jet, and then filled to parts of its depth by a flexible filler to prevent ingress of moisture and other deleterious materials till the cracks become dormant. After the crack has become dormant, the filler can be removed and the crack cleaned and filled with a rigid (epoxy) filler.

It is possible to repair non structural cracks by filling the gap using high polymer special adhesive material like epoxy resin; however structural cracks can be effectively maintained if and only if the load carrying capacity of the section is improved by provision of sufficient reinforcement system. Therefore, this study separately deals with the above two types of cracks. The user of this study shall conduct a detail structural investigation of the bridge to categories the observed cracks are structural or non structural before applying any of the maintenance schemes specified below.

The main purpose of structural crack repair is to restore structural integrity across the rack, to increase load carrying capacity of the section and to block access of water and other harmful chemicals to the reinforcing steels.

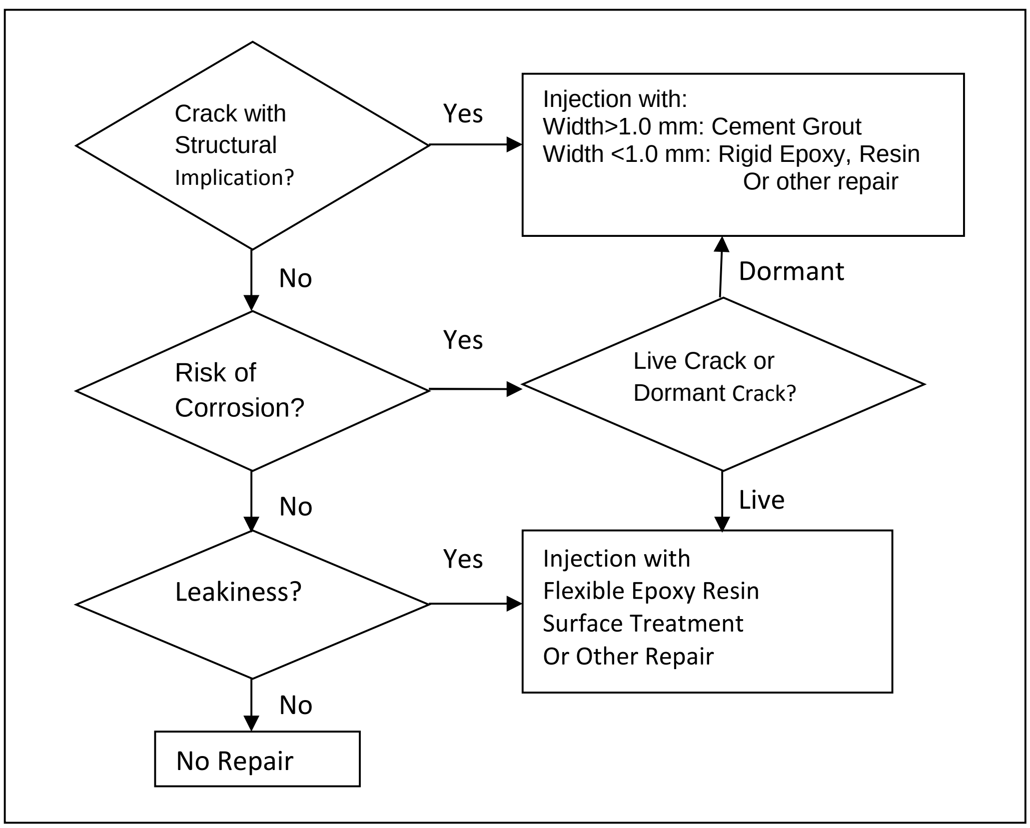


Figure 4.2.1: Repair method chart for cracks

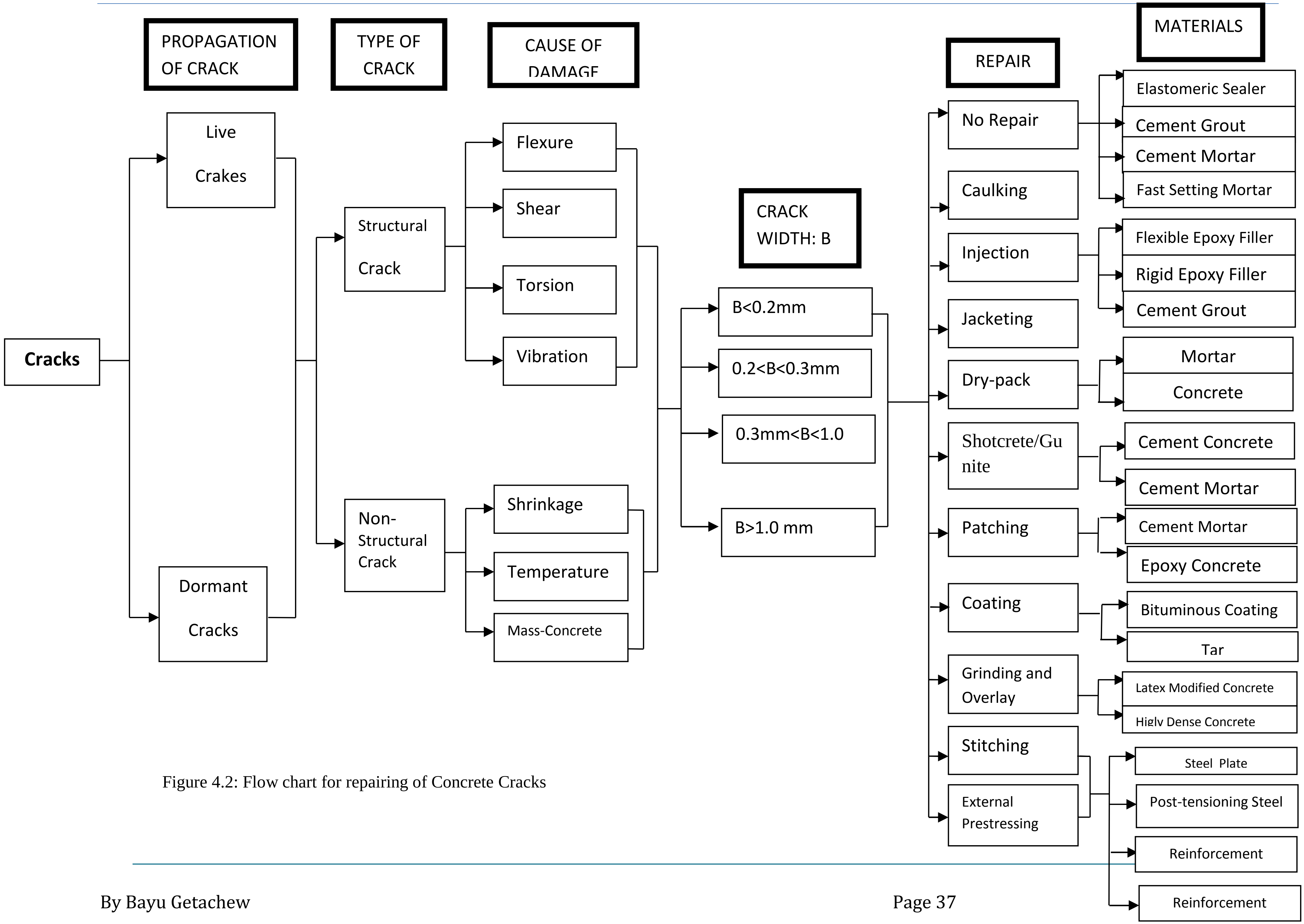


Figure 4.2: Flow chart for repairing of Concrete Cracks

### 4.2.2 Stitching With Reinforcement Steel Pins Bonded With Epoxy Resin

**Description**

This task involves repair of single live cracks width more than 5 mm or multiple cracks width of more than 3mm, together with water leakage, free lime or salt. In bearing area, single crack width of more than 3 mm and multiple crack width of 1 mm which cause reduction in loading capacity.

This is applied when tensile strength must be reestablished across major cracks. Stitching a crack tends to stiffen the structure, and the stiffening may emphasize the overall structural restraint, causing the concrete to crack elsewhere. Therefore, it may be necessary to strengthen the adjacent section using external reinforcement embedded in a suitable overlay.

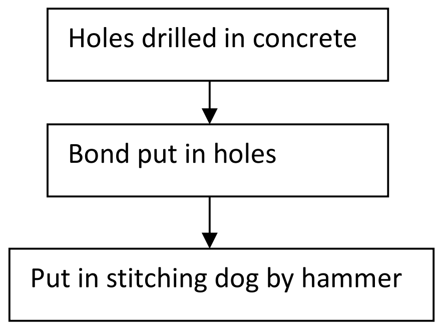


Figure 4.2.2 stitching procedure

Stitching" across" the cracks in reinforced concrete members is done either along the cracks or as a series of bands around the members. Reinforcement is placed across the cracks in suitable grooves which are suitable gunited or gunite / shot crete. Steel pins are used to stitch across the cracks.
The work covered by this division consist of furnishing all labor, materials and equipment to perform all operations in connection with the complete installation of the work, which involves drilling holes on both sides of a crack and grouting in stitching dogs (U-Shaped metal units with short legs) that span the crack according to defect analyses and /or as specified herein.

**Material**

- Epoxy adhesives used to rebound the crack should conform to ASTM C881, Type I, Low-viscosity grade.
- High yield strength Reinforcement bar Reinforcing steel AASHTO M31

**Procedure**

1. Drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the dogs in the holes, with either a non shrink grout or an epoxy-resin-based bonding system. The stitching dogs should be variable in length and orientation or both, and they should be located so that the tension transmitted across the crack is not applied to a single plane within the section but is spread over an area.
2. Spacing of the stitching dogs should be reduced at the end of racks. In addition, consideration should be given to drilling a hole at each end of the crack to blunt it and relieve the concentration of stress.
3. Where possible, both sides of the concrete section should be stitched so that further movement of the structure will not pry or bend the dogs. In bending members, it is possible to stitch one side of the crack only. Stitching should be done on the tension face, where movement is occurring. If the member is in a state of axial tension, then the dogs must be placed symmetrically, even if excavation or demolition is required to gain access to opposite sides of the section.
4. The dogs are relatively thin and long and cannot take much compressive force accordingly, if there is a tendency for the crack to close as well as to open, the dogs must be stiffened and strengthened, for example, by encasement in an overlay.

*Note: Stitching will not close a crack but can prevent it from propagating further. Where there is a water problem, the crack should be made watertight as well as stitched to protect the dogs from corrosion. This repair should be completed before stitching begins. In the case of active cracks, the flexible sealing method may be used in conjunction with the stitching techniques.*

5. No remedies (repairs) to the newly repaired concrete shall be performed without the prior inspection and approval of the Employer's Representative.
6. On Completion of the works, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

### 4.2.3 Injection With Flexible Filler

The task involves repair of single live cracks width of more than 1mm or multiple crack width of more than 1mm. It can also be used in bearing area single crack of less than 1mm with no water leakage in concrete bridge structures.

This type of repair covers the repair of an active crack by flexible seals against the migration of water into the crack. This method involves routing out active cracks; cleaning them by sandblasting, air –water jetting, or both; and filling them with flexible Bonder or other suitable molded flexible sealant. Flexible bonder is used for active cracks when a bond breaker is placed over the crack.

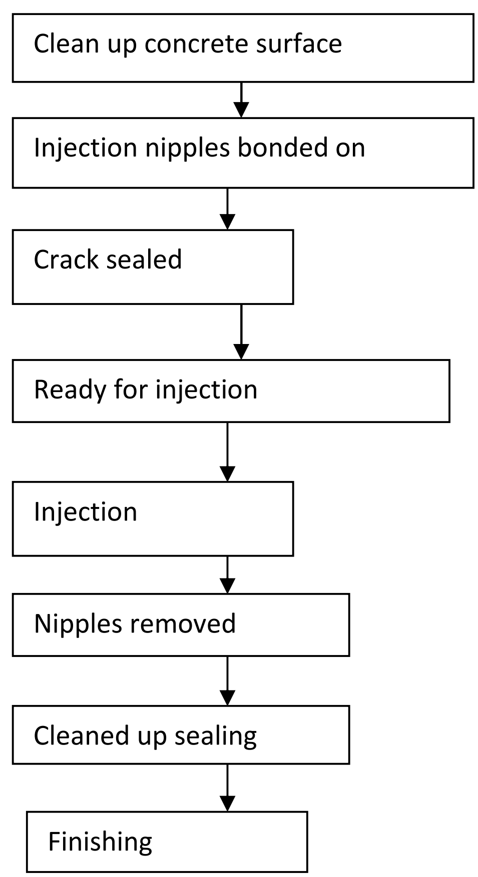


Figure 4.2.3: Injection procedure

**Material**

Flexible sealant or mastic, polyethylene strip/pressure-sensitive tape bond breaker are materials involved for repair. Non Structural cracks observed on RC or Plain Concrete components of bridges are effectively repaired with high polymer materials such as Epoxy resin, polyurethane resin, Acrylic and others: either by high pressure injection(up to 30 $N/mm^2$) or low pressure injection (up to 2 $N/mm^2$) techniques. The main purpose is to restore structural integrity across the crack and to block access of water and other harmful chemicals to the reinforcing steels.

**Procedure**

1. Traffic warning signs shall be established at both ends of the works section.
2. The crack should then be cleaned by sandblasting, air- water jetting, or both.
3. A bond breaker should be provided at the bottom of the slot to allow the sealant to change shape without a concentration of stress on the bottom.
4. The bond breaker may be a polyethylene strip, pressure-sensitive tape, or other material which will not bond to the sealant before or during cure.
5. Narrow cracks subject to movement, where esthetics are not important, may be sealed with a flexible surface seal if the crack width is greater than 5mm.
6. By using a bond breaker over the crack, a flexible joint sealant may be toweled over the bond breaker providing an adequate bonding area.
7. To maintain hydraulic efficiency in some structures, it may be necessary to cut the concrete surface adjacent to the crack and to place the retaining cap flush with the original flow lines.
8. The crack should then be cleaned by sandblasting, air –water jetting, or both. The mastic is placed into the routed crack slot and a retaining cap placed over the mastic to confine it. A simple retainer can be made by positioning a metal strip across the crack and fastening it to expandable anchors or grouted bolts installed in the concrete along one side of the crack.
9. No remedies (repairs) to the newly repaired concrete shall be performed without the prior inspection and approval the Employer’s Representative.
10. On completion of the works, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

### 4.2.4 Injection With Rigid Epoxy Filler

**Description**

The task involves repair of single dormant crack width of more than 1 mm or multiple crack width of more than 1 mm. In bearing area single crack width of less than 1mm with no water leakage in concrete bridge structures such as deck slab and girder.

Epoxy injection of cracks in concrete is a highly skilled process and its success depends largely on the efficiency of the operator. Considerable skill and experience are needed for the successful application of epoxy resin materials. They have to be applied within a very limited time before they harden and have to be handled cleanly to avoid contamination of both the resin mixture and the people working with them.

Therefore, the Supervisor should make sure that the Contractor’s personnel appointed for this particular job are a specialist on the matter.

Epoxy injection system can be applied for repair of cracks for rigid sealing, dry, moist or wet cracks in reinforced concrete members as well. However, unless the crack is dormant (or the cause of cracking is removed, thereby making the crack dormant), cracking will probably reoccur, and structural repair by injection should not be used.

This system shall consist of a paste epoxy used to seal the surface cracks and an injection epoxy used under low pressure 1400 kPa (1.4 N/mm$^2$) max. to penetrate and fill the cracks and bond the crack surfaces together. Material for each epoxy shall consist of a two-component modified resin bonding system, the base and the hardner.

Accurate batching and proper mixing of the components is crucial for attaining maximum strength and other properties of the epoxy materials. Chemical reactions start as soon as the resin components are combined and the working time shall depend on the system, the temperature and the handling process.

Jacketing method involves fastening of external material over the concrete members to provide the required performance characteristics and restoring the structural value. The jacketing materials are secured to concrete by means of bolts and adhesives or by bonding with existing concrete. Fiber-glass reinforced plastics, and polypropylene can also be used for jacketing.

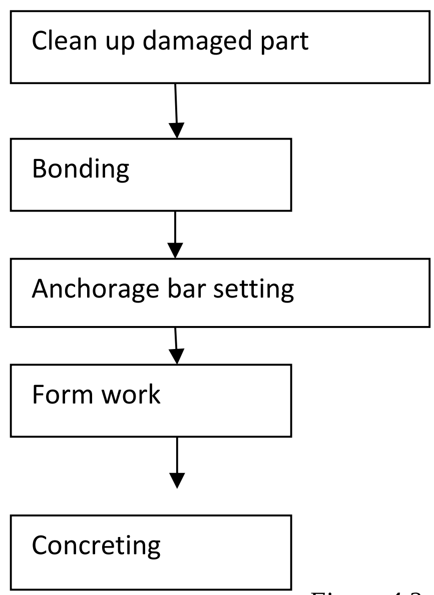


*Figure 4.2.4 Jacketing method*

**Materials**
Epoxy Injection fluid shall confirm the following requirements: The resins for crack injection system shall have a two part solvent free low viscosity polymer. The flexible, low viscosity, polymer, crack injection resins mixed in proportions specified by a supplier & injected in to cracks in concrete, the resin shall form a slightly flexible & impermeable barrier in both dry & damp condition, and thus, shall form permanent seal in cracked concrete.

### 4.2.5 Caulking Using Cement Grout (Hydraulic) or Cement Rigid Epoxy Filler

**Description:** The task involves repair of single dormant crack width of more than 5mm or multiple cracks width of more than 3mm, together with water leakage, free lime or salt. In bearing area, single crack width of more than 3mm and multiple crack width of 1mm which causes reduction in loading requires repair. *Caulking* method is used for cracks wider than about 0.5mm.

The job consists of cleaning the concrete along the crack, Cutting the concrete following along the crack with a concrete saw or with hand or pneumatic tools and opening the crack sufficiently in to “V” or “U” shape to receive the cement grout or mortar installing injection ports (grout nipples) at intervals aside the crack (to provide a pressure-tight contact with the injection apparatus), sealing the crack between the injection ports, flushing the crack to clean it and test the seal, and then grouting the crack.

**Materials:** Mixtures of neat Portland cement, and water. Other additives and admixtures (siliceous residue, diatomite) may be added on the approval of the Engineer.

The proportions of ordinary Portland cement to sand will depend upon the size of the spaces to be filled and will vary from a neat grout to about 1:2 mix. Mix containing two parts sand to one part cement can be successfully pumped if all the sand passes the No. 16 sieve and 15 percent or more passes the No.100 sieve. The amount of water to be added depends upon the consistency required. Grouts with as little as 16 liters of water per bag of cement could be handled and it should seldom be necessary to use more than 35 to 40 liters of water per bag of cement. Where necessary and approved by the engineer, admixtures to Portland cement grout mixtures may be added for delaying the setting time, increasing flow ability minimizing segregation and shrinkage. Water shall be fresh, clean, and free form injurious amounts of sewage, oil, acid, alkali, or organic matter.

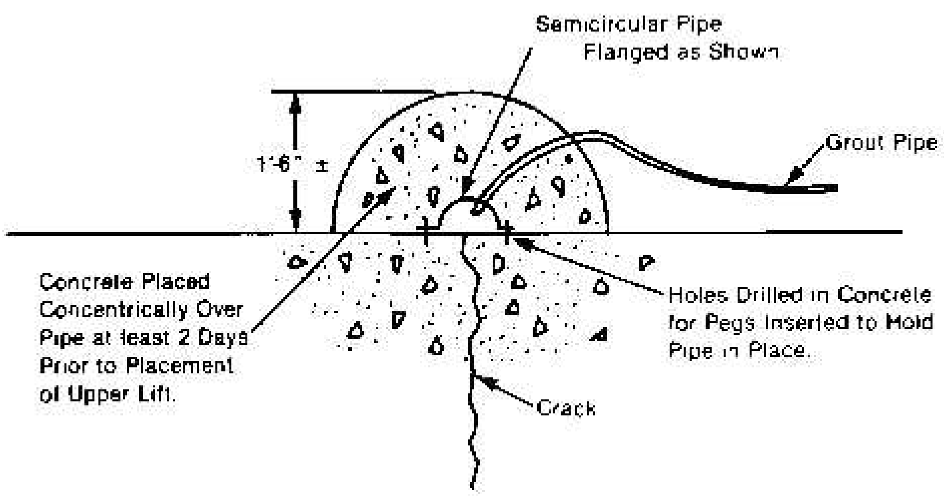


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*Figure 4.2 crack arresting method using semicircular pipe during concrete repair*

## 4.3 Repair Methods for Concrete Peel off, Delimitation and Void

Concrete voids are created due to poor vibration of fresh concrete during pouring (unable to vibrate it sufficiently) of failure to vibrate it before the initial setting time. Concrete voids on the permanent structures have to be maintained to restore the integral concrete strength of the structure designed to act as a unit, and to protect reinforcements and the concrete from effect of water leakage or dampness which potentially generates rusting and deterioration. Removal of the defective concrete and replacement with a suitable material and workmanship are the major techniques discussed under.

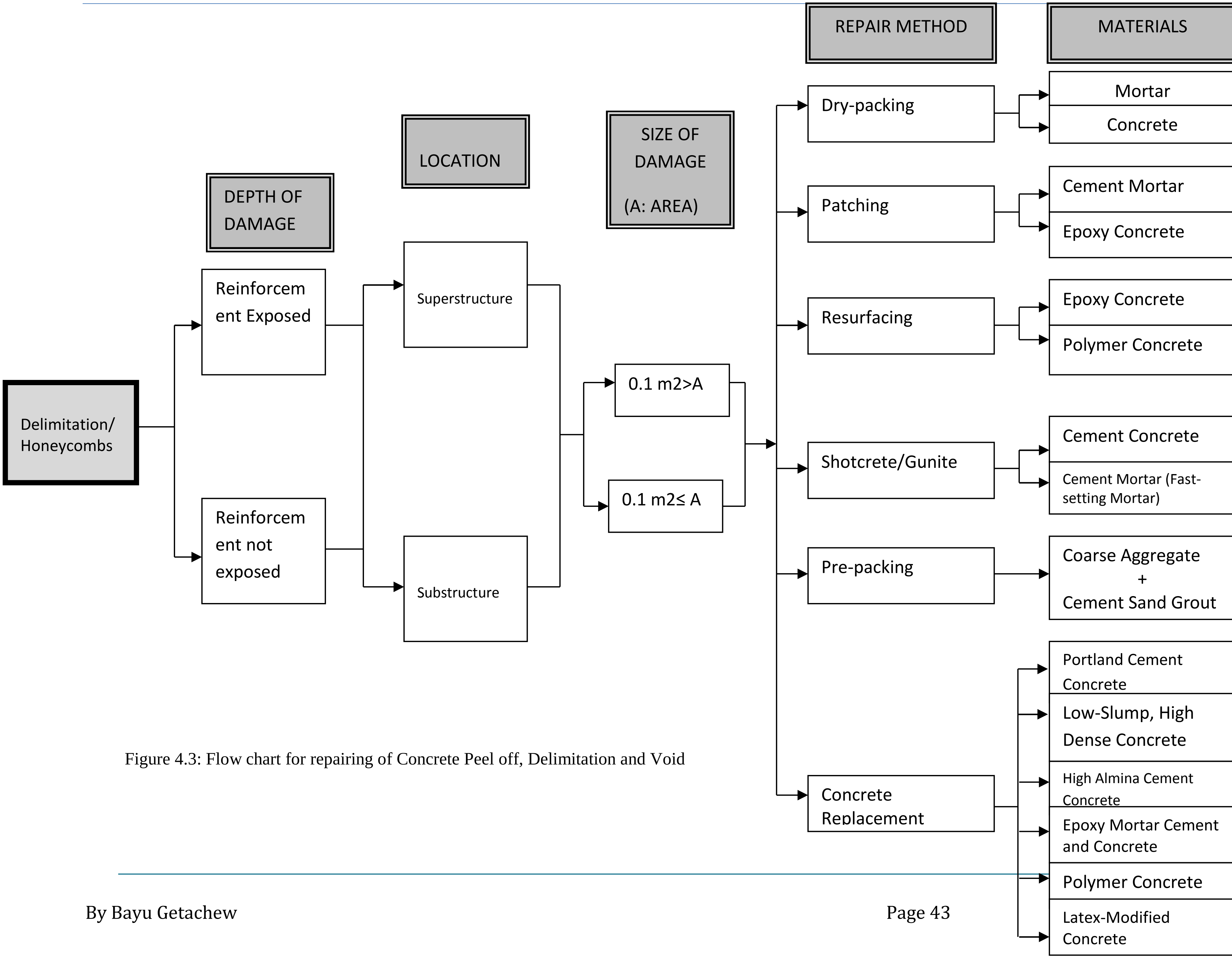



Figure 4.3: Flow chart for repairing of Concrete Peel off, Delimitation and Void

### 4.3.1 Concrete Void Repair by Using Dry-Pack Mortar

The task involves repair of partial range of honeycomb or de lamination, which affect the durability of concrete bridge structures. This item shall consist of furnishing the necessary labor, material and equipment to repair honeycomb and delaminating in concrete bridges with dry-pack methodology, the item includes preparation, mixing placing, finishing and curing of the dry-pack mortar.

Dry packing is a process of ramming or tamping into a confined area a low water-content mortar. Because of the low W/c material, there is little shrinkage, and the patch remains tight and is of good quality with respect to durability, strength, and water tightness. This technique has an advantage in that no special equipment is required. However, the method does require that the craftsman making the repair be skilled in this particular type of work.

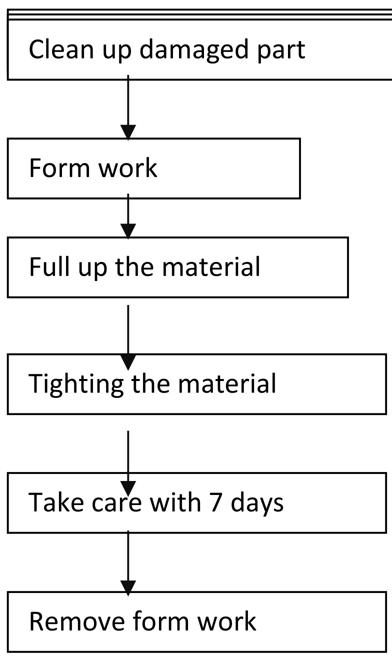



Figure 4.3.1: A dry pack method

**Materials:** The material needed for maintenance by dry-packing method is a slurry bond and a low water-content mortar. The cement slurry bond coat consists of equal parts of cement and fine sand and the mortar consists of one part cement, two and one-half (2 1/2) to three (3) parts sands passing a No. 16 sieve, and only enough water so that the mortar will stick together when molded into a ball by slight pressure of the hands and will not exude (give off) water but will leave the hands dry.

If the patch must match the color of the surrounding concrete, a blend of Portland cement and white cement can be used. About one-third white cement is adequate for blending, but the precise proportions should be determined by trial.
Dry pack, mortal shall consist of type I or II Portland cement, clean sand that will pass a 1.18mm (No.16) sieve, and clean water.

## Procedures

1. The Employer's Representative will indicate what part of the existing structure is to be removed and the required dimension of the new work
2. The area to be repaired should be undercut slightly so that the base width is slightly greater than the surface width.
3. After the area or slot is thoroughly cleaned and dried, a bond coat should be applied. Placing of the dry-pack mortar should begin immediately.
4. Dry-pack mortar should be placed in layers having a compacted thickness of about 10 mm (3/8 in.) Each layer should be compacted by use of a hardwood stick. It is usually necessary to scratch the surface of the compacted layers to provide bond for the next layer. One layer may be placed immediately after another unless an appreciable rubbery quality develops; if this occurs, work on the repair should be delayed 30 to 40 minutes.
5. Successive layers of dry pack are placed without interval, unless the material becomes spongy, in which case there should be a short wait until the surface stiffens. Area should be filled flush and finished by striking a flat-sided board or the flat of the hard wood stick against the surface.
6. After being finished, the repaired area should be cured. Procedures for curing and protection of dry pack repair area should be protected and not exposed to freezing temperatures for at least 3 days after application of the curing compound.
7. No remedies (repairs) to the newly repaired concrete shall be performed without the prior inspection and approval the Employer's Representative.
8. On completion of the works, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

### 4.3.2 Concrete Void Repair by Using Portland Cement/Sand Mix Mortar Blended With Epoxy Resin

The task involves repair of wide range of voids, which affect the durability of concrete bridge structures having a volume of less than 600 $cm^3$.
The concrete Void will be repaired by a Portland Cement/sand mix mortar blended with Epoxy Resin. The plastering will be applied either using a pressure grout or conventional hand tools. In areas where formwork erection and concrete casting is possible, the maintenance operation is done using a Portland Cement Concrete. The suitable concrete mix shall have a minimum cement content of 340kg/m3 with a maximum aggregate size of 10mm and slump in the range of 25mm to 75 mm. The same techniques of mixing and paving of the cement based polymer modified concrete shall be adopted as concrete peel of maintenance.

**Materials**

The Epoxy Resin and cement based polymer modified concrete shall also fulfill the criteria set above or like the materials used for concrete void repair by using dry-pack mortar.

**Procedures**

A. Employer's Representative will indicate what part of the existing structure is to be removed and the required dimension of the new work.

B. Determine the extent of defective area by sounding with a hammer or other approved method and mark the area to be removed. Remove all defective concrete portions marked up to 10 mm below the reinforcement, if any, using the following techniques.
   - Small pneumatic hammer
   - Small electric Jackhammer
   - Sludge hammer and chisel the concrete may be removed using high – pressure water blasting. In all the above mentioned techniques, care must be taken to a avoid defect to the surrounding concrete.

C. After properly cleaning the removed part, the old concrete surface shall be primed with Epoxy Resin (avoid applying too thickly). The concrete Void will be repaired by a Portland cement/ sand mix mortar blended with Epoxy Resin. The plastering will then be applied either using a pressure grout or conventional hand tools. In areas where formwork erection and concrete casting is possible, the maintenance operation is done using a Portland Cement Concrete. The suitable concrete mix shall have a minimum cement content of 340Kg/m$^3$ with a maximum nominal aggregate size of 10mm and a slump in the range of 25mm to 75mm. The same techniques of mixing and paving of the cement based polymer modified concrete shall be adopted for concrete peel of maintenance. Forms and scaffolds shall be erected both for the actual construction purpose and for curing of the fresh mortar or the Portland cement concrete.

D. No remedies (repairs) to the newly repaired concrete shall be performed without the prior inspection and approval of the employer's Representative.

E. On completion of the works, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

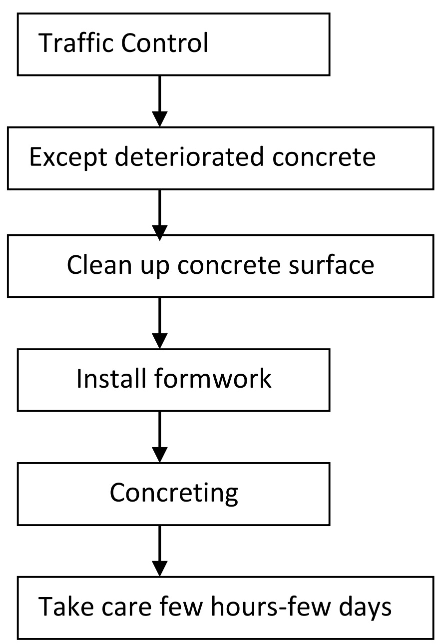



Figure 4.3.2: Patching method

## 4.4 Repair Methods for Concrete Structure Honey Comb

Honey comp is the voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate materials. This is caused by lack of vibration or over vibration, which creates air bubbles. Repairing of honey comp requires preparatory work and resurfacing.

### I. Preparatory work

It is always better to avoid imperfections such as honeycombing in concrete rather than repairing. However, if honeycombing does occur then it can be repaired using the following techniques.

- The extent and depth of the honeycombed area first needs to be defined. This can be done by chiseling out the affected area to expose sound concrete or by using non-destructive testing techniques such as impact-echo.
- If the honeycombed area is small in extent and depth does not significantly jeopardize the quality of the cover concrete protecting the reinforcement then it can be repaired by patching with mortar of a similar color to the base concrete. Remove any lightly attached stones before the mortar is worked into the spaces between the aggregate ensuring that it completely fills the honeycombed area.
- The area should be slightly over filled and screeded off to give a similar texture to the surrounding surface. The patch should then be cured.
- Consideration needs to be given to the appearance of the repaired surface relative to adjacent untreated surfaces.
- As a general rule, mortar used for patching should be made from the same materials as the original concrete except to lighten the color and thus better match the existing surface.
- If the honeycombing is extensive and requires penetration down to the reinforcement or even deeper, it is necessary to cut out the defective concrete and replace it with sound concrete.

It is essential that the reinforcement be surrounded by sound concrete. The advice of a suitably qualified engineer should be obtained to check that the load-carrying capacity of the member, as repaired, will be satisfactory.

### II. Resurfacing

Honeycomb can be repaired by using Dry-Pack Patching or Gunite/shotcrete Pre-placed aggregate.

Shotcrete (Pneumatically applied cement-concrete) and Gunite (pneumatically applied cement-mortar) are suitable for forming the new concrete (i.e. the restoration- concrete) and for strengthening and jacketing of various structural elements.

Re-surfacing method, here –in after, describing about polymer concrete overly, a polymer concrete overlay protective system has been used as an experimental project in several countries.

The overlay consists of an application of monomer resin to the desk surface, followed by an application of the fine aggregate.

The process is repeated until four layers have been placed. The overlay is relatively impermeable and skid resistant. Generally, the resin is over the deck and fine aggregate is covered over the resin. After polymerization, the excessive aggregate is removed and the process is repeated for other layers. The four layers produce a thickness of about 12 to 15 mm. The overlay system consists of the following steps for each layer.

1. Surface Preparation,
2. Mixing and application of monomer resin,
3. Fine aggregate application and compaction
4. Polymerization of monomer and removal of excess aggregate.

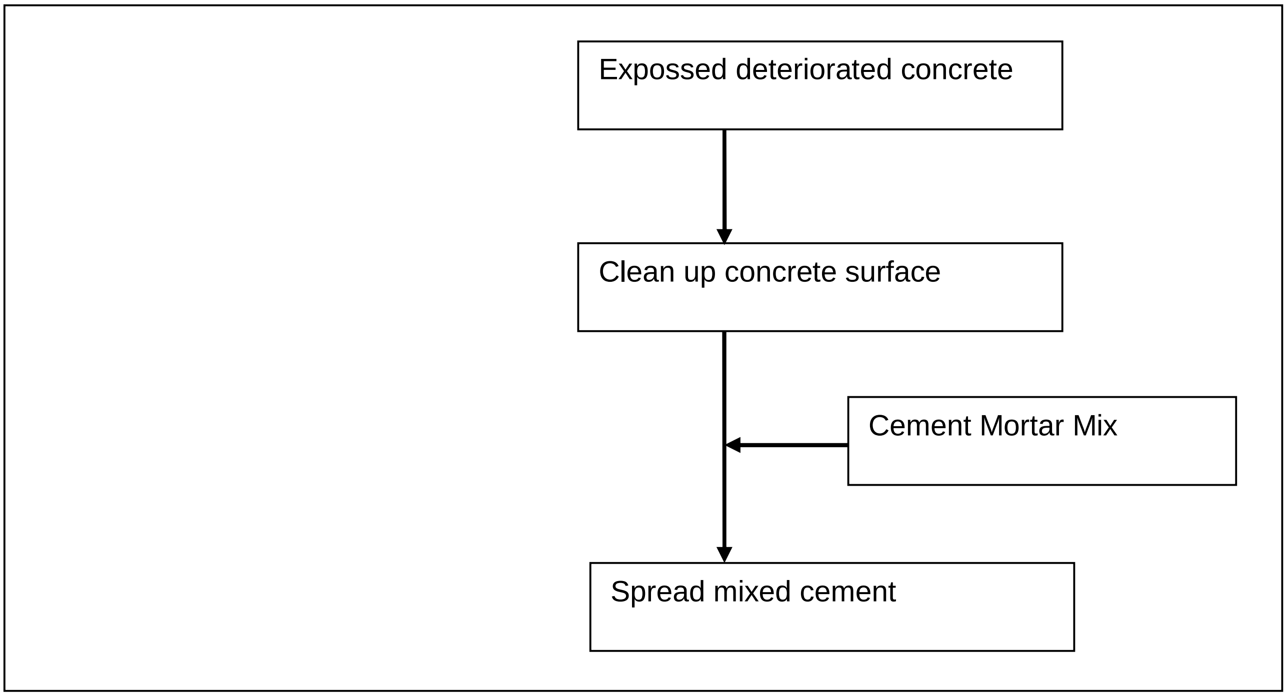



Figure 4.4.2a: Shotcrete/Gunite Method

### 4.5 Repair Methods for Scaling or spalling of Concrete

1. **Scaling**: Scaling is a form of disintegration. A common cause of scaling is freezing and thawing conditions. Localized flaking or peeling is normally a form of scaling. Scaling, which can also be referred to as spalling, is rated based on the depth of the defect. The rating system is as follows:
   - ***Light spalling****: is* when the loss of surface mortar does not expose any coarse aggregate.
   - ***Medium spalling****:* occurs when the damage has a depth of up to 10mm.
   - ***Severe spalling:*** is determined when the depth of the damage ranges from 5mm to 10mm. There is also some loss of mortar surrounding aggregate particles with a depth range of 10mm to 20mm.
   - ***Very severe spalling:*** is the loss of coarse aggregate particles, as well as surface mortar and surrounding aggregate, generally to a depth greater than 20mm.

Scaled concrete surfaces can be repaired by applying a thin resurfacing of concrete properly bonded to the underlying old concrete. All defective concrete must be removed from the surface, by scarifying or scrubbing with hydrochloric acid, before applying the new concrete.

A thin layer of neat cement paste should be brushed into the damp surface of old concrete is placed, finished and cured by normal procedures. Any relief joints present in the old concrete should be carried through the new resurfacing.

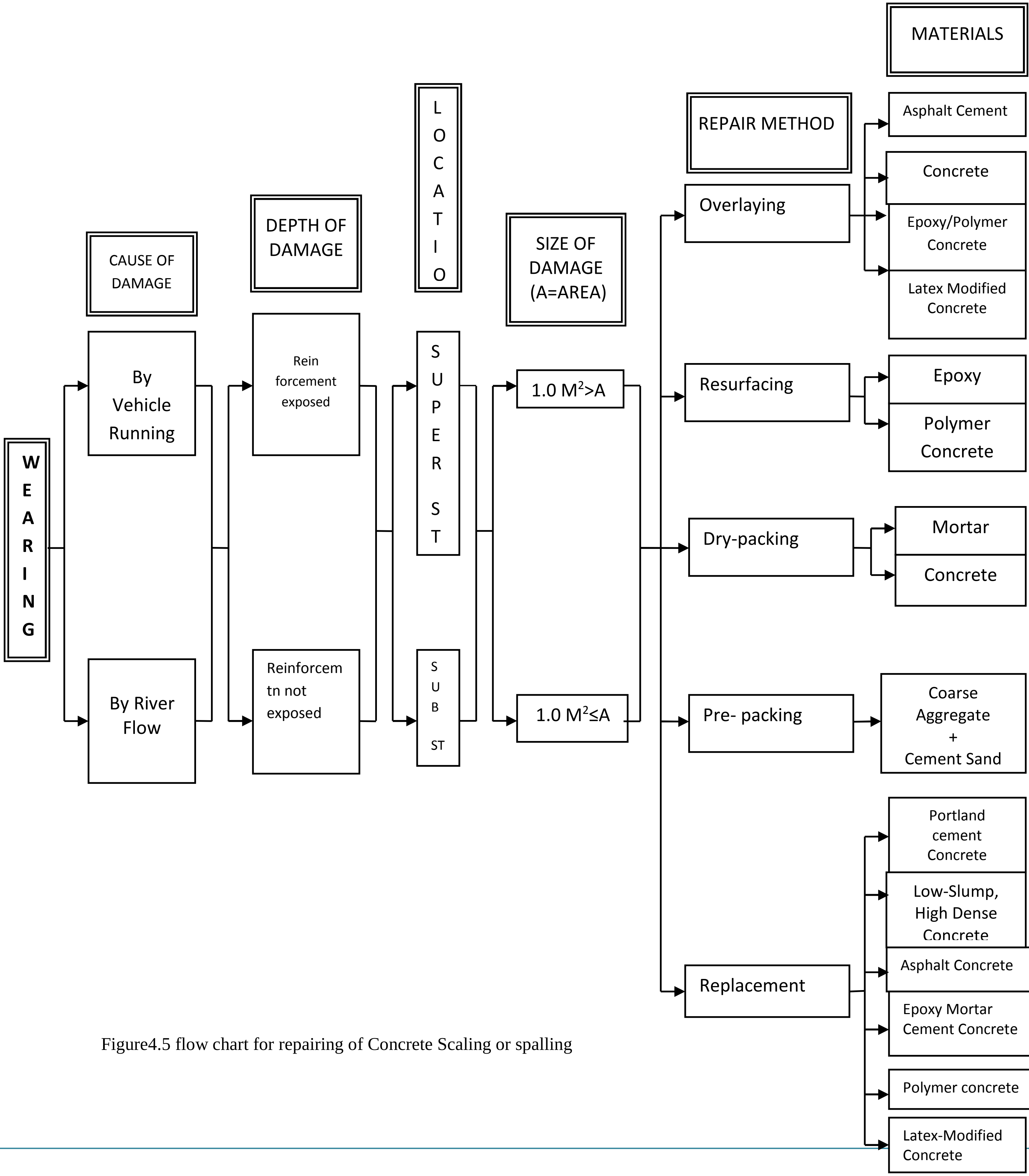



Figure4.5 flow chart for repairing of Concrete Scaling or spalling

## 4.6 Other Defects Repair Methods

### 4.6.1 Scouring and Erosion

#### 4.6.1.1 Repair Methods for Scouring

Riprap remains the most common countermeasure used to prevent scour at bridge abutments. A number of physical additions to the abutments of bridges can help prevent scour, such as the installation of gabions and stone pitching upstream form the foundation. The addition of sheet piles or interlocking prefabricated concrete blocks can also offer protection.

Trapezoidal-shaped channels through a bridge can significantly decrease local scour depths compared to vertical wall abutments, as they provide a smoother transition through a bridge opening. This eliminates abrupt corners that cause turbulent areas. Spur dikes barbs, groins, and vanes are river training structures that change stream hydraulics to mitigate undesirable erosion or deposits. They are usually used on unstable stream channels to help redirect stream flow to more desirable locations through the bridge. The insertion of piles or deeper footings is also used to help strengthen bridges.

If a pier is found to be suffering from adverse scour conditions, the problem can be corrected by changing the structure (enlarging the footing, strengthening or adding piles, providing a sheet piling barrier around the pier foundation) or replacing the material which has been washed away (broken stone, concrete rip rap,..)
Hydraulic protection techniques include slope protection, foot protection, river bed protection and river realignment depending on the extent and nature of the hydraulic problems encountered such as scour, erosion, and fold flow.

Slope protection is applicable to river banks adjacent to abutments where erosion is observed.
Footing protection is applicable to footing of the slope area in order to prevent slope failure caused by scouring action on the river bed. River bed protection is applicable to river bed surrounding the river piers where local scouring or river bed lowering is observed.
River realignment work is applicable to extremely eroded banks of a meandering river located at the vicinity of a bridge upstream.
Selection of a specific protection technique depends on the stream type, river scale, flood flow velocity, foundation type and geology of each site.

- **Gabion Protection for Scouring:** The task involves preventing slope failure caused by scouring action on the river bed, for small scale river.
  Materials used for construction of Gabion walls and mattresses are:

***Rock:*** Rock used for gabion structures shall consist of clean, sound durable stones that are resistant to weathering and water action. Shale or other soft rock may not be used. The stones shall be angular in shape with a height and width dimension of at least one third the length.

The gradation of the mixture shall be such that at least 80 percent (by weight) of the stones have a minimum dimension of at least 125mm. The maximum dimension of a stone shall be the lesser of 300 mm or the gabion structure thickness.

***Gabions***: Gabion baskets shall be cubical in shape and shall be assembled from independent rectangular faces laced or clipped together. They shall comprise galvanized steel wire of the following minimum diameters: mesh wire 3mm (or Gauge 17), Perimeter/selvage to all edges 3.9mm (or Gauge 19), tying/binding 2.2mm (or Gauge 15). The individual gabions shall not be greater than 2m x 1m x 1m although the contractor may substitute equivalent multiple of smaller sizes at his own additional cost. They shall be fitted with the manufacture's recommendations such that the individual cells do not have a length exceeding the width. Meshes shall be hexagonal with openings no greater than 100mm x 120mm.

***Procedures***

1. Traffic warning signs shall be established at both ends of the work section
2. All stumps, roots debris and rocks shall be roved and disposed of as directed by the Consultant, prior to placing gabions. Excavation to accommodate gabion installation shall be carried out to the lines and levels as specified on the plans or as directed by the Consultant.
3. Gabion cages shall be assembled by tying the appropriate faces together along the self edges with binding wire. The binding wire shall be tightly looped around every other mesh opening to form a spiral with single and double loops alternating.
   When assembled, gabion baskets shall be divided by the diaphragms into compartments having a plan dimension of one meter square. Gabion mattress shall be separated lengthwise by the dividers in to 1m wide strips. The diaphragms shall further subdivide the mattress into compartments that have a plan dimension of 1m x 3m. Gabion units, grouped together to form a gabion structure, shall be securely bound to each other along all contacting self edges in the same manner as the faces are bound in the assembly of the cages.
4. Extend gabions, on slope, at least 1m below streambed or to non- erodible material. Where it is feasible, extend gabion out from the toe across the streambed of an erodible channel a horizontal distance of at least 5 times the thickness of the gabion mattress.
5. Rock for filling gabion boxes and mattresses shall be hard durable stone of low porosity having an interlocking texture with few discernible defects. Grading Rock filling for the gabion boxes shall comply with the following grading.

| Sieve Size (mm) | Percentage Passing |
|---|---|
| 200 | 80 -100 |
| 150 | 0 – 40 |
| 75 | 0 -10 |
| 9.5 | < 2 |

Rocks shall be filled in the assembled cage units either by machine or by hand. When machine is used, minor rock repositioning shall be done by hand to fill the voids between larger rocks and there by achieve a dense structure. Rocks along visible faces shall be selected and placed by hand form among the larger sizes with a flat face toward the exterior to produce a likely of a masonry structure and a neat and work man like appearance.

6. Following the filling of each gabion unit, the lid shall be affixed in position so that the self edges coincide with the perimeter of the filled gabion unit. The self edges shall then be laced together in the same manner as described above.
7. Following filling of each gabion unit final level is reached, filling around gabions and sides of excavations will be accomplished. Backfilling shall comprise compacted gravel or crushed rock, free from organic matter and clay lumps, conforming to the following grading.

| Sieve Size (mm) | Percentage passing |
|---|---|
| 200 | 100 |
| 75 | 80 -100 |
| 0.075 | 0 – 15 |

Backfilling shall be placed and compacted in layers not exceeding 200 mm thickness. Backfilling shall be compacted to a density not less than 95% of the maximum dry density ratio determined for the in situ material using Standard Compaction. Material directly above gabion boxes shall be placed without compaction. On completion of the works, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

❖ **Spur Dike by Stone Masonry:** The task involves reducing erosion caused by water flowing along the upstream side of the embankment. Scour may still occur with spur dikes, but it will be moved upstream and away from the abutments. Spur dike is applicable for large-scale river. This item shall consist of providing the necessary labor, materials and equipment to construct spur dike at the vicinity of a bridge upstream including clearing, excavation, driving wooden log piles, and construction the spur dike as specified by the engineer.

1) **Spur Dike by Stone Masonry**
2) **(Type A)**

**Procedures**

1. Traffic warning signs shall be established at both ends of the work section
2. Areas on which spur dike is to be constructed shall be cleared, grubbed, and excavated as specified on the plans or as directed by the Consultant.
3. A box like compartment shall be prepared by driving wooden piles of diameter 150mm at 15cm to 30 cm center to center. The piles are secured by wooden bracings. The hollow spacing is filled up by boulders.
4. The dike shall be constructed in successive layers of earth about 45cm thick by mechanical compaction. The layers are thoroughly compacted by rollers of recommended weight and type. When compaction of one layer is fully achieved, the next layer should be laid and compacted. The designed spur dike section hence shall be completed layer by layer.
5. These dikes shall consists segments of dikes located river ward from the existing bank with gaps between the dikes 2 or 2-1/2 times the structure length. The length of the gaps between the dikes hall be about 50 to 60 percent of the length of each vane. The dikes should be placed at a slight angle to the direction of flow, about 10 to 15 degrees, with the downstream end of the dike farther riverward than the upstream end.
   The side slopes (upstream and downstream faces) of spur dikes should be maintained on the natural angle of repose of the earth material used to construct the dikes.

6. Slopes shall be finished to a reasonably smooth and compact surface within a tolerance of 15cm from the surface lines shown on the plans. Immediately prior to placement of riprap bedding, the prepared base will be inspected. Riprap or bedding shall not be placed until the prepared base has been approved.
7. The finished slope shall be back filled with gravel and sand which is spreaded uniformly. Compaction of the bedding material will not be required, but material shall be finished to a reasonably even surface, free form mounds or depressions.
8. Riprap shall be placed over the backfill material in a manner that will produce a reasonably well-graded mass of rock with the minimum practicable percentage of voids. Riprap shall be placed to its full course thickness in one operation and in a manner to avoid displacing underlying material.
   Finished riprap shall be free from objectionable pockets of small stones and clusters of larger stones. Hand placing may be required to the extent necessary to secure the results specified and form uniform slopes.
   Rock for grouted Riprap shall be thoroughly moistened and any excess of fines shall be sluiced to the underside of the stone blanket before grouting. Stones shall weight between 50 and 150 pounds each. At least 60 percent shall weigh more than 100 pounds, and approximately 10 percent may weigh 50 pounds less. Care shall be taken during placing to keep earth or sand from filling spaces between stones. After stones are in place, spaces between them shall be filled with grout from bottom to top and the surface swept with a stiff broom.
9. Grout shall consist of 1 part hydraulic cement and 3 parts sand, thoroughly mixed with water to produce grout having a thick, creamy consistency.
   Riprap shall not be grouted in freezing weather. In hot, dry weather, the work shall be protected from sunlight and kept moist for at least 3 days after grouting by the use of saturated burlap.

   The grout may be delivered to the place of final deposit by any means that will insure uniformity and prevent segregation of the grout. If penetration of grout is not obtained by gravity flow into the interstices, the grout shall spaded or roded to completely fill the voids in the stone blanket. Pressure grouting shall not unseat the stones; and during placing by this method, the grout shall be spaded or roded into the voids.

   Penetration of the grout shall be to the depth specified on the project plans. When a rough surface is specified, stone shall be brushed until from one-fourth to one-half of the depth of the maximum size stone is exposed. For a smooth surface, grout shall fill the interstices to within a 1.25cm of the surface.

   On completion of the works, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

❖ **Dumping Stone**

The task involves preventing slope failure caused by scouring action on the river bed, for small to Medium River and foundation ground is relatively solid.

**Materials**

The rock material shall be sound and durable, angular in shape, resistant to weathering and water action. The material should be free of overburden, spoil, shale or organic material, cracks or other structural defects and shall have a specific gravity of a t least 2.40.

Gradation of the rock shall be weighing not less than 5 kgs and at least 50 percent of the rock shall weight not less than 50 kgs.

**Dumped Stone & Wire Mesh Gabion**

**Procedures**

1. Traffic warning signs shall be established at both ends of the work section
2. Areas on which footing protection is to be constructed shall be cleared, grubbed, and excavated. A footing trench shall be provided along the toe of the slope and the trench shall be constructed as detailed in the plans. The river bed should also be cleared and leveled and backfill the river bed in layers using gravel, broken stone or quarry waste up to a minimum depth of 0.5 to 1.5 m.
3. Place mass stone with minimum practicable percentage of voids and a minimum thickness of 24 mm. The scoured area to be filled with rock using stone of 10-30 kg weight, or heavier, and place the smaller size stone in the lower layer
4. Fill spaces between stones with smaller size stone
5. Continue work layer after layer until final level is reached. The top layer should contain the heaviest stones and have an even flat surface at river bed level
6. When it is not possible to place stones in regular layers due to water flow, the scour area can be filled by random filling of the scour depression. Drop stone blocks into scour depression either from the bridge or from the bank until the depression has been filled.

❖ **Placing of Rip Rap**

This methodology is applicable in preventing foundation failure caused by scouring action on the river bed, and at the base of abutments and piers.

This item shall consist of providing the necessary labor, materials and equipment to repair foundation scouring including the preparation of the ground surface to receive gabions, the construction of the gabion structures in place, complete with rock filling at locations specified on the drawings.

1) **Stone Masonry (Type A)**

**Materials**

Materials used for rehabilitating scour are stone fulfilling the 2002 ERA standard Technical Bridge Repair Manual, Division 8400 and 8900.

**Procedures**

Stakeout the area around the river bed, the pier or abutment wall where scour has occurred

Excavate the scoured area to the lowest eroded level

Place riprap stones in layer in the excavated and prepared scoured hole starting with the smaller size stone in lowest layer.

Fill space between stones with a cyclopean concrete (1cement: 4 sand: 8 stone by volume).

Continue work layer after layer until normal bed level is reached. The top layer should contain the heaviest stones and have a flat even surface at river bed level.

## 4.6.2 Water Leakage and Deteriorations

### 4.6.2.1 Repair by Coating – Using Acrylic Polymer

The task is applicable for stopping serious and wide range of water leakage through cracks or voids which may progress and cause a reduction in loading capacity, together with leaching free lime or salt.

**Materials:** Materials used under crack, voids, and blockage of drains are independently specified on the respective defect repairs. The material used for coating of concrete surface to prevent water leakage is Acrylic Polymer Coating.

**Procedures**

Following the maintenance steps of the concrete, all surfaces to be treated with the acrylic polymer shall be dry and free from contamination such as oil, grease, loose particles, decayed matters, moss, algal growth, and all traces of mould release oils and curing compounds. This is best achieved by lightly grit-blasting the surface. The surface shall be then treated to be pre-soaked with clean water.

The liquid formed from acrylic polymer modified cementitious coating supplied in ready to mix kit shall be poured into a metal drum and an equal volume of clean fresh water shall be added for brush application consistency.

Mixing shall be done with a propeller agitator attached to a slow speed drill all as per the supplier's instruction.

The powder component shall be added gradually to avoid lump formation and mixed for 2 to 4 minutes.

The prepared mix shall then be immediately applied after mixing up to a total dry thickness of not less than 2mm. For further detail, the user shall follow the supplier's manual.

Coating is a kind of water- proofing "membrane" system (for preventing moisture ingress). The bitumionous wearing surface with "membrane" has been widely in Europe and United States, and its performance has been acceptable.

The advantages of a membrane are its easy installation and relatively low cost. The advantages are as follows.

1. Premature deterioration of bituminous overly in area of high volume traffic and inadequate drainage.
2. Blistering, caused by expansion of trapped and water vapor after placement
3. Poor bonding at the protection layers in the area near the expansion joint.
4. Local instabilities due to bleeding and bubbling
5. Replacement of the membrane wherever the surface is removed

It is suggested that the minimum thickness of asphalt wearing surface over the membrane be a minimum of 65 to 80 mm. If placed in two coarse, the lower course should be denser or more impermeable than the upper course in order to prevent trapping of water in the low course.

#### 4.6.2.2 Repair by Grouting – using Portland cement

The task is applicable for stopping serious and wide range of water leakage through cracks or voids which may progress and cause a reduction in loading capacity, together with leaching free lime or salt.
Wide cracks may be repaired by filling with Portland cement grout. This method is effective in stopping water leaks, but it will not structurally bond cracked sections.

**Materials:** Grout mixtures may contain cement and water or cement plus sand and water, depending on the width of the crack. However, the water – cement ratio should be kept as low as practical to maximize the strength and shrinkage.

**Procedures**

- Traffic warning signs shall be established at both ends of the work section
- Clean the concrete along the crack
- Install built-up seats (grout nipples) at intervals astride the crack to provide a pressure tight connection with the injection apparatus and seal the crack between the seats with a cement paste.
- Pump grout into the crack through the nipples. Maintain the pressure for several minutes to ensure good penetration of the grout. The grout should have a water-cement ratio of one part cement to one to five parts water.
- No remedies (repairs) to the newly repaired concrete shall be performed without the prior inspection and approval of the Employer's Representative.
- On completion of the works, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

### 4.6.3 Concrete Deck – Slab and Pier Columns Deterioration and Repair Methods

#### 4.6.3.1 Repair of Concrete Deck – Slab by Removing and Casting new Concrete

❖ **Chiseling, Demolishing and Cleaning**

A) All elements of the bridge shall be chiseled and plastered (horizontal, vertical and overhanging) and all surfaces, as directed by the Engineer.

B) Chisel out and remove all spelled, unsound, damaged, fouled, porous and loose concrete plus other identified area of unsound concrete. During removal of concrete, the concrete should be removed to expose the full circumference of steel reinforcement and should extend along the length of the corroding bar for at least 50 mm beyond point at which corrosion is visible. Exercise care when chipping out concrete so as not to cause structural damage.

C) All exposed reinforcement should be cleaned/ brushed to remove scale and rust. It must be ensured that all areas prior to treatment are free from all unsound materials such as dust, oil, grease, corrosion by products and organic materials.

D) Treat substrate using biowash.

❖ **Placement of a new Rebars and Concrete**

A) Prime substrate by bonding primer to obtain maximum adhesion.

B) Apply polymer modified repair mortar using shot concrete or approved method for piers.

C) Place reinforcement. Transverse bars shall be bent up so as not to block the traffic on the other lane

D) Place form work for expansion gap at every end of pan.

E) Pour polymer modified concrete as per the drawing.

F) Cure using curing membrane as per the specification.

G) After seven days coat with water proofing material including the main span.

H) After curing as per the manufacturer specification, place asphalt concrete for the whole span to level with the main span.

### 4.6.4 Repair of Pier Columns – Encasing

The repair work shall be conducted for all elements of the pier as indicated in the drawings and as directed by the Resident Engineer (pier column, pier cap, bracing).

A) Remove existing concrete cover.
B) Brush cleans the existing reinforcement.
C) Place additional reinforcement bars as per the design.
D) Apply polymer modified repair mortar using shot concrete or approved method.
E) Cure using curing membrane as per the specification. After the mortar is cured coat with water proofing material.

**General procedure for Application of materials**

A) The areas to be treated must be free from all unsound material that is dust oil, corrosion, byproducts and organic growth.

B) Smooth surfaces should be roughened; all loose material and surfaces has to be removed and steel cleaned to bright metal preferably using wet grit or water blasting techniques or equivalent approved methods.

C) The prepared substrate concrete should be thoroughly soaked (preferably 24 hours before) with clean water until uniformly saturated without any standing water. Highly porous substances may require sealing with polymer admixture.

D) Mix of priming material shall be as per the specification of the manufacture

E) Placing shall be applied using spray techniques. Make sure air is not entrapped and ensure total protection is achieved to the satisfaction of the Resident Engineer. Manufacturer specification shall be strictly followed.

F) Application of curing membrane should take place as soon as after any residual surface water form trawling has evaporated. But generally, manufacturer specification shall be strictly followed. It is important that the surface of the coating is protected from strong sun light and drying wind with curing membrane.

G) For maximum curing efficiency, if the surface is subject to strong sunlight or drying winds, a second coat should be applied. This waiting time is generally 15 minutes.

H) Overcoat as per the specification of the manufacturer.

I) To obtain maximum adhesion to coatings and cement based substrates, the surfaces of the reveals should be primed with bonding primes. Sealant must be applied as per the specification of the manufacturer.

J) Biowash shall be spray applied. It kill active mould, fungal and bacterial spores and chlorophyll containing organisms such a moss, Lichen and algae, within a maximum of two days, Remain active after its initial application, guarding against subsequent infection for up to two years.

K) Application should take place after cleaning visible areas of growth by wire brush, scraper or mechanical means. Apply biowash undiluted by brush, roller or airless spray to areas exhibiting visible contamination, ensuring that all surfaces are thoroughly wetted. Wash off bleach solution and remove dead growth by hosing or brushing. Allow to dry before subsequent treatment.

### 4.6.5 Practical example of deck repair on Awash River Bridge

General repair of Awash Bridge (along Addis - Jimma, A5 route) was conducted under capacity building program of ERA and JICA cooperation. The repair work focused on resurfacing of highly damaged girders side, restoration of deteriorated decks and highly exposed Girders.

**In repair of Deck slabs the following procedures were followed.**

Deck slabs at drainage locations

- Remove deteriorated concrete (use hammer sounding technique)

- Remove the rust of exposed rebar and set a new rebar by welding or wiring considering the required overlap which is not less than 60 cm,
- Paint anti-rust paint to rebar
- Wet the surface by water to create a surface saturated water condition for bonding
- Prepare and plaster using a specially prepared mortar mix with bonding agent (if necessary use form work)
- Apply the normal mortar mix shortly before bonding agent dries, use your hands to apply the mortar hard
- Treat the surface with cement screed
- Then, use water spray to cure for avoiding drying shrinkage crack.

Along with the deck slab repair, drainage repair was made using the following procedures

- Removing the accumulated soil on the top of the deck blocking the drainage
- Removing the old drain pipe and making a hole for the new PVC drain pipe
- Set the new pipe of Dia,50 and 75 mm with enough length for avoiding damage by flushed water
- Fill up a gap between the pipe and the concrete by epoxy resin with sand to avoid water leakage
- Set bars at upper opening for protection against debris and set elbow at bottom of pipe for avoiding flush of water to girder and deck
- Provide the upper draining area with a tapered surface for easy
- Apply the mortars like the above repairs
- Treat the surface with cement screed
- Then, use water spray and vinyl sheet to cure for avoid drying shrinkage crack

### 4.6.6 Rust Treatment of Concrete Reinforcing Bar

#### 4.6.6.1 Repair of Rusted Re-bars

The purpose of reinforcement bar repairing is to replace the rusted or chemically affected and severely defect portion, and to cover the reinforcement for avoiding further strength deterioration. The task involves repair of partial rebar exposure without corrosion, which affects the durability of the deck slab and beams. For proper repairing or replacing of rebar exposure, the following steps may be used

Step 1 Concrete removal around the full circumference of the corroded re-bar

Step 2 Removal of rust and other bad material of re-bar

Step 3 Repair or replacement of defect bars or bars with critical section loss.

Step 4 Anti-corrosion coatings may be applied to re-bar protection

If the reinforcing steel has lost more than 25% of its cross section, then repair of rebar is generally required. In this cause, supplemental bar over affected length has to be provided. New bar may be mechanically spliced to affected bar or placed parallel to existing bar.

a. **Repair Using Water-Abrasive Blasting**

   Water-abrasive blasting is the most effective method for cleaning the reinforcement. The abrasion shall be done till it remove all solid rust and water dissolves the chloride away. Enough concrete shall be cut away on the blind side of reinforcement to allow room for water-abrasive blasting. The space shall be used for providing cover to reinforcement steel.

b. **Repair Using Electro Chemical Extraction**

Internal unexposed reinforcement bar corrosion can be cleaned using an electrochemical extract ion of corrosive chloride method. The chloride extraction shall be carried out by applying a regulated current in order to create a safe electric field between the reinforcement in the concrete and a temporary, externally mounted anode mesh. During the treatment, negatively changed chloride ions are driven form the concrete by an induced positive/negative field effect. Concurrent to the chloride ion removal, electrolysis at the reinforcement surface produces a high PH environment which repassivates the steel within the effective treatment zone. "Cathoding method"

**Materials for Treatment of Rusted Re-bar**

A. ***Patch with Cement Concrete (Type A)***: The mixture shall consist of 1 part high-early-strength Portland cement, 1and ½ Parts fine aggregate and 1-1/2 parts coarse aggregate by volume. Sufficient air-entraining agent shall be added to maintain an air content of 8 plus or minus 2 percent. The slump shall be the minimum practical for placing and in no case shall it exceed 50 mm. The materials shall be mixed at the site. Ready-mixed concrete shall not be permitted. The mix shall be placed in the area to be patched while the bonding grout is still wet. Hand finishing with a wood float may be required to produce a tight, uniform surface.

**B. Patching With Cement Mortar (Type B, or Type C :)** Patching material shall be made using Quick Setting Concrete Mortar, Type 1 or 2, ASTMC 266. The mortar shall be mixed and placed as per manufacture's recommendations. Coarse aggregate may be added in accordance with the manufacturer's instructions when the depth of the patch exceeds 25 mm.

**C. Quick Setting Concrete Mortar**: Provide prepackage mortar material that requires the addition of water only. Use materials capable of being extended 50 percent by dry mortar weight with aggregate meeting the following requirements:

- Do not use materials containing more than 50 parts per million of chloride.
- Do not use any admixture containing more than 50 parts per million of chloride in conjunction with these materials.
- Provide quick setting concrete mortar packaged in strong moisture resistant paper bags or other suitable containers capable of withstanding shipping, normal handling, and storage without breakage. The package shall protect the material form deterioration when stored in a dry condition for a period of 1 year. Each package or container must display information regarding the minimum nominal yield and instructions for mixing. Calculate volumetric yield determinations using the manufacturers' recommended water content.

**Work procedures**

**1.** The Contractor will indicate what part of the existing structure is to be removed and the required dimension of the new work.

**2.** The perimeter of all removal areas shall be sawed to a depth of 25 mm to produce a vertical or slightly undercut face. Additional saw cuts may be required to facilitate removal. All unsound concrete including all patches other than sound Portland cement concrete, and all loose and disintegrated concrete shall be removed. Chipping or hand dressing may remove the unsound concrete. Chipping hammers shall not be heavier than the nominal 16 kg class and shall be operated at an angle of less than 45 degree measured from the surface of the deck. Concrete shall be removed in a manner that prevents cutting, elongating or damaging of reinforcing steel. Where the bond between the concrete and a primary reinforcing bar has been destroyed, or where more than one half of the periphery of such a bar has been exposed, the adjacent concrete shall be removed to a depth that will provide a minimum of 19 mm clearance around the bar except where other reinforcing bar make this impracticable. Reinforcement, which has become loose shall be adequately supported and tied back into place. After completion of the secondary removal operations, the Engineer will re-sound the deck to insure that only sound concrete remains.

### 4.7 Mortar Mix and Plastering Works

#### 4.7.1 General

Mortar is a mixture of cement paste and fine aggregate. Grout is a mixture of cementitious material and water, with or without fine aggregate proportioned to produce a pourable consistency without segregation of the constituents. **[1]**

| **Mortar** | Sand: cement | sand: lime: cement |
|---|---|---|
| General building (Above ground) | 5:1 | 5:1:1 |
| Bridges and general Building (below ground) | 3:1 | 6:1:1 |
| Internal walls | 8:1 | 9:2:1 |

Mortar will take months to reach its full strength, however, after about 24 hours it should be fairly hard and after 4 or 5 days, the strength should be enough to stand up to normal loading condition.

**The Various Components Include the Following**

***Cement***: For normal ‘around the house’ types jobs, Ordinary (or Portland) cement is required. This is normally available in 50kg bags, although smaller 25kg bags are increasingly becoming available to take account of the UK manual handling regulations. Try not to buy more cement that you need as it cannot be stored for very long. Some special cements are available (i.e. quick drying) which may be required for special situation.

***Lime***: Lime is sometimes used in cement and reduces the amount of water drawn into the bricks, thus preventing the cement from drying out too quick and shrinking.

The main types of lime are:

**Hydraulic**: - which sets by combining with water

**Non- hydraulic**: - this hardens by drying out

**Semi-hydraulic**:- which a half-and-half, it mainly needs to dry out but has some hydraulic properties.

Hydrated hydraulic lime must be used straight from the bag. Semi hydraulic or non-hydraulic are better to use after soaking in water for 24 hours, i.e - stir it into water and leave it overnight and the lime sinks to the bottom and excess water can then be poured off. Mix the lime with the sand before adding cement.

***Sand:*** Two type of sand are available but are not interchangeable in all applications, whichever type is being used, always pass it though a sieve before use to remove any small stones etc.

- Soft sand (or builders' sand):- a smooth sand, non-gritty, loamy and with cohesive properties, can be used for bricklaying mortar, for bedding paving slabs, for rendering walls, etc.
- Sharp sand: - this has a gritty feel and is similar to that used to condition soils and potting composts and can be used for concrete, and for rendering of floors and walls.

### 4.7.2 Plastering Work for Concrete Defects Repair

Mortar of a consistency suitable for toweling usually does not contain enough cement paste to coat the old concrete surface or the reinforcement adequately. So a bonding coat of cement grout or polymer admixtures shall be used.

Bonding coats containing polymer admixtures dry quickly and work shall be organized so that application of mortar follows the bonding coat within few minutes.

#### 4.7.2.1 Surface Defects Repair (Peel Off/Spalling/Scaling)

Concretes may be peeled off/scaled or spalled due to external impact, aging, or chemical attacks.

Surface defects such as small areas of Peel Off, Spalling, Scaling, honeycombing or cavities produced by form ties, large isolated blow-holes, broken corner edges, etc, shall be repaired with mortar having a cement and sand ratio equal to that of the concrete being repaired.

For the repair of large or deep areas of honeycombing and defects, special approved methods and techniques, such as pneumatically applied mortar, pressure grouting, epoxy bonding agents, etc, may be used.

Where, in the opinion of the Engineer, the extent of the honeycombing or defects is of such a degree that doubt exists about the effectiveness of repair work, making of a load test is necessary to prove that the structural safety of the repaired member has not been prejudiced, failing which, the structure shall be rebuilt in part or in full at the contractor's cost.

Where the concrete has been damaged by adhesion to the formwork panel, the cracked and loose concrete shall be removed; or where the fresh concrete has lifted off at construction joints, the crack shall be scraped out immediately on both sides of the wall to a depth of at least 50 mm. The cavities so formed shall then be repaired as described above.

***Rubbing the surfaces***

If the finish of exposed formed surfaces does not comply with the requirements for uniformity of texture, appearance and color, rubbing down the exposed surfaces of the entire structure or of any part of it is necessary.

The surface shall be saturated with water for at least one hour. Initial rubbing shall be done with a medium-coarse carborundum stone, where a small amount of mortar, having sand and cement ratio equal to that of the concrete being prepared, is used on the surface.

Rubbing shall be continued until all form marks, projections and irregularities have been removed and a uniform surface has been obtained. The paste produced by the rubbing shall be left in place. The final rubbing shall be carried out with a fine carborundum stone and water: this rubbing shall continue until the entire surface is of a smooth, even texture and is uniform in color. The surface shall then be washed with a brush to remove surplus paste and powder.

Where the concrete surfaces formed by sliding formwork require treatment to achieve the surface finish specified for the member, the concrete shall, as soon as the surfaces under the formwork are exposed, be floated with rubber – lined floats to the desired finish.

**4.7.2.1.1 Patching Repair**

This method is applicable for maintenance of small range of peel off, spalling or scaling of otherwise sound concrete due to external forces which affects the durability of concrete surface.

Total area is between 400 -100 $cm^2$.

This item shall consist of furnishing the necessary labor, material and equipment to repair concrete bridge decks and concrete surfaces using cement-sand mortar including the removal of deteriorated concrete, preparation of concrete surface, placing, consolidating and curing the mortar.

**Material**

The economically recommended material for plastering of concrete honeycomb is a mortar having Cement – Sand ratio equal to that of the concrete to be repaired (usually 1:3 by volume). Advance mortar containing specialized binders such as potassium silicate, calcium aluminates, sulfur, and oxysulfate or polymer resins. They cure or set through film drying (air setting), chemical reactions, thermo set bonds, hydraulic bonds, hot melting, and multiple component binder systems. Unlike conventional construction products, specialty mortar is not based on Portland cement. Instead, specialty mortar consist of specialty cement such as potassium silicate that is mixed with water, a coarse aggregate such as gravel or crushed stone, and a fine aggregate or sand. Specialty cement mortar is used to join components and form structures.

**Procedure**

a. Traffic warning signs shall be established at both ends of the work section.
b. The Employer's Representative will indicate what part of the existing structure is to be removed and the required dimension of the new work.
c. The defects, unsound and contaminated concrete shall be removed and the edges of the patch area should be prepared.
d. The reinforcement shall be cleaned if exposed and contaminated with rust.
e. Prepare the patch material and bonding coat (as per the maintenance designed) for the job. If a propriety pre-packaged formulation is to be used the Contractor shall carefully follow the manufacturer's recommendations. For common repair jobs a cement and coarse sand mixture in the ratio of 1: 3 by weight is generally adequate.
f. The cement-sand mortar shall be prepared with minimum amount of water. Slump of the mix for shallow patches should not exceed 25mm. To minimize shrinkage in place, the mortar shall be allowed to stand for half an hour after mixing and re-mix prior to use. Water shall not be used to re-temper the mix.
g. The bonding coat shall be applied (as per the design) to concrete substrate and to the reinforcement.
h. The mortar shall be applied immediately following the bonding coat. The mortar shall be forcibly projected or dashed onto the substrate and placed in layers about 10mm thick. Each surface using a blunt piece of wood or hammers. Each layer shall be cross-patched to facilitate bonding with the next layer. Generally, there need be no time delays between the layers. For vertical and overhead repairs of considerable thickness, in order to prevent sagging of mortar, the repair may be limited to about 50mm thickness at one time, and shall then be kept moist for a day before applying the successive layer.
i. The patch shall be finished to the texture of the surrounding concrete by using similar form material and hammering with mallet or wood floating or steel trowel ling as instructed by the Engineer.
j. Curing shall be started as soon as possible. The curing should be thorough and continuous to develop strength and impermeability and to reduce drying shrinkage to a minimum while bond strength is developing. Water used for curing shall be free from ingredients harmful to concrete. Curing shall be continued for a minimum of 4 days in temperate weather and 7 days in hot, dry or windy conditions.
k. On completion of the work, the site shall be cleaned of all surplus materials and waste, and left in clean, tidy condition.

#### 4.7.2.1.2 Gunite/ Shot-crete Repair

Gunite (pneumatically applied cement-mortar) and Shot Crete (pneumatically applied cement-concrete) are suitable for forming the new concrete (i.e. the restoration-concrete) and for strengthening and jacketing of various structural elements.

This task involves the maintenance of serious peel off, spalling or scaling which affects the safety of third parties due to a possibility of concrete falling down. Total area is more than 900 $cm^2$.

Pre- treatment of the exposed concrete surface is prime importance when using gunite /shot crete.

Sand blasting has proved to be efficient surface treatment procedure. The exposed sound concrete surface should be sufficiently pre-moistened. No bonding agent is necessary because at the interface mortar enrichment occurs as result of aggregate rebound.

Shotcreting in multiple layers requires that the preceding layer achieves a sufficient degree of hardness prior to shooting- on the next layer. Some nominal reinforcement may be required for a thickness lager than 50 mm. This reinforcement should be fixed in position in such a manner that it remains stiff and keeps its position during shotcreting operations (chicken wire mesh is handy).

Curing may be accomplished by evaporation protection method, (e.g. plastic sheet cover), to prevent a rapid drying out. If a freeze-thaw/salt resistant concrete is required, air entrainment admixture may have to be added to the mix. Also, surface protection measures may be necessary in certain cases.

There are two basic gunites or gunite / shotcrete processes.

1. A “dry mix” process, where the mixing water is added at the nozzle to which the cement-sand mixture is brought by compressed air through the delivery hose.
2. A” wet mix” process where all the ingredients, including water, are mixed before entering the delivery hose.

The process consists of removal of deteriorated concrete using pneumatic hand hammers. Then the cracks are grouted and dowel bars are anchored into the fasten temperature and shrinkage reinforcement bas (generally 10 mm dia, @ 150 mm centers, into orthogonal directions).

A form is placed around the perimeter of the repairs, then clean coarse-grade aggregate (minimum 16 mm size for thick sections, and minimum 12 mm size for thin sections) is placed and compacted before pumping an especially designed cement sand grout into the aggregate by especial insert fitting placed in the face of the forms. The coarse aggregate may be of any suitable size, depending on the thickness of the repairs. Normal size varies from 20 to 40 mm down.

**Work Procedures**

**Material and Site Preparations**

a. All unsound material should be removed from concrete and masonry surfaces. Chipping should continue until there are no offsets in the cavity, which would cause an abrupt change in the thickness of the repair.

b. Forms should be made of plywood sheathing, expanded metal sheat, or other suitable material, true to line and dimension.
c. Safe, adequate scaffolding should be provided so that the toweler, plasterer or nozzle man can hold the tools at the optimum angle and distance from the surface for all parts of the work. The scaffolding should also provided easy access to the gunite/shot crete surface for screeding and finishing operations.
d. Concrete around the reinforcing should be removed until clean, un-corroded steel is reached. Concrete behind reinforcing steel should be removed to a depth to allow proper placement from a nozzle angles not more than 45 degrees to the surface. Cutting out the defective length and replacing with a new section of reinforcing bar. Anchoring new bars in the existing, sound concrete should be done by drilling holes and anchoring the ends with an epoxy grout.
e. New bar reinforcement must be sized and positioned to minimize interference with shot creating. Generally, bar sizes smaller than 16 mm diameter should be used. One layer of reinforcement is generally sufficient for sections 20 cm, or less. Wire fabric should be tied similarly to bar reinforcement for gunite /shot crete. Fabric sheets should be lapped one and one-half space in all directions. At least one layer of fabric is used for each 7.5 cm. of gunite/ shot crete.
f. Anchorage of gunite / shot crete follows practice for conventional concrete.

**Batching and Mixing:**

a. Mixing equipment must be capable of maintaining an adequate and continuous flow of uniform material. Aggregate particles should be well coated with cement paste. Batching by mass is preferred and should normally be required. Water may be batched by mass or volume. For small jobs, approval may be given to batching by a volumetric container, provided periodic checks of mass are made, or batching by volumetric mobile-mixing equipment.
b. Jobsite mixing: Since many gunite / shot crete jobs have a low production rate and are in isolated locations, a small drum mixer at the jobsite often does the mixing. In such cases, the mixing time should not be less than 1 minute: where other mixers are proposed, satisfactory evidence should be presented to show they are capable of thorough mixing. The mixer should be capable of discharging all batched material without any carry –over from one batch to the next. It should be inspected and cleaned thoroughly at least twice a day, more often if necessary, to prevent accumulations of batched material and minimize unplanned shutdowns.
c. Dry-mix process: The moisture content of the fine aggregate should be such that the aggregate- cement mixture will flow through the delivery hose at a uniform rate. The optimum moisture content will depend upon the delivery equipment being used, but it is generally within the range of 3 to 6 percent, by mass, for the fine aggregate fraction. Volumetric batching and mixing plant operations conforming to ASTM C 685.
d. Wet-mix process: Where ready mixed concrete is used, it should conform to ASTMC 94. Continuous batching and mixing meeting the requirements of ASTM C 685 may also be used.

e. Admixture dispensers: For either the dry-mix or wet-mix process, admixture dispensers should receive special attention to ensure that the material is dispensed with in plus or minus three percent of the required batch quantity and is uniformly dispersed through the mixture.

**Application Techniques:**

a. Nozzle angle. Plane surfaces should generally be gunite/shot crete with the nozzle held at 90 degrees to the surface. Interior corners should be gunned by directing the nozzle in the plane bisecting the angle of intersection of the two surfaces, which reduces the amount of rebound entrapped in the corner. Areas with reinforcing steel should be gunned at a slight angle from each side. When gunning horizontal work, the nozzle should be held at a slight angel from vertical so that rebound is blown onto completed work for ease of removal.
b. Nozzle distance: the optimum distance between the gunite / shot crete nozzle and the surface is generally about 0.90meter.
c. Nozzle motion. A steady circular or elliptical movement of the nozzle across the surface is the proper gunning technique.
d. Encasing reinforcement: A blowpipe should be used during the gunning operation to remove accumulation on the front of the bars and entrapped rebound from behind the bars. All obstacles to the flow of the gunite/ shot crete material stream should be kept to a minimum size.
e. Progression of work
   - The bondable material to which gunite/ shot crete is to be applied should be clean and free of bond-breaking substances such as dirt, grease, oil, curing agents, paints, or deteriorated material.
   - A thin initial coat of gunite / shot crete should be rapidly applied to the selected work surface before starting the layering of guniter/shot crete. The work area should be of such size that the surface could be maintained “wet” with fresh gunite / shot crete so that initial set does not occur until shooting of the area is completed.
   - Once the initial bonding or wet coat is applied to the entire work area, a second pass over the area may proceed at a slower rate. Corners should be filled first to prevent the accumulation of overspray and rebound, followed by application onto the flat areas.
   - When the limited work area has been completed, rebound and overspray should be removed from adjoining areas with air before the gunite/ shot crete takes initial set.
   - When gunning vertical work, gunite/shot crete should be applied from the bottom up. For thick walls, “shelf” or “bench” gunning may be used, where, instead of gunning directly against the vertical surface, a thick layer of gunite/shot crete is built up from the bottom, maintaining a 45-degree slope.

f. Protection

Gunite/ shotcrete cannot normally be applied during period of rain, or high wind. If proper shields cannot be erected to reduce the effects of the wind, the shotcreting should be discontinued. Because gunite/ shot crete rebound, overspray, and dust can defect adjacent surfaces, protection for these surfaces may be needed. Means of protection include plastic or cloth covers, masking materials, temporary coatings, or plywood or other wood. If protection is not feasible, then adjacent surface should be cleaned before the contaminant hardens

g. Construction joints:

Construction joints are normally tapered about one-half of the gunite/ shot crete thickness or a maximum of 25 mm thick to and edge, over a width of 250 to 500 mm. square joints can be cut by a trowel at initial set. Ordinarily, square joints should be avoided in gunite/ shot crete construction because they form a trap for overspray and rebound. However, if the joint will be subjected to compressive stress, square or butt joints may be required. Steps must be taken to avoid or remove trapped rebound at the joint. The entire joint should be thoroughly cleaned and wetted prior to the application of additional gunite/shot crete. These joints may be required in some applications, such as canal linings, to control shrinkage cracking of the gunite/ shot crete. Pre positioning strips of plastic or metal, and leaving them in place, or by saw cutting the newly hardened gunite/ shot create may create the joints.

h. Water stop:

Due to the difficulty of placing gunite/ shot crete around water stops, use of water stops in gunite/ shot crete applications should be avoided.

i. Multiple layers:

When a layer of gunite/ shot crete is to be covered by a succeeding layer, it should first be allowed to develop its initial set. Then scraping, or other means should remove all loose material and rebound. Surface deposits, which take a final set, should be removed by sand blasting and the surface cleaned with an air-water jet.

**Time limitations:**

The time from the batching of gunite/ shot crete to final placement should not exceed 45 minutes during warm weather, i.e ambient temperatures exceed 270c.

# 5 CURRENT DEFECT REPAIR PRACTICE IN ETHIOPIA

## 5.1 Discussion

This study addresses the increasing needs of skill upgrading trainings on bridge maintenance which is not available in universities or higher technical institutions in the country. Conducting this research study is found necessary in order to make simple application of the methods considering the local condition by incorporating international maintenance methods and materials that can be available in the country. In addition, it is intended to make it friendly applicable and usable for contractors, consultants, and other interested users.

Many bridges in Ethiopia have attained about design period, as most are constructed 40-70 years ago. Others have suffered abuse by unscrupulous (ignorant) transporters who overload or move over-height containers. As a result, the structures exhibit cracks and deterioration leaving the steel rebar in most cases exposed to aggressive climatic conditions.

Thus, maintaining and rehabilitation of existing bridges is a better option provided the relevant strength requirements are satisfied. In this aspect to tackle the problems, a number of construction chemicals suppliers advertise wide variety of concrete repair products to meet the needs of all kinds of repair situations, indicating availability for use.

Collection of inventory data and inspection (regular, major or emergency) of defects is the primary activity conducted during rehabilitation. Different defects like, cracking, peel off, rebar exposure, honeycomb, void, water leakage, deformation, corrosion, wearing, bolt missing on different structural parts (superstructure, substructure or miscellaneous structural elements) has to be rater based on the rating system specified. That is whether the defect is in rank “A”, rank “B” or rank “C” shall be categorized.

Defects that appear on the surface of concrete during construction or within a relatively short time after completion, are usually caused by poor quality materials, improper mix design, lack of proper placing and curing procedures, or poor workmanship. The repair of surface defect is both difficult and costly. The best repair work will not be as good as an original properly finished surface. Every effort should be made both prior to and during construction to avoid the use of materials or construction practices that can cause surface defects.

Various causes may have contributed to the formation of a particular defect. However every effort should be made to determine the cause to ensure that the correct repair strategy is adopted. Sometimes the cause is clear, for example fire or collision damage.
Structures may be overstressed by conditions outside the control of the designer and constructor, such as overloading, change to the flow of a river, failure of adjacent structures and various natural causes.

Settlement of a structure, which was not anticipated and allowed for in design, can result in very severe damage to concrete structures. Wide cracks and crushing where members come into unintentional contact may indicate that settlement has occurred.

Following a vehicular collision with a bridge, careful consideration of the structural effects must be carried out by an experienced structural engineer. Damage to primary elements can severely weaken a structure, or even cause collapse.

Generally defect in concrete structures result from many factors such as poor design detailing, construction deficiencies, structural failure due to overstress or loss of section resulting from other defects, free/thaw effects, chemical attack, settlement of the foundation, changes to the support or loading conditions caused by scour or silting, failure of bearings or expansion joints, and traffic collision defect.

The defects mentioned above are rehabilitated by different materials, one of the fundamental materials and widely used one is concrete. With a worldwide estimated consumption of between 21 and 31 billion tones of concrete in 2006, concrete is the second most consumed substance on Earth after water! A world without concrete is almost inconceivable!

The principles of producing concrete and understanding the laws of concrete behavior are well enough established through long experience and extensive research to make it possible to design and erect structures that meet the recognized requirements of engineering use and safety. There is still a need for continued research, however new questions are constantly arising, and new methods and machines for construction operations are being developed. If concrete is to meet increasingly higher expectations with regard to durability and structural efficiency, and continue in the forefront as a building material, the new requirements need to be met by ever-increasing knowledge obtained from research and experience.

Concrete sets, hardens, gains strength, and exhibits reduced permeability with the passage of time, but it is not the passage of time alone that causes these things to happen. If the concrete is kept very cold, none of this will happen. If all moisture is removed, none of this will happen.
Many or even most concretes are confronted with potential deteriorative service conditions. If the concrete has not been provided with immunity against these influences, it may well slowly deteriorate as time passes, but not simply because time passes. Concrete need not deteriorate.

Concrete is essentially a compressive material. While it has adequate strength for most structural uses, it is best suited for relatively massive members that transmit compressive loads directly to the founding material. Although concrete has low tensile strength, reinforcing it with steel bars produces a material that is suitable for the construction of flexural members such as deck slabs, bridge girders, etc.

Concrete is a mixture of sand, gravel and/or other aggregates (the matrix), bound together by a water-based binder, cement. Admixtures (modifying agents) and additives (fine mineral powers) are sometimes introduced to improve the characteristics of the fresh concrete, of the mixing process and/or of the final hardened material.

Cement is the fundamental component of concrete, so cement alone or in combination with polymers or epoxy can be used for maintenance. Based on the type of the defects the materials used for maintenance can be grouped in to four. These are:

(1) materials used for large defects or cracks (pure cement or polymer modified cement type materials) Polymer modified cement type : this is cement modified using different polymers and fibers
(2) materials used for small defects or cracks (Resin type repairing materials or crack injection materials)
(3) crack sealing materials, so that small cracks will be ready for injection
(4) materials for bonding

The repair work will be accomplished after conducting inspection and preparation of the repairing materials. During repairing the procedures has to be properly followed as per the specification or order of the expert. But removal of concrete if necessary, surface cleaning, substrate preparation and repairing material application are the general steps applied during rehabilitation.

When removal of part of concrete structure is required, use power driven chipping tools or hydro demolishing equipment to remove all loose or defective concrete. Avoid defect to sound concrete to remain in place. Avoid hitting reinforcement steel with the chipping tools. Once the initial concrete is removed, use small power-driven chipping or hydro demolishing equipment to undercut all exposed reinforcement steel. Expose the entire perimeter of the steel bars for the full area of the repair provide a minimum clearance of 1cm between the exposed steel and the surrounding concrete or two times the maximum aggregate size, whichever is greater. Remove additional concreter as necessary to keep the repair area to reasonably uniform depth. Defect to sound concrete or to the bond of reinforcement steel outside the repair area shall be repaired at the Contractor's expense. The Contractor shall obtain approval of the completed concrete removal before proceeding to surface preparation.

The area to be repaired shall be cleaned by abrasive blasting, high pressure water blasting, or other methods approved by the Engineer. All loose particles, dirt, deteriorated concrete or other substances that would impair the bond of the repair material shall be removed. Exposed reinforcement steel of concrete, rust and other contaminants shall be cleaned and this should be followed with a high pressure air blast for final cleaning.

Unless directed otherwise, use a bonding agent if cement mortar or concrete is used for the repair material.
Use either a cement scrub or epoxy as the bonding agent. Follow the manufacturer's recommendations for bonding agents if pre-packed repair material is used. Apply a cement scrub coat bonding agent to the saturated surface-dry substrate by scrubbing, brushing, or other methods approved by the Engineer immediately before placing the repair material. Apply an epoxy bonding agent in accordance with the manufacturer's recommendations. Ensure that any bonding agent used does not set or cure prematurely, creating a bond breaker.

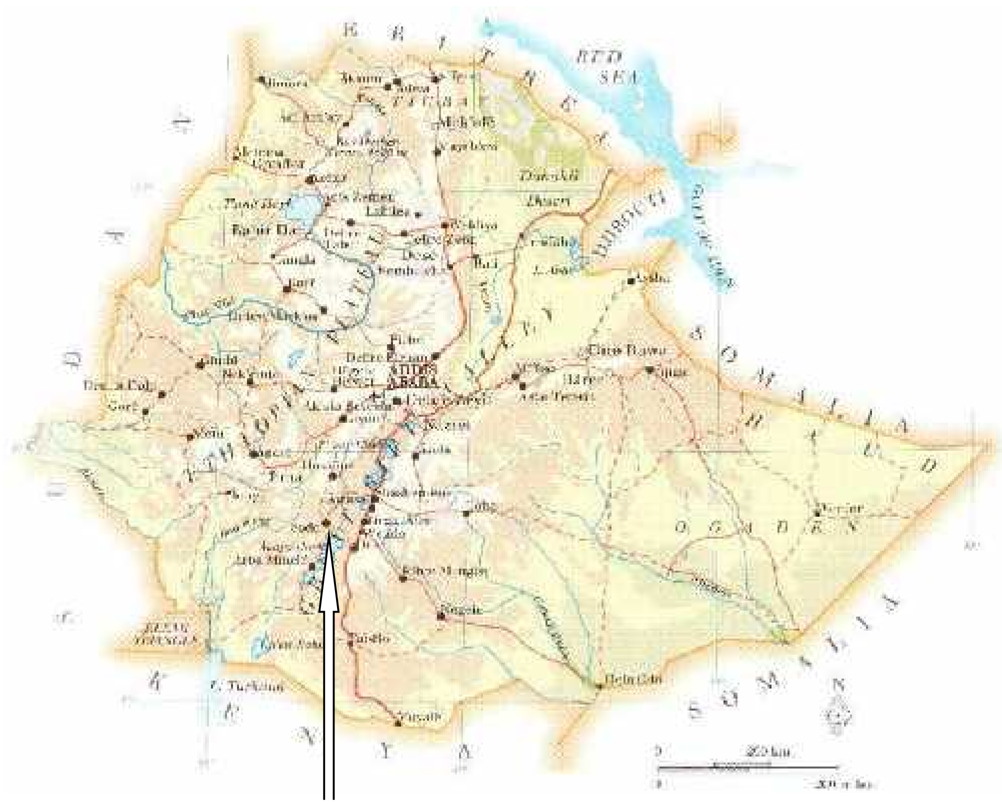
Where saturated surface-dry (SSD) conditions are needed, pre wet the substrate by pounding water on the surface for 24 hours. Before placing the repair materials, if pounding is not possible, achieve SSD conditions by high-pressure water blasting 15 to 30 min. before placing the repair material. A saturated surface-dry condition is achieved when the surface remains damp when exposed to sunlight for 15min.

Place the repair material in an approved manner ensuring that the repair material is in intimate contact with the substrate and free of voids. Follow the manufacturer's recommendations for pre packed repair materials. Place the repair materials so that the original lines and surfaces of the structure can be restored.

So far there were no detailed specifications and standards for rehabilitation of concrete defects. This is due to lack of repairing materials and techniques, unavailability of expertise on the field (no university or college providing courses on concrete rehabilitation), and lack of awareness about the cost and related problems in erecting of new bridged as compared to that of rehabilitation. Nearly some companies are providing repairing materials and techniques in Ethiopia with corresponding manuals and specifications for application. That is why currently rehabilitation is being practiced to some extent on some deteriorated bridges. For example Ethiopian Road Authority in collaboration with JICA has rehabilitated many bridges in the country for the last five years. The following are some of the rehabilitated bridges.

## 5.2 Sodo Destrict, Kulfo Bridge Rehabilitation Work

Kulfo Bridge is located in Southern Nation Nationalities &People Regional State in trunk road A7-5 at station 497.2 km from Addis Ababa to Arba-Minch in road segment M/Abaya-A/Minch. This Bridge was constructed by Italian Engineers during a year 1974 G.C. But after 22 years the Bridge had failed and stopped giving service for traffic in 1996 G.C due to settlement of pier. Between November 1996 – June 1997 G.C. ERA replaced the settled Pier and opened the road for traffic over the Bridge. A hole with deteriorated concrete around it & rebar exposure has been exhibited on the deck slab near to Arba-Minch side abutment in 2011 G.C. ERA has accomplished the maintenance work. See the Location Map of this Bridge below.




**Kulfo Bridge**

Figure 5.2: Kulfo Bridge Location

### 5.2.1 Materials Used for Repair

**1. Nitobond EP**: bonding agent

Plate 5.2.1a: NitoBond (hardener & base)

Plate 5.2.1b: Pouring hardener in to base

Plate 5.2.1c: NitoBond (hardener & base)

Plate 5.2.1d: Mixed NitoBond

Plate 5.2.1e: Application of NitoBond

Plate 5.2.1f: Cleaning of equipments

2. **Nitofill & Concresive 1315:** for filling cracks

Plate 5.2.1g: Nitofill)

Plate 5.2.1h: Concresive 1315

Plate 5.2.1i: Nitofill (mixing)

Plate 5.2.1j: Concresive (mixing)

3. **Nitomortar:** for sealing of cracks

Plate 5.2.1k: Nitomortar (hardener & base)

Plate 5.2.1l: Nitomortar (pouring)

Plate 5.2.1m: Nitomortar (stiring)

Plate 5.2.1n: Nitomortar application)

4. **Normal Mortar with fiber: -** It is a mortar prepared by mixing sand and normal Portland cement with ratio (1:3) and micro fibers. The fiber is used to improve dry shrinkage and tensile strength of normal mortar

Plate 5.2.1o: sand, fiber and Portland cement respectively from left to right

## Mixing Procedures

1) Mix Portland cement & sand thoroughly using a shovel according to mix ratio
2) Disperse the micro fibers in a water can ($0.6kg/m^3$)
3) Slowly add the water to cement-sand mix and mix it well
4) Apply it on the prepared substrate

### 5.2.2 Honey Comb Repair Work

- **Procedure of the repair work**
  1 Cut the defect area with grinder
  2 Chipping
  3 Cleaning with water jet
  4 Removing the corrosion by grinder
  5 Applying anti-rust paint
  6 Applying Bonding Agent (NITOBOND EP)
  7 Applying EMACO S88CT
  8 Curing

Plate 5.2.2a: Honeycombed surface

Plate 5.2.2b: Cut the defect with grinder to make small squares with 5cm sides

Plate 5.2.2c: Chipping or removing the deteriorated concrete

Plate 5.2.2d: Cleaning with water jet

Plate 5.2.2e: Applying anti-rust paint


Plate 5.2.2f: (Nitobond EP)

Plate 5.2.2g: Applying Bonding Agent (Nitobond EP)

Plate 5.1.2h: Applying EMACO S88CT placing and curing

### 5.2.3 Repair Work of Hole on Deck Slab

- **Procedure of the Repair Work**

1 Remove the deteriorated concrete around the hole with hammer
2 Construct the formwork( soffit )
3 Cleaning with water jet
4 Removing the corrosion by grinder
5 Applying anti-rust paint
6 Applying Bonding Agent (NITOBOND EP)
7 Placing EMACO S88CT
8 Applying Bonding Agent (CONCRESSIVE 1414)
9 Placing concrete treated with fiber(RHOFIBER)

Plate 5.2.3a: Remove the deteriorated concrete around the hole with hammer, construct the formwork (soffit), Cleaning with water jet and applying anti-rust paint


Plate 5.2.3b: Concresive 1414

Plate 5.2.3c: Applying Bonding Agent Concresive 1414


Plate 5.2.3d: Nitobond

Plate 5.2.3e: Fiber (Rhofiber)

Plate 5.2.3f: Applying Bonding Agent Nitobond

Plate 5.2.3g: Mixing concrete with fiber (Rhofiber)

Plate 5.2.3h: Placing concrete treated with Fiber (Rhofiber)

Plate 5.2.3i: Finished repaired concrete

### 5.2.4 Cracks Repair Work

- **Procedure of the Repair Work**

  **1** Cleaning the crack with water jet
  2 Sealing the crack with EMACO S88CT since the cracks more than 5mm
  3 Cleaning by grinder
  4 Cleaning with water jet
  5 Drilling holes a diameter of 6mm at 15 cm spacing
  6 Installing pipes in holes to a depth of 3cm
  7 Sealing the crack and the holes again with NITOMORTAR FC
  8 Injecting NITOFILL EPLV or CONCRESSIVE 1414
  9 Cutting the pipes with grinder
  10 Removing 5cm width seal from the crack for monitoring

Plate 5.2.4a: Cleaning with water jet

Plate 5.2.4b: Sealing the crack with EMACO S88CT


Plate 5.2.4c: Sealing preparation

Plate 5.2.4d: Cleaning using grinder

Plate 5.2.4e: Drilling holes diameter of 6mm at 15 cm spacing

Plate 5.2.4f: Installing pipes in holes to a depth of 3cm


Plate 5.2.4g: CONCRESSIVE 2200

Plate 5.2.4h: Sealing the crack and holes with NITOMORTAR

Plate 5.2.4i: Injecting Nitofill EPLV or CONCRESSIVE 1414

Plate 5.2.4j: Cutting the pipes with grinder

### 5.3 Debre Markos District, Kulech Wenz and Timberbada Bridge Repair Work

1. **Kulech Wenz Bridge**: It is RC-Box Girder type, located on D/Markos – Dembecha road segment, 17km from D/Markos town. It is located near to D/Markos town and the bridge river is wet by now, and it is located on a curve road alignment.

**2. Timberbada Bridge:** It is RC Deck Girder a type, located on D/Markos – Dembecha road segment 43 km from D/Markos Town. Timberbada River is wet at winter the water way adequacy is enough at all weather conditions. But the bridge is highly deteriorating and no proper repair has been done so far.

#### 5.3.1 Materials Used for Repair

**1. NitoBond EP**

It is special adhesive epoxy resin concrete bonding agent
1 can of base = 0.75Kg, and 1 can of hardener = 0.41Kg, then mix and apply at cleaned substrate.

Plate 5.3.1a: NitoBond

Plate 5.3.1b: NitoBond application

**2. EMACO S88CT**

It is a special mortar with RehoFiber to avoid crack due to shrinkage. One bag = 25 Kg of mortar mixed with 3.5 – 4 liter of water and will be applied over the NitoBond Epoxy bonding material. The RehoFiber shall be added to the mixed mortar.

Plate 5.3.1c: EMACOS88CT

Plate 5.3.1d: RehoFiber

3. **Renderoc TGXtra + RHEOFIBER (Polypropylene Fiber)**

It is another type of Polymer modified mortar with Rheofiber to avoid crack.

One bag = 25Kg of Renderoc TGXtra mixed with 4.5 liters of water and 8g of Rheofiber.

4. **Nitomortar FC or Concresive 2200**

   It is high strength epoxy coating Mortar. One Can of base = 4.965Kg mixed with one Can of hardener = 0.9Kg and applied over the crack, so that the crack will be sealed for injection.


Plate 5.3.1e: Concresive 2200

Plate 5.3.1f: Concresive 2200 (mixing)

Plate 5.3.1g: Concresive 2200 (mixing)

Plate 5.3.1h: Concresive 2200 application

5. **Nitofill EPLV** It is low viscosity epoxy injected in to the crack through the drilled holes by pressure.

Plate 5.3.1i: Nitofill EPLV

Plate 5.3.1j: Nitofill EPLV application

### 5.3.2 Timberbada Bridge Peel off and Rebar Exposure Maintenance


Plate 5.3.2a: Saw cut and chipping


Plate 5.3.2b: Grinding and removing of corrosion

Plate 5.3.2c: Cleaning by jet water and painting anti rust

Plate 5.3.2d: Applying NitoBond

Plate 5.3.2e: Applying EMACO S88CT

Plate 5.3.2f: Applying Renderoc TGXtra + RHEOFIBER (Polypropylene Fiber)

### 5.3.3 Kulech Wenz Bridge RC Deck Girder Crack

Plate 5.3.3a: Cleaning crack area by grinder and wire brush

Plate 5.3.3b: Drilling injection hole

Plate 5.3.3d: Sealing the crack by NitoMortar for injection by Nitofill EPLV or CONCRESSIVE 1414

Plate 5.3.3c: Cutting and inserting injection pipes

# 6 CONCLUSION AND RECOMMENDATIONS

## 6.1 Conclusion

In concrete bridge failures, reconstruction of the structure instead of rehabilitation for every defect or failure is very difficult in terms of money and construction. That is the amount of money involved for reconstruction of bridge is much and very expensive. In addition closing of the road may interrupt traffic flow, which has significant impact on the economy of the country especially when the bridge is on the federal road. So rehabilitation or maintenance of concrete bridges become very crucial and mandatory to stop failure of bridges before reaching their design period and to avoid unnecessary expense to construct a new bridge instead of maintaining and lengthen the service life of the bridge.

Proper design and construction does not mean that the bridge will serve about its design life. Because lack of inspection and controlling with minor rehabilitation may make the bridge to fail before serving to its maximum capacity. So monitoring, inspection, and maintenance of every concrete bridge have to be done starting from construction day before failure, which leads to erection or construction of a very expensive new bridge.

Unlike the practice we used to do before, concrete bridge rehabilitation techniques, materials and procedures are burning and crucial issue now a day, being many of the bridges are reaching about their design life and need rehabilitation before failure. Considering the urgency of the issue, the universities in particular and the country in general with the respective parties have to think of the problem and participate on provision of possible solutions. Although not satisfactory or to the requirement of the country, Ethiopian Road Authority (ERA) in collaboration with Japan International Cooperation Agency **(**JICA) has maintained some bridges within the last five to eight years.

Concrete bridge maintenance is not an easy task, because regaining the overall condition especially the structural strength of concrete bridge by simple plastering is difficult. So the use of different admixtures (modifying agents), additives (fine mineral powers) and epoxies is mandatory following the procedures and specifications given by the suppliers. At this time there are many suppliers for the construction company involved in maintenance or construction.

Considering the importance of concrete bridge rehabilitation on a national base currently, this study has done to address the basic defects, causes of defects, materials for maintenance and possible techniques and procedures of rehabilitation.

Before rehabilitation of any defect, inspection is the most important activity to know the types and causes of defects. Rating or ranking of the defect makes maintenance simple and avoids unnecessary expenditure of money. So, inventory and inspection of defects with corresponding ranking is the primary activity before performing any maintenance work.

Having bridges ready for maintenance, the next task is selection and preparation of materials involved for maintenance. The different materials used for maintenance can be grouped in to three categories.

(1) Cement type repairing materials: this is simply Portland cement mortar (concrete) or non-shrinkage mortar (concrete)
(2) Polymer modified cement type : this is cement modified using different polymers and fibers
(3) Resin type repairing materials: this is an epoxy or chemical used for repairing purpose

Before applying any repairing materials, the substrate that receives repairing materials has to be prepared and made ready to receive the new materials. Rehabilitation of concrete bridges is very wide, so that maintenance techniques of all bridge defects might be a course by itself. However during maintenance of any defect works; removal of concrete, surface cleaning, substrate preparation, and repair material application are the basic procedures that any worker has to follow.

## 6.2 Recommendations

The absence of detailed specifications and standards for rehabilitation of concrete defects makes maintenance difficult in Ethiopia. This is due to lack of repairing materials, unavailability of expertise on the field (no university or college is giving courses on concrete rehabilitation), and lack of awareness about the cost and related problems in erecting of new bridged as compared to that of rehabilitation.
On the contrary many bridges in the country are deteriorated and needs replacement or rehabilitation. That is why preparation of documents vital for rehabilitation and production of expertise about rehabilitation is mandatory. Materials involved for maintenance in addition to cement or concrete have to be produced in the country or imported from abroad.

Considering the limitations to perform maintenance and the urgency of the need of maintenance the country in general and the universities in particular should take the assignment and shall forward relevant contribution towards rehabilitation. So:

- The universities shall incorporate concrete maintenance courses in the department, so that the country can have professionals or expertise on concrete rehabilitation.
- The universities and respected officials shall discuss and forward proper specifications and manuals for concrete rehabilitation.
- The universities shall prepare course material or module on concrete rehabilitation.

- Materials required for maintenance should be imported if not available in the country or the government should encourage domestic investors to produce locally.
- Workshops shall be prepared, so that well trained professionals will be produced in addition to creation of awareness about the topic for the related industries.

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