Government of Nepal

Ministry of Physical Infrastructure and Transport

DEPARTMENT OF ROADS

Guidelines for Inspection and Maintenance of Bridges

Vol. 2 - Minor Repairs (Recurrent Maintenance)

Waterway and Bridge Protection Works

Sub Structure

Superstructure

Components, Ancillary Items and Protective System

Concrete Repairs

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श्री ५ को सरकार

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1. Procedures for the Inspection and Maintenance of Bridges, June 1996
2. Guidelines for Maintenance of Highway Structures, Part 2-Minor Repairs to Bridges, March 1997

Organization of Guidelines for Inspection and Maintenance of Bridges

Volume 1: Procedures for Inspection and Maintenance, Bridge Inspection Manual, Guidelines for Routine Maintenance

Volume 2: Minor Repair (Recurrent Maintenance)

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1. INTRODUCTION

1.1 GENERAL

Procedures for Bridge Inspection and Maintenance, Bridge Inspection Manual and Guidelines for Routine Maintenance are described in Guidelines for Inspection and Maintenance of Bridges Volume 1. Routine Maintenance tasks, which are preventative or bridge servicing operations undertaken at given interval, are given in the Part 2 – Routine Maintenance of Bridges of the guideline. This volume of Guidelines i.e. Guidelines for Inspection and Maintenance of Bridges volume 2 Minor Repairs (Recurrent Maintenance) are introduced in order to formalize the procedures for minor repairs.

Repairs to small defects are not necessarily beyond the scope of routine maintenance activities. These minor repairs are remedial works which may include renewal of structural elements or components which have become unserviceable because of wear and tear or have deteriorated for other reasons. The general operations that have to be carried out during minor repair works are described in this volume and the tasks are grouped to Recurrent maintenance works. These operations may not be appropriate in all circumstances and may need to be modified by taking account of local conditions and the characteristics of the individual structure.

The items of minor repair work described in this guideline should be regarded as those which fall generally within the technical capability of the Division staff. This guideline also contains some maintenance activities which are beyond the scope of minor repairs. They are incorporated herein with a view to assist the Division maintenance team about what is to be performed next, if it is beyond their maintenance capabilities. Repairs of a highly technical nature should be carried out with the coordination from the Bridge Unit and through a specialized consultant. There is a danger that unskilled maintenance staff can do more harm than good carrying out minor repairs to damaged bridges. Personnel must be trained to carry out repairs in accordance with correct procedures or the repair works shall be carried out by the specialist contractors short listed.

Repair work on special structures, such as cable stayed and suspension bridges, is generally outside of the scope of these guidelines except when appropriate to common components or parts. Prior to any repair to special bridges such as Karnali Cable-stay Bridge and the Mugling, Marsyangdi and Bheri suspension bridges, reference should be made to the specific maintenance manual where these exist.

1.2. OBJECTIVES

The objectives of a bridge repair programme are:

1. To ensure road safety for the road user.
2. To maintain the load-carrying capacity of the bridge and continued serviceability for as long as possible.
3. To maintain the capital asset value of the crossing for as long as possible.
4. To ensure economic management of limited maintenance funds (by prioritization of repair and comparing present repair cost with respect to future rehabilitation or replacement costs.)
5. Minimizing road closure due to bridge traffic unsafe breakdown.
6. Providing comfort and reliability to the road user.
7. Maintain acceptable standards of appearance.

1.5 EFFECTIVE MAINTENANCE PROCEDURES

Although many of the tasks listed in these guidelines are fairly minor in themselves, failure to carry them out may lead to rapid deterioration of the structure, and the need for more serious repair operations in the future. Prompt action shall be taken whenever maintenance is required.

Before undertaking any repair, it should be tried to determine the cause of the problem, whether it is due to impact damage, premature failure of a component part, design or construction defect or fair wear and tear. It may not always be appropriate to replace "like with like" and an alternative solution may be called for. Always various ways are looked to improve the performance of the structure.

The work need to be planned in advance with particular regard to access and safety. As with all road works the safety of the bridge maintenance crew and that of the vehicles and pedestrian traffic on or near bridgeworks is of paramount importance. Temporary works must comply with safe working practice. For the duration of the work warning signs, lights, barricades, delineators and if required traffic control flag-men must be used. Workers should have appropriate personal safety equipment such as hard hats and reflective vests, etc. The first volume of the guidelines "Part 1: Procedures for the Inspection and Maintenance of Bridges" shall be referred as safety guidelines.

Should repairs require restricted or complete closure of a bridge sufficient notification should be issued in advance to the public, police emergency services and other authorities. This may involve newspaper advertisements, radio bulletins or letters from the respective Division Chief.

Disturbance to the environment should be kept to an absolute minimum. For example, the unnecessary removal of vegetation may destroy protection cover and promote soil erosion. On completion, the work site should be cleared of all rubbish, spoil heaps, scraps of materials and the like.

It is beneficial to establish a habit to audit previous repairs to see if they have been effective and review the repair procedures to improve performance.

1.6 BRIDGE MAINTENANCE SYSTEM

Many Bridges are suffering premature loss of strength resulting reduced functional life due to inadequate Maintenance. Department of Roads Bridge Policy addresses the strategy for Bridge Maintenance and Emergency Work. A bridge maintenance system has been introduced in the department. The Department is updating the Bridge Inventory and making condition survey of preliminary assessed critical.

The Department has recently established an interim survey for routine bridge maintenance works based the routine maintenance operations set in the first volume of this guideline.

For recurrent maintenance of bridges, current practice is to set a lump sum 20% amount of total recurrent road maintenance work for Causeway, Bridge, Road signs, Delineation Parapets, Guard rails, Gabion Crash barrier, km post and road marking paintings (see the Norms for Recurrent Maintenance of Paved Road in the appendix). We must now start institutionalizing the recurrent maintenance works. The Division Office must do Routine Bridge Inspections every year and Superficial Inspections as often as required. The Bridge inspection forms and the summary shall be used to prepare the minor repair work needed to carry out and the cost estimates. The Format for item-wise cost estimate is provided in the volume 1, page 18 – 20, of this guideline. The recurrent maintenance works and other major works should be then programmed and budget requested.

The Standard Specification of Roads and Bridges and the approved norms shall be used as far as practicable. A Bridge Maintenance and Repair is often a small-size specialized work, additional provisions may need to be added to these specification and norms. Manufacturer's detail often may have to be referred.

2 WATERWAY AND BRIDGE PROTECTION WORKS

(River Channel, Stream Bed and Banks)

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2.1. INTRODUCTION

A structure is only as stable as the foundation that it rests on. Many rivers are generally scour prone and considerable efforts are required to maintain the stream-bed in a condition which does not aggravate the tendency to scour and undermine bridge foundations. Alluvial channels in particular, have a tendency to shift their locations, often resulting in adverse scour effects on bridge foundations. When water-borne debris is abundant, channel blockages are common causing damage to bridge superstructure during high floods. Abutments, piers and embankments and the waterway channel must resist the resultant forces and abrasive degradation from the fluctuating flow and bed load.

The imposition of bridge on waterway is not the only cause for change in the river channel and scour is not the only result. The river channel is naturally dynamic and scours and deposits material in a continuous process toward equilibrium. The engineer should be aware of the possibility of these changes, particularly in unstable and geologically young environments.

Some common problems in the stream bed and banks along with general solutions which are effective in certain conditions are given in the succeeding paragraphs. The costs to these works sometimes become very high. A competent expert should be consulted in case of major problems.

2.2. TIMING OF REPAIRS

As a rule where river protections are required working conditions can be difficult. The defense structure is usually placed on an embankment slope or in the channel and under rapidly flowing water. In this respect the first consideration for a repair is to ensure that any construction work is undertaken during the driest season available, when the water is at its lowest level.
The works however usually suffer initial damage during floods. Further deterioration can occur rapidly in flood situations and often the Engineer in the Division Offices may need to employ contingency measures for a prompt, emergency repair.

2.3. LOCAL DAMAGE AND MATERIAL FAILURES

Many protection works comprise rock placing, either loose as rip-rap, contained within Gabion mesh or bound together with cement to give rock-walling. For abrasion resistance the Gabion basket may be concreted either whole or in part. The problems encountered involve rock loss from plucking, scour, or failure of the Gabion wire mesh. Sometimes this is age related where the Gabion wires have deteriorated with time or vegetation has broken through the rock armouring.

Prevention and Control

For simple local failures, prevention can be done by replacing the rock. With Gabion baskets either revise or repair the basket completely depending on if the cause was local damage or general deterioration. Simply replacing Gabions is not always the answer if they have failed prematurely from inappropriate design, for example if they are being used where the flow is too aggressive. An alternative solution may be better. Gabion techniques are discussed in greater detail later in the chapter. Disruptive vegetative growth should be removed as early as possible before it becomes established and becomes increasingly difficult to remove. Judgement should be exercised with vegetation removal, in some situations the vegetation can act as a flow retarder, thereby reducing scour effects. It can also hold the slope together preventing soil erosion.

2.4. SLUMPING OF PROTECTION WORKS

The general cause of slumping of protection work is due either to scour or the washout of fine materials from behind the works. The cause must be established before attempting the repair as an inherent design and/or construction fault may result in repeated failures. Problems can occur in vertical and sloping revetments and check dams where the works are founded on erodible or fine permeable materials. In flood conditions flow paths through and under the construction cause fines to be washed out resulting in settlement often leading to complete failure.

Prevention and Control
Check dams are well founded with adequate aprons and cut-off walls. They also must be tied into strong bank protection works to prevent outflanking (breaching in between the check dam and river bank). Serious consideration should be given to the incorporation of a drainage blanket to prevent the migration of fines. Relevant techniques are discussed later in the chapter.

2.5. DEPOSITION AND DEBRIS REMOVAL

Obstructive deposits in a stream bed can deflect the water current against abutments, piers or embankments causing scour problems. Debris accumulated at the bridge opening may catch more debris until the stream becomes partially blocked. Flooding could then wash out approach embankments or damage the structure.

Prevention and Control
All drift, debris, logs and trees are cleared at the bridge and also at upstream and downstream reaches. Particular attention should be given to debris or other obstructions which introduce turbulence near to the structure, cause flows to be other than parallel to the axis of the piers and abutments or which deflect the Current against approaches and banks such that the stream could wash them out.

The channels are cleared when the water level is low using labour or equipment as required. Bulldozers and front end loaders are appropriate for large scale work, sometimes working with cranes. Controlled blasting may be necessary for rock obstructions. At sites where debris is a frequent problem permanent right of way for access may be advisable. In particular, causeways and flood-ways need such regular maintenance to prevent blocked floods from causing structural damage.

2.6. ENCROACHMENT

Encroachment is any work near a bridge structure that adversely affects the performance of the bridge/waterway. Examples include building, cultivation, roads constructed under bridges. All of these restrict the waterway in flood conditions. Uncontrolled removal of sands and gravel deposits increases scour problems at bridges and are forms of encroachment. Another example is the disposal of solid waste along the bridge approaches as can be seen at some bridges in the Kathmandu Valley. The problems are usually caused by third parties where as some bridge protection works themselves create obstructions and excavations cause problems by being built too far into the channel or above the natural scour level.

Precaution and Control
The optimum approach is to discourage encroachment before it becomes established at the site. It is much more difficult, time consuming and expensive, to remove the encroachment after it occurs. The only recourse to encroachment is to remove the obstructions where these are removed, or where excavations have taken place either to allow the river to fill them in naturally or, if necessary, to have them filled in.

1.7. EROSION AND SCOUR

Undermining of the piers, abutments, approaches or channel protection may result in serious damage. In the case of the bridge it could result in settlement and serious damage to the bridge. Erosion may also result in the reduction of friction pile stability since it removes some of the material from the friction area. Bearing piles may become unstable due to scour. The lowering of the bed level of the rivers in the Kathmandu Valley exposing pile foundations is a prime example.

Erosion is caused by river action on the bridge substructure. It is increased whenever the orientation of the pier and flow differ. It is also caused by the constriction of flow at the bridge site, irregular geometry of the stream, stream- bed material, bank material and size of the piers. It often occurs during a flood flow when a large discharge moving at high velocity acts on the stream bed, carrying away large quantities of material thus lowering the elevation of the bottom of the stream.

The effects of erosion are particularly evident after rare and unusual floods. Many complex factors interact to cause stream beds to erode, shift alignment and change profile. Expert advice should be obtained before attempting to correct a serious erosion problem.

Precaution and Control
Many different methods are used to control and prevent erosion. The methods outlined in this chapter represent only a few options which are general in nature. It is recommended that expert advice be obtained in determining the specific method which should be used.

The repair involves slope protection, toe protection, river bed protection and realignment/channelization of the river. The choice depends on the extent and nature of the problem. Slope protection measures must be undertaken when erosion is observed at the river bank adjacent to the abutment. When lowering of the river bed and local scour occur at the bridge pier or abutment river bed protection is undertaken. Realignment/channelization work must be undertaken when the bank of a meandering river is seriously eroded within the bridge reach.

Before describing the details of repair methods the principles of selecting bank protection and training works should be stated:

- The costs should be comparable to the benefits to be derived.
- Permanent works should be used for important bridges on main roads and where the result of failure would be unacceptable.

- Temporary or expendable works may be used where the traffic volumes are light, alternative routes are available, and the risk of failure is acceptable.
- Designs should be based on channel hydrology and on experience with similar situations.
- The ultimate effects of the works both upstream and downstream should be considered.
- Site reconnaissance by the designer is desirable, supplemented, and possibly substituted, by aerial photograph study.
- Wherever possible the minimum amount of river training work is advocated if the consequential effects on the river regime are unpredictable.
- It is important to maintain, extend or amend the work if needed, particularly in the immediate post construction years.
- Each site should be considered as unique as the technical and economic circumstances will always differ.

2.8. REPAIR METHODS FOR EROSION AND SCOUR

Methods commonly adopted in bank protection and river training works can take the form of:-

- Bank and Slope Revetments
- Bulkheads and Walls
- Groynes and Embankments, Dykes and Guide Banks
- Pier Foundation Protection Works
- Vegetation
- Check Dams

Often a combination of a number of forms, techniques and/or materials are used.

2.8.1 Bank and Slope Revetments

Bank and Slope Revetments may be either a natural bank or a slope graded fill. They may be located at an abutment, along embankments adjacent to the crossing or along the channel edge. Following common methods are employed in the bank and slope armouring system.

- Sand Filled bags
- Riprap
- Gabion mattress (Reno mattresses)
- Rock placing
- Concrete block works
- Grouted works, particularly as above mentioned methods
- Placing of vehicle tyres, oil drums etc.

The controlling factors which determine the necessity for, and extent of, armouring to the revetment are:-

- erodability of the embankment material
- stream velocity at design flood discharge and the angle at which the flow meets the bank (either parallel to or impinging against the bank)
- the slope of the bank,
- the bank height

i. Sand Filled and Sand Cement Filled Bags
Sandbag construction is a long established technique particularly for emergency situations. They are tend to be better suited to temporary work and light to medium duty locations on shallow slopes. The life of a system is subject to deterioration of the bags from sunlight, and, to some extent, from impact damage and vandalism, resulting in spillage of material. Flushing of individual bags soon causes the development of local failure which will progress rapidly if left unattended. The successful use of sand filled bags is improved with attention to the following:

- improvements in stability is obtained with large bags where puncturing by debris or vandalism is not a problem
- for reasonable life the fabric must be UV resistant
- bags must have a stable foundation and a stacking system for structural stability
- bags should not be overfilled as this decreases [illegible] ability

An extension to the sandbag technique which overcomes the inherent weakness of the fabric in sandbag construction is to fill the bags with sand-cement grout. The higher specific gravity and rigidity of the grout filled bags also increases stability and resistance to external damage. This is a well established technique, sometimes referred to as bagwork construction. As soon as the grout hardens, the strength of the fabric is no longer a factor. The bags merely serve as sacrificial, flexible forms for the concrete. A particular advantage in using concrete bagwork is in placing the units underwater where the bag prevents the cement from being washed out of the concrete mix.

As with most river protection systems toe scour and embankment slumping can be problematic. A good key way to [illegible] to combat scour and prevent collapse. Scour resistance can be increased with a rip-rap launching apron of dumped rock if key way depth is insufficient. Use of a geotextile can control slumping whilst an insertion of PVC drainage tubes at suitable intervals to act as pressure relief outlets. Bagwork construction is very labour intensive and it requires a high degree of maintenance. Small local failures soon expand into wider area of collapse in a continued flood unless there is prompt response to rectify damage. Wash out of fines is a common problem under the river flow. Large hollow cavities are created over a period of time and often noticed only after collapse.

It is possible to build the embankment by raising the fill height with the bagworks. This helps to secure the embankment toe and lower sections during a sudden flood and the work remains safe as long as the flood does not overtop the work.

ii. Rip-rap
Rip-rap or stone pitching is one of the more successful armouring systems. Rip-rap should consist of a gradation of rock. The smaller rocks are necessary to bind the larger rocks and fill the voids. Sometimes from a quarry source the material may also be sourced from a river bed provided its extraction does not detrimentally interfere with the river regime.

The irregular shape of the quarry material is more suited to the purpose than rounded river bed material. The rock performance is related to density, ability to resist degradation and the rock size or class needed to resist the effects of flood waters.

In the case of a bund with an armoured face, over-topping can damage the unprotected face by washing away, possibly leading to collapse. Where over-topping is likely, the bund height should be increased.

iii. Rock Placing

The method of placement must be compatible with the intended design performance. A footing trench, or key way, should be excavated along the toe of the slope. It is not necessary to excavate into hard non-erodible strata should it be encountered as this itself forms a naturally erosion resistant bed. Key ways can be dug with crane and [illegible] or backhoe.

Rock Placing is carried out in three different ways: end dumping by truck, crane skip placement and crane placement of individual rocks on large rock protection works. End dumping is the least expensive placement method, more suited to shallow slopes. As material will segregate it may be necessary to place smaller material first followed by larger on the top surface work the material by hand or backhoe after tipping to produce the design layer grading. Care must be taken to avoid any damage to geo-textiles incorporated as a filter medium.

The crane and skip method of placement is more expensive than end dumping but reduces segregation and hence calls for less finishing work when smoothing out the rip-rap. Individual rock placement is the most expensive and is used to place very large rip-rap (5 tonnes and over) in areas where proper placement and stone fitting is critical to the performance of the protection works. The rocks may be drilled and fitted with lifting bolts to assist handling.

The most important rule in laying a protection on a slope is always to lay the toe stones first and work up the slope.

iv. Reno Mattress (Gabion Mattress) and Gabion Basket

In the situation where the design class of rock armouring is unavailable, a Reno or Gabion mattress can be placed. The saving on winning, supply and transportation of rock can offset the cost of baskets. Mattress size and thickness can be matched from available stock to suit the design requirement. They are most effective when used with a filter particularly a geotextile. The launching apron technique is an appropriate form of embankment toe protection. By using crane and handling frame, filled sections of mattress can be lowered directly into the stream flow to avoid the need for placing underwater and to increase the working reach into the channel.

This form of construction is not always successful and should be used with great caution as there are a number of disadvantages. These disadvantages and other details are covered further in the section on Gabion construction.

v. Concrete Blockwork

Various sizes and shapes of concrete blockwork modules can be utilized in revetment protection. The advantage of the block system is its simplicity of installation without the need for heavy plant. However large unit sections may need the application of crane and frame. They are mostly placed as a single layer over a filter fabric to make them cost competitive with heavier revetment systems. Modules used include [illegible] and hollow concrete building blocks which are reported as performing well in comparison with other forms. Transportation of the blocks to the site can be a significant cost factor, but in some situations it may be possible to cast in situ if material and labour is available. Factors to be considered in block construction include:-

- design size and shape suitable to the site conditions
- shallow slope for both stream flow forces and to resist embankment slumping
- environmental considerations including ability to resist impact and likelihood of theft

Filter Material
The success of protective systems is largely dependent on maintaining the integrity of the channel bed and bank. Stream action, water level variation and natural ground water flows can progressively draw out the finer fraction from the soil mass through the voids in the face stone. There follows a consequent increase in instability and eventual collapse. The loss of the finer fraction may well have been allowed in the design. An example of this is the use of a launching apron where washed out material is replaced by more stable rock stones. In other cases loss of fines must be prevented by the use of a filter blanket. There are three basic methods of providing this layer:-

1. By placing two or more layers of progressively coarser material between embankment and rock slope. Each layer is uniformly graded. Unfortunately the filter layers are often difficult to place on a slope and are all too easily displaced by uncontrolled dumping of subsequent layers or the flow action of the water.
2. When quarry run face material is dumped into place most of the finer material naturally settles against the embankment face with coarser stones working towards the outside. This avoids the need for a filter material. It is preferred due to its simplicity in installation.
3. The filter medium can be provided by a geotextile which replaces either all or part of the filter layer system. The use of a geotextile is recommended wherever possible as it provides efficiency in construction. The placing of the finer fraction of a graded granular filter structure may be impossible in a rapidly moving river and a geotextile may be the best solution.

2.8.2 Bulkheads and Walls

Bulkhead and wall construction is an alternative to revetment construction, generally serving the same purpose and employing many of the same materials with some additional techniques. There are different design considerations as the retained materials have increasing influence on the structural form as do the hydraulic forces from the waterway. The span of bridged structures is reduced where vertical abutment walls are used in preference to a sloped revetment. The site may preclude a sloped embankment, for example where a road runs alongside a waterway and it is not feasible to bench it into the hillside. They are used where there is insufficient room to batter the waterway bank side, the river banks may be too steep or the vertical wall may simply be the most economic or viable form of construction. Some of the more common systems include:

i. Rockwalling
Rockwalling is mass wall construction using stone from either a quarry or river bed source. It can be dry pitched, cement grouted or a combination of both. If dry pitched a geotextile fabric or filter layer is recommended to prevent fines from being washed through the wall. The material behind the wall contributes to long term stability. Cement mortared rockwall may avoid the need for a geotextile but may require weepholes for pressure relief and is less flexible to settlement than dry wall construction. Dry wall construction

is more limited than cemented and built systems will be limited to the practical height that can be attained. Stream flow forces against a vertical or near vertical face will be greater than with revetments. Undercutting of the toe may result in severe collapse.

ii Gabion Wall

Gabion wall construction is suited to steep or vertical banks, producing a mass construction reinforced by the interlocking action of the baskets. A fabric filter behind and beneath them is recommended. Scour protection is enhanced with a mattress at the toe of the construction. The system lends itself to labour intensive methods. In severe or emergency abutment washout situations Gabion construction can provide a controlled response. Where log impact or other damaging debris can split the wire baskets, a concrete cover to the baskets will strengthen the mass of the structure.

iii Concrete Walls

Concrete walls may be part of the abutment or wing walls of the bridge structure, either in the form of mass concrete or reinforced concrete retaining wall. When intended to act as a bank protection system they tend to be limited by cost and construction time. Structures need to be well founded to transfer loads to the bearing strata of the soil and to avoid scour damage. Pile foundations have lesser problems of scour. Concrete walls for river training are not very common in Nepal.

iv Pile Wall System

A piled wall structure can be formed using concrete, steel or timber piles. The piles are usually driven but may be bored and in situ in case of concrete piles. Scour protection by piled wall is not common in Nepal due to specialized techniques needed, higher cost, and the seismic locations. However, pile foundations have been increasingly used for the bridges recently.

Sheet pile construction calls for a reasonable engineering design input with consideration given to soil factors, imposed loading, scour and other hydraulic factors in order to determine the depth of embedment of the pile and pile section properties. Specialised techniques and equipment are needed for the installation. Sheet piling became very difficult in the ground which consists of large cobbles and boulders. Work of limited extent may employ the use of less specialised steel sections such as trench sheeting.

Timber, either in the form of straight logs or sawn lumber is a useful material because of the ease with which it is fastened together for fabrication. Where the timber easily and cheaply available this method can be used. A number of efficient and portable tools are available to facilitate the preparation of cut sections. Proper design and installation of the structure and its connections are required to prevent structural failure. Structures retaining fills need to be sand tight and this can be provided by tongue and groove sheet piles or a backing of sheathing planks with filter material. Timber has comparatively shorter lives but it can be extended by treatment of a good preservative. Structural properties vary with the type of timber, the nature and duration of seasoning, preservative used and its environmental exposure in the structure. The metal connectors, when used between the pile sections, may be galvanized.

Sheet pile systems are anchored back for stability if the design penetration can not be achieved or for reasons of economy. Anchorage systems vary from buried timber logs, driven anchor piles or continuous concrete ground beams depending on particular requirements. The ties, steel strand cables for example, are tensioned either by 'Spanish windlass' or by placing back fill. Steel bar with threaded ends for tensioning and adjustment.

are incorporated into more formal structures. Galvanizing and/or Denso tape provides corrosion protection to the ties. In deep sheet pile walls a number of anchorages are installed at different levels. The frequency of ties in the horizontal direction is a function of the design.

The sheet pile can also be installed to protect only the toe of the work against scour rather than to support the full height of the soil mass. The upper soil mass is supported by other protective systems.

A further alternative combines piles at greater centres with horizontal bulkheads spanning between the piles. Bulkhead depth is required to be sufficient to prevent scour.

2.8.7 Groynes and Embayments, Dykes and Guide Banks

Groynes and Embayments, dykes and guide banks employ techniques that attempt to control the meandering river, improve the flow of flood water and restrict the occurrence and extent of scour at the bridge crossing.

i. Groynes

Groynes are walls projecting from the bank side into the river channel. Their purpose is to protect the bank side and structures by directing the flow in the channel either away from or towards the bank in which they are located. This is achieved in the former case by inclining the projecting groyne upstream, and in the latter case, downstream. A single groyne may achieve the intended purpose of diverting the flow, but usual effects are more appreciable. Placed in series they are used to repel or attract flow with reduced scour. Groyne design is controlled by a number of factors incorporating crest height, depth of flow, path of the river in flood, river banks and bed material. Their length and number is determined by economic considerations as well as hydraulic constraints. Shorter length groynes will call for closer spacing whereas longer units can have wider spacing. In general the length of the groyne will not exceed more than one quarter of the channel width for bank protection work. Specific formulae have been developed for the determination of the spacing of groyne groups. From a practical viewpoint the longer the groyne and further it projects into deeper water the greater will be the scour at the end of the groyne. It follows that construction of the longer groyne will be increasingly problematic where this is undertaken in water. Construction in the dry season or temporary bunding decreases cost and risk.

Groyne construction may be permeable or impermeable and many of the techniques reviewed within this Chapter will be viable. Systems may comprise rip-rap, Gabion wall, pitched wall or tyre wall. The design of the groyne takes into account the flow forces acting upon them as well as the scour action on their fabric. Positioning is determined from a study of the river regime and experience. The advantages of using geo-textiles under rip-rap and Gabion work should be carefully assessed. Damage to groyne structures is not critical as it does not involve direct risk to the crossing structure. They should nevertheless be properly maintained to continually perform as intended. Negligence eventually threatens the area they are meant to be protecting.

ii. Embayments

Groynes can be used to encourage sedimentation of bed material in the silt laden river. The embayment takes this concept one stage further. Embayments have been developed as a river training scheme control technique with the objective of establishing waterways on a desirable alignment by developing new banks and/or protecting the existing banks. This can involve comprehensive schemes for the overall control of the outside of a river. The river is established on a suitable combination of alignment and width past the eroding banks. Following considerations shall be made:-

- the existing configuration of the river is followed as closely as possible
- guidance of the river is achieved by the plantations of dense trees between the selected course and eroding banks
- protection for the trees is needed until they are established. This consists of installing retarding barriers, the upper level of which is about one metre above low flow levels
- provision of an adequate width of river channel adjacent to these works is essential
- the barriers retard the flow outside of the desirable width and alignment resulting in the deposition of bed load within the [illegible]
- trees consolidate the deposits and take over from the barriers which deteriorate as time lapses

An essential feature of river control work consists of clearing the tree growth in the channel and removing fallen trees. This removes major obstructions from the waterway which may otherwise divert and concentrate flows against vulnerable river banks.

The determination of the hydraulic geometry establishes the desirable channel width corresponding to the dominant discharge, which is compared to widths of nearby stable reaches. If the new channel is made too wide then low flow meanders develop, and if too narrow, high velocities develop.

It should be recorded that in the more aggressive rivers this technique has met with only limited success, particularly the lighter stone filled wire mesh cylinders. The works are particularly vulnerable to damage from river debris during and immediately post construction and require appreciable maintenance. The [illegible] were found to fill with sediment quite quickly, but the selection of plant is critical. As a general rule, the vegetation that is already established growing in the vicinity of the works is selected. The actual positioning of the river training work was evolved from aerial photographs. A series of aerial photographs taken at different intervals over a number of years is invaluable in establishing the development of the channel and forecasting river meanders by identification of vulnerable and critical points.

iii. Dykes

Dykes are embankments or bunds which run parallel to the river channel and are intended to prevent inundation of the land behind them when the river is in flood. As such they are constructed to a height to prevent over-topping. For economic construction they should be located well back from the main flow of the river where the lower flow velocities can be contained by work of lighter construction, such as a gently sloping revetment.

iv. Guide Banks

The guide bank, or spur dyke as it is otherwise known, is probably the best form of protection to both abutment and piers of a river crossing. They protect the bridge and approaches by guiding and confining the flow through the bridge opening. Its modern form as presented in recent texts originated from laboratory research in 1960 at Colorado State University. Guide banks may be used to:-

- confine the flow to a single channel in braided reaches
- improve distribution of discharge across waterway opening

- control the angle of attack on piers
- break up meander patterns
- prevent erosion of approach roads
- distribute concentrated flow at the abutments away from the abutments
- reduce mean velocity adjacent to abutment and decrease the turbulence, thereby reducing scour at the abutment.

Guide banks are used on meandering and braided rivers whose widths are greater than necessary to take the flood discharge, and to reduce the scour at the bridge where approach embankments extend into the flood plain.

There are a variety of plan shapes for guide banks. Original research recommends an elliptical shape with:-

- minor axis along upstream road shoulder
- side slope of (?) tangent to the abutment in the case of spill through abutments or revetments
- aspect ratio of major axis to minor axis of 2.5

Generally the guide bank will extend upstream equivalent to three quarters of the width of the waterway opening and downstream by one quarter. In estuaries the banks may be symmetrical. A greater upstream length may be necessary to control larger upstream meanders, and these may be combined with armouring to the bridge approach embankment. The minimum width between guide banks is selected to provide the waterway area through the bridge to accommodate the design flood discharge. Where one side of the waterway flows adjacent to a hard non-erodible bank, then only one guide bank will be needed. Two would be required if constructed in the flood plain or if the bank is erodible. Guide bank construction will follow the features of revetment construction reviewed earlier in the Chapter. Bank slope, height and armouring are determined to suit the flow conditions.

3.8.4 Pier Foundation Protection Works

Most of the techniques and procedures so far described apply to direct or indirect protection to the bridge abutment. Piers located within the waterway will need suitable protection from scour if they are not designed for predicted scour level and/or founded below predicted scour level. Protection works are commonly in the form of a rip-rap apron or Reno mattress. It should be noted that the top of the protection works should not be placed lower than the general scour level. If there is no rock source available the foundations may need to be protected with sheet piling to prevent scour. Rip-rap sizes and thickness of Reno mattress must be adequate for the flood flow conditions.

Back-fill to excavations in the river bed must be with material similar to that removed unless specified otherwise by the designer. For example a clay should not be used as back fill to a pier excavation in a sand bed, since the clay plug could become an obstruction to flow and increase local scour. Temporary sheet pile cofferdams should be removed or cut off at the bottom of the general scour level or top of footing level. Any temporary works left in place will need to have been taken into consideration in the design. The use of temporary bunds or berms to divert the flow from the excavation is common. They too must be removed after construction and the river channel restored to its original or desirable formation.

2.6.3 Vegetation

Vegetation is a bank protection medium in its most natural form. By increasing the channel roughness it retards the flow velocity of flood water, minimising erosion. Strong, deep root systems reinforce the bank side against scour. Natural vegetation which serves as protection against erosion should be preserved during construction, and due consideration should be given to the effects of alternative construction procedures on the natural regime of the stream and on the biological habitat. Vegetation can be developed as part of the bank protection or river training measures. This is described in the section on Embankments in this Chapter.

2.6.4 Check Dams

It is a common form of scour protection in Nepal. It has been used in many rivers in Kathmandu valley in order to arrest the lowering of bed levels. It is basically a retarding barrier which helps to restrict the migration of bed material in steeply flowing locations. They are generally provided at the downstream of the bridges. They help to restore the bed levels by deposition when they are constructed at heights above the bed levels. They are considered to protect the bridge foundations as well.

The common form of check dam construction in Nepal is gabion which is found to breach out quite often. Construction by reinforced cement concrete, sheet pile are more of permanent nature. It is recommended to be used in conjunction with local foundation scour protection.

Modes of Check Dam Failure

Failure of gabion check dams are common. The consequences of failure can be very serious often resulting in considerable erosion of the river bed and adjacent land. The failure mechanism can be rapid as serious scour can be generated within days or even hours as the river drops to flood scour level. The three most prominent failure modes are:

- material degradation
- settlement (leading to slumping and/or rotation)
- outflanking

Gabion construction although easy to build, has a limited life as the constituent materials degrade. Use of Gabions are discussed in greater detail later in this chapter including the disadvantages. Once the Gabion check dam starts to break up the whole of the bridge and surrounding area is at risk.

Piping action during even modest flows can draw out fines from beneath the check dam, resulting in settlement and/or overturning.

Any bridge protection work is only as good as the weakest point. Even if the check dam is well constructed, the adjacent banks may be weaker and can fail if over-topped. The check dam is then out-flanked and the scour pattern develops rapidly adjacent to the check dam construction.

Practical Check Dam Construction Using Gabions

Where Gabions are employed for check dams, a few simple rules must be observed.

First, the construction should mitigate against the effect of a flow path forming under the construction, with resultant slumping. To do this the dam foundation should be keyed into a material that does not readily scour or is impervious to water flow. Cut off trenches should be employed and the foundation trenches made long enough to resist the formation of a flow path.

The height of the dam should be increased gradually, allowing the bed level to grow with the work. If the height of the initial check dam is too high it can create an obstruction and encourage outflanking. This failure mode, and overtopping, was observed at a number of locations in the Kathmandu Valley.

It is not necessary to construct the check dam to a level profile. In fact it is not only easier but more desirable to have lower sections along the length of the dam. This will help in construction and will assist in maintaining the river along a natural course. For example the centre of the river channel is normally lower, being the area of highest flow. It is desirable to maintain the flow pattern therefore the check dams should be lower at this location.

The construction of the river banks adjacent to the check dams should be at least as strong as the dams themselves, if not stronger.

Finally the weir must be maintained and strengthened where necessary with broken areas repaired.

2.8.7 An Overview of other Techniques

There are a number of techniques that have not been discussed and deserve inclusion. Channel straightening or the cutting of a straight new channel between meanders has been undertaken successfully on a number of occasions. Another important technique involves the adoption of a policy to accept the possibility of washout, in the meander temporarily severing the approaches, but maintaining the bridge intact. This is achieved by maintaining the bridge high relative to the approach roads and permitting a major flood to pass over the road in a predetermined location. The acceptance of some damage to the road is less costly than to replace the bridge. The adoption of this policy will, of course, be controlled by the physical constraints of the site.

2.8.8 Gabion Construction

Gabion Baskets and Reno Mattresses are essentially compartmentalised rectangular baskets made from wire mesh, producing a structural form when packed with stone and interconnected. The strength of the Gabion basket lies in the mesh, and the design commonly employed today was developed in Italy. The Reno mattress was originally produced just before 1900 to repair a breach in the River Reno. The baskets are readily made in Nepal from galvanised wire. The baskets vary in sizes with commonly used thicknesses of 0.3 m, 0.5 m, 1.0 m. The sizes are fixed to suit the specific requirements.

Product specification will present a variety of wire mesh forms and wire gauge thickness including hex mesh. The life of the mesh can be extended by protective coatings such as PVC or galvanising. Demonstration tests in the US suggest that PVC coated wire lasts longer than galvanised wire, even in freshwater. Much of the integrity of this form of construction comes about when individual units are tied together to form a mass structure.

The Gabion system has a number of uses. In the simplest form the baskets may be used as bridge abutments, particularly for timber bridges. They may comprise the whole substructure of abutment and wing walls.

They can be stacked to form a wall or placed over an embankment slope or in a channel bed for scour protection. River training works can be developed from groyne or revetment systems.

Several disadvantages can negate the versatility of Gabion techniques. Baskets must be filled properly to maintain shape and integrity, as must the correct fixing of internal and interconnecting tie wires. Regular maintenance is required to repair broken wires and replace lost stone. The units can be vandalised. Settlement can occur with subsequent straining and breaking of tie wire which may lead to collapse. Failures are most likely to occur during flooding when water level and flow velocities are at their highest.

Filter blankets or a geotextile membrane are used with Gabions as a measure to control settlement and deformation. It is important that Gabions should never be used without a geotextile filter. The life of Gabions is very much dependent upon the environment in which they are expected to perform. In the absence of specialist advice the following guidelines are recommended:

- Use 150mm to 250mm stone where available.
- A filter layer should be used under and behind the Gabions, preferably a geotextile.
- They should not be used where impact by wave borne logs, cobbles or bed load can damage the wire.
- The baskets should be filled tightly to prevent stone movement abrading the wire.
- Gabions should be repaired and refilled as necessary to maintain structural integrity.
- May not be appropriate in fast flowing rivers and streams.
- PVC coated wire should be used in preference to galvanised wire.
- Where toe scour is anticipated, the baskets at the toe of the system should be entrenched sufficiently to prevent undermining and resultant deformation of the baskets. This problem may be reduced by founding the baskets on a mattress apron.
- Lacing together adjacent baskets is important to maintain structural integrity.

2.8.9 Geotextile Membranes

Geo-textiles, membranes, fabrics or filter cloths made of synthetic materials have many engineering applications. They are particularly useful in bridge protection works and river training. They can reduce settlement of structures in soft material, prevent loss of embankment material through revetments, river walls and abutment walls and prevent build up of pore water pressure behind the structure.

Many types of geo-textiles are available on the market. The engineer must carefully review the manufacturers data as there is a wide specification range available within each generic grouping. Factors to be taken into consideration for membrane selection are its permeability, form of construction (woven or non-woven), material, tensile strength in each direction, tear resistance, resistance to salt water, other ground water chemicals and pollutants and in particular its resistance to ultraviolet (UV) attack. Many membranes can suffer from UV light degradation which will limit their useful life unless they are covered up promptly and kept covered. The UV resistance of some products are so low that they can disintegrate to dust within weeks in strong sunlight. This problem can be overcome by selection of the most appropriate specification for the job. There are composite materials available comprising a UV proof intermediate webbing to support the soil, whilst a non-woven fabric bonded to the back performs the soil filter function.

Some non-woven fabrics made from synthetic fibre mats or machine punched sheets of synthetic material have been noted to lose or otherwise lessen their filtering capacity when stressed into embankments. These geobetter results laid horizontally, or over a gentle slope. In this fashion they prevent settlement and bottom material from working up into a superimposed structure, such as a Gabion or rubble mound groyne or these stone mattress.

Woven fabrics are normally made with polypropylene or polyvinylidene-chloride monofilament yarns, heat treated after weaving to maintain uniform width openings by fixing together the weft and warp yarns. The size of the opening, or material porosity, must be appropriate to the soil on which the cloth is to be placed. If too fine it may become clogged with silt and fine sand, allowing hydraulic pressures to build up and increasing the possibility of embankment slumping.

Manufacturers advice should be followed with respect to field seams and jointing. Field seams stitched between adjacent sheets of cloth running horizontally along the slope can fail when strained by differential settlement of the revetment. Sheets of cloth are better placed from top to bottom on the slope, with field seams either stitched or a generous overlap provided. Failures due to excessive stretching may be avoided by pulling it into loose folds after it is unrolled, rather than stretching it out. Where placed behind a bulkhead with an irregular face, such as rubber tyres or logs, the cloth should be pushed into crevices, or allowed to yield into these under progressive back filling. In terms of detailed fixing, the fabric can be rolled down the revetment slope where not underwater, and may additionally be pinned to the ground if required. When laying underwater it may be necessary to sew pockets onto the fabric in order to insert stone ballast. Some fabrics can be obtained with heavy threads sewn in which can be used to attach such weights to. The slope revetment construction rule applies to geotextiles, to always lay the toe stones first and work up the slope. If stones are dumped near to the top they will pull the geotextile downslope.

Geo-textiles are particularly effective behind Gabion facings, Reno mattress and rip-rap construction. One of the greatest problems with these forms of construction is the loss of fines in soil beds with consequent slumping and premature failure. This is true in most waterway situations utilising abutment wall, river wall, revetment, groyne and embankment construction. A Gabion embankment toe scour prevention system performs better with a geotextile.

3.8. SUMMARY

The selection of waterway and bridge protection works as a remedial course of action will depend on the type of erosion, river scale, flood flow velocity, type of foundation and the site geology. Table 1 in the appendix indicates the repair method and the corresponding application criteria.

3 SUBSTRUCTURES

3 SUBSTRUCTURES

3.1. SPREAD FOOTING

The spread footing distributes the structural load to the ground by direct bearing. Any erosion of the material under the footing increases the bearing pressure on the remaining contact area. Once the bearing pressure exceeds the support capacity settlement movement may occur which could result in serious failure of the structure. Other failure modes may be design or material based such as earthquake pressures or live load overload and slip circle rotation of the soil mass in which the footing is founded. It is important to identify the failure mode before attempting corrective action. Abrasion or damage can occur in aggressive rivers.

3.1.1 Cavities

It is essential that cavities under footings are filled and action is taken to prevent a repetition of the occurrence. For example if material is washed out by scour, it should be back-filled with well compacted cohesionless material of such a gradation as to check the scour. Repair with lean mix concrete may be necessary as scour prevention measures. If possible water should be removed from the repair area by diversion, coffer damming etc. If it is not possible then work is done when the water level is low. The tremie technique should be used for underwater concrete operations.

3.1.2 Local Material Failures and Cracks

Failure of local footing material can be addressed with re-construction of the parent material. Temporary propping or traffic restrictions may be called for where additional breakout of the footing is necessary to remove unsound material. Concrete repair techniques including crack sealing are described in Chapter 4: Concrete Repairs.

3.1.3 Settlement and Rotation of Footings

The seriousness of the problem depends on a number of factors, predominantly the extent of movement, its effect on the structure and whether the movement is ongoing. Where movement is minor and has stopped or is controlled it may be possible to re-level the superstructure by jacking and resetting the bearings. (Please refer to Chapter 5 which includes bearings). Shoring and load relieving measures, for example adding an approach slab to reduce earth pressure on the back of the wall, can be tried. Approach slabs in concrete structures also serve to mitigate against settlement at the back of the abutment wall. In concrete bridges they are commonly 3m to 4m long but may be longer in truss bridges, such as Bailey bridges. In the latter case they may be referred as ramps and can be used to act as a minor approach span. The use of an approach span is a technique that can be economically justified in aggressive rivers, meandering rivers, or to reduce earth pressure loads where the embankment is high (over 5m to 6m). The short approach span is generally founded on simple bank seats. In more serious cases re-construction of the sub-structure may be the only solution.

3.2. PILES AND CAISSONS

Piers and abutments may be supported by piles or caissons (wells). The pile and caisson footing transmits the load by skin friction in the surrounding soil or by end bearing on hard material or by combination of both. In cases where piles are exposed by scour there can be loss of material section through scaling and spalling of concrete piles, corrosion of metal piles or rot in timber piles. Where there is serious lowering of the bed level, such as can be found in the Kathmandu Valley, the pile capacity will be reduced and settlement results. The structural response of the bridge is also affected and it may become more prone to damage in an earthquake.

3.2.1. Local Material Failures

A concrete repair can redress local material failures taking load relieving measures. Corroded steel piles may be plated after removing unsound material. New steel plates should extend far enough above and below the deteriorated area to develop the full load carried by the pile. A new protective coating should be applied to all steel repairs. Concrete encasement is another option to reinforce weak sections that are damaged or deteriorated, particularly if the repair is underwater. Similarly in concrete substructure deficiencies can be remedied following the repair methods detailed in Chapter 8. Local material failure caused by seismic overload sometimes goes un-noticed. It is important for the designer to design and detail plastic hinges in locations that can be both identified and repaired following major seismic overload.

3.2.2 Settlement and Rotation of Piles and Caissons, Scour

Settlement and rotation of piles and caissons are serious problems depending on the amount of the movement and the potential effect on the structure. Movement when caused by scour of the supporting soil mass can sometimes be stopped by controlling the erosion by protective measures as discussed in Chapter 2 – the Waterway and Bridge Protection Measures. It may then be possible to reset the deck. In more serious cases additional piles or even the reconstruction of the substructure may be the only solution. Failure of the supporting soil structure due to plastic or excessive elastic deformation can be difficult to remedy. Either reconstruction of the foundation, extending the foundation by installing more piles and tying them to the existing foundation or other load relieving options are a consideration following detailed investigation.

3.3. PIERS AND ABUTMENTS

These are basically vertical components including columns and walls transmitting horizontal and vertical forces to the footings and foundations. Repair problems commonly encountered include settlement or movement, cracking caused by differential settlement or seismic forces, surface deterioration, sub-standard parent material, damage of the bearing shelf and loss of back fill. Log impact and/or debris loading can cause severe damage especially where the debris comprises massive bed load in a high flood situation.

3.3.1 Settlement and Movement

This can be a serious problem to footing and foundation instability or scour. An investigation is always necessary to determine if movement has stabilized before remedial measures are undertaken. The bridge superstructure can be re-leveled within reasonable limits however more comprehensive reconstruction may be needed in the case of serious and continuing movement. Load relieving measures offer an intermediate solution. These include extending the foundation, providing additional piles or reducing the abutment forces with the provision of an approach slab. Using the propping action of a deck by fixing both bearings should not be discounted for minor structures.

Another load relieving method is to reduce the live load on the superstructure. This can be achieved by closing off a part or all of a road lane. Following cessation of settlement or corrective action to prevent further settlement the superstructure may need to be re-levelled or the bridge bearings re-set. Please refer to Appendix C which discusses aspects of lifting bridge decks. Details with respect to re-setting of bearings are discussed in the section on bridge bearings.

3.3.2 Cracking caused by Differential Settlement or Seismic Forces

The repair of cracks is outlined in Chapter 6: Concrete Repairs. The above types of crack are caused by two different mechanisms. The criterion for repair of settlement cracks depends upon the extent of the damage and the cessation of further movement. Seismic cracks can be caused by overload not considered in the design and may be caused in whole or in part by construction and maintenance deficiencies. For example where earthquake restrainers have deteriorated or are not maintained to function properly, excessive forces may be transferred to the bridge structure with resulting damage. An alternative scenario is that seismic overload is allowed in the design and a failure mechanism developed at a pre-determined location, resulting in cracking. An approach slab can mitigate against the effect of back fill pressures caused by both the above problems.

3.3.3 Surface Deterioration and Surface Damage

Surface deterioration and surface damage to concrete and masonry piers and abutments can result from aging of the parent material, particularly when this is of poor quality, when acted upon by water and water borne particles such as sands, gravel or boulders. Chemical and frost action are also the contributors. Corrosion of reinforcement promotes the surface disruption of concrete and may develop into more serious structural problems.

At the outset the cause of the problem is identified to determine the type and extent of the repairs. Further deterioration may be prevented by reconstruction of the parent material either in whole or in part. Deterioration may be repaired by a simple render or plaster. The most common concrete repairs are outlined in Chapter 6. In masonry structures, the individual blocks may need to be broken out and replaced with a new one.

3.3.4 Impact Damage and Debris Loading on Piers and Abutments

Impact damage fracturing the surface of a structural element is repaired by re-facing the element in a way to prevent further deterioration in future occurrences. In the re-facing exercise improved impact resistance is achieved by increasing the section size or by applying or fitting a more durable material, such as a steel can-nister to a pier. Serious damage may call for reconstruction of the element.
Debris loading is reduced or controlled by removing obstructions in the waterway. Where there is a known problem of debris, for example a logging project upstream, it is possible to screen the channel and drive vertical piles into the stream-bed upstream of the bridge in order to catch the debris before it reaches the structure. These debris guards must be carefully placed to avoid creating an obstruction and causing a diversion of the waterway. They require constant clearing but can serve to protect the bridge structure or approach embankments from damage or erosion.

3.3.5 Scour and Deposition at Bridge Abutments and Piers

Rivers are always in a constant state of change and for this reason the bridge site should be carefully monitored in order to plan corrective measures when the sub-structure abutments or piers get threatened. The bridge will perform better with a clear opening. It is therefore important to remove obstructions.

Encroachment in particular must be discouraged. If the waterway width is reduced the river will scour during flood conditions. Maintaining the bed level can be difficult when the river is changing level under a natural process. The incorporation of channel controls such as check dams may be necessary to reduce scour effects. Siltation may become more of a problem as the channel becomes blocked with a large quantity of sands and gravel. In some instances it may be beneficial to encourage gravel extraction before the bridge site. It may also be necessary to raise the level of the bridge if siltation becomes unmanageable.

3.4. WINGWALLS AND GABION RETAINING WALLS

Wing walls and retaining walls interface the bridge and approach roads. It retains backsoils and keeps the river channel aside. The problems at the wing wall and retaining walls are similar to the problems at abutments. The main problems are deformation, rotation, cracking and general deterioration. As they do not directly carry the bridge structure they are not as critical as the bridge superstructure. Nevertheless deficiencies need to be corrected otherwise the bridge performance and road approaches will be affected. Scour protection measures can be applied equally to wing walls and retaining walls as bridge abutments. Unless structures are free draining, hydrostatic loads can be considerable therefore it is important to ensure that there are sufficient weepholes and that they are working. In absence of a drainage layer behind the structure the migration of fines can lead to settlement behind walls.

3.4.1 Vegetation

Moss, plants and small trees easily grow in the damp dirt and debris accumulated on the bridge seat, pile cap or in the joints. Vegetation becomes established quickly within the growing season. If left uncorrected it becomes denser and stronger, disrupting the structure, obstructing access to the bridge for inspection and maintenance work. It is important to remove any vegetation from the structure and allow clear access.

Any vegetation growing on the structural member shall be removed as soon as it is detected. This maintenance operation does not require any special techniques but depends on regularity of routine inspections etc.

3.4.2 Gap Sealant

Gap sealant seal the joints between abutments, wing walls and retaining walls. They restrict water and soil wash out of fines. It prevents plant seeds from entering and give the joint a tidy appearance. Most materials deteriorate with time. When it happens, the gaps should be raked out and new sealant installed. The most common and effective material is poly sulphide which is gunned or trowelled into the joint. Grey, white and black finishes are available and grey is commonly used for concrete work.

4. SUPERSTRUCTURES

4. SUPERSTRUCTURES

4.1 BRIDGE DECK SURFACING

Bridge deck surfacing or pavement is defined as the topmost layer or course of material applied upon or with the structural deck to provide a smooth rigid driving surface. Moreover, the paving or wearing surfaces are placed to protect the deck from the effects of traffic weathering and chemical action. Bridge deck surfacing may be either an integral part of the deck superstructure or a separate wearing surface fixed to, or laid on top of the superstructure. The common forms are concrete, asphalt, steel or timber. The surfacing should provide a smooth riding surface, reducing impact, vibration and other such dynamic forces. The wearing surface protects the superstructure from the effects of water, weathering, chemical action and abrasion. It also disperses traffic loads to surfaces below.

4.1.1 Asphalt Surfaces

Asphalt wearing surfaces are usually placed onto a concrete superstructure. In some cases they are laid onto steel decks and occasionally onto timber decking.

The most common problem observed with asphalt surfaced bridge decks is the tendency to overlay the existing surfacing. The overlay increases the bridge dead load with a resultant loss in live load capacity. If we take one of the suspension bridges as an example, with a span of 125m and a width of 6m, an additional overlay of only 50mm adds an extra 37.5 cubic metres of asphalt to the deck or some 75 tonnes of dead load. Even with a simple 20m span road bridge a 75 mm overlay adds 9 cubic metres or 18 tonnes of dead load to the deck. The bridge deck design thickness of surfacing must not be exceeded. The old surfacing must be removed by scarifying to maintain live load capacity of the structure.

Other problems found with overlays are that deck drainage and movement joints tend to be buried. In the former instance this affects the bridge deck drainage. In the latter as the bridge moves with the effects of temperature, cracks occur in the surfacing which soon lead to potholing in the adjoining area.

Asphalt surfaces help to discharge water from the bridge. However when they are porous water can percolate through the asphalt to sit on the concrete surface. Waterproof membranes are incorporated to check this effect.

Cracking of asphalt surfacing on bridge decks can take a number of forms. Map cracking is generally due to ageing of the material as the asphalt dries. It may also be caused by excessive deflection. Reflective cracking of overlays will follow the crack pattern in the underlying deck. Slippage cracks caused by lack of adequate bond between deck and surfacing show up as crescent shaped cracks. Early detection and repair of minor defects are important so as to control them from growing up. With extensive deterioration it is necessary to replace surfacing down to sound material. Minor damages may be rectified by a light surface treatment such as a slurry seal over the entire surface.
Distortion caused by rutting or depressions are remedied with local application of asphalt cement over a tack coat and surface treatment overlay to the whole bridge. Corrugations are indicative of slippage or instability and reconstruction is needed in such cases.

Potholes are bowl-shaped holes of various sizes in the surfacing resulting from localized disintegration. Increased impact loading is a consequence of potholes and the exposed deck is increasingly vulnerable to damage.

Pothole patching will control local disintegration. Ravelling or the progressive separation of aggregate from the surface course is a construction fault generally addressed by a surface treatment. Wherever possible, the minimum size of the repair should be a full lane width by at least one metre. This policy should be applied in particular on Major Highways, otherwise a series of small local repairs will give an uneven road surface and increase impact effects both to vehicles and the road.

4.1.2 Asphalt Surfacing on Timber

The Mugling and Marsyangdi Suspension bridges and the Tadi Khola truss bridge are examples of asphalt laid over timber. It is not easy to maintain such surface. The timber decking of the suspension bridges was specially constructed with timber planks placed on edge and transversely clamped with bolts to form deck panels. The panels increase deck stiffness and reduce deflection. The timber planks are of different depth to give a keyed finish to hold the asphalt. It is essential that the timber is properly seasoned otherwise increasing deflection will disrupt the asphalt surface. As the timber gets older, deflections increase and the asphalt surfacing starts to fail. Replacing the asphalt is insufficient to prevent a repetition of the damage. Except for above three bridges, this type of surfacing is not in practice in Nepal.

4.1.3 Asphalt Surfacing on Steel Decks

Asphalt surfacing on steel decks can spread tyre loads reducing fatigue effects and extend the service life. A tack coat is normally required for adhesion between the steel surface and the bitumen wearing course and to reduce the possibility of de-bonding. Local de-bonding and pothole formation can occur if deflections are excessive or if the bond is poor. This type of surface is also not found in common use.

4.1.4 Concrete Wearing Surface and Concrete Decks

The use of concrete as a wearing surface has started but it is sometimes assumed to be an integral part of the deck superstructure. The concrete wearing surface is usually an additional layer of material laid on top of the deck. This is identifiable where construction joints are incorporated into the surfacing. Observed in the bridges constructed under aid from the People's Republic of China along the Arniko highway where a de-bonding/waterproofing layer is also fixed between the deck and surfacing. It is less obvious on the bridges in the Kamalaa Sector of the East West Highway. However, there is a concrete surfacing overlay on a concrete(pre-cast) deck with a waterproofing layer. Usually the surfacing has a light mesh size or is nominally reinforced. The common mode of failure with concrete surfacing is cracking and the formation of potholes. Damage will have a greater frequency at deck joints, particularly at the ends of the bridges where impact forces are greatest. A concrete repair is the appropriate solution and this is best carried out in a similar fashion to a pothole repair in a road surface. In this respect the damaged area is squared off with a 25 mm deep saw cut around the perimeter. The marked area is broken out neatly taking care not to damage any membrane beneath the surfacing. If the separation membrane is damaged or has failed, this too must be replaced or relocated. It is important to note that every concrete surfacing has a finite service life. Once failure has started, it becomes worse with water infiltration increasing pore water pressures in the surfacing under vehicle load. Eventually the only solution will be to replace all of the concrete surfacing. Similar to asphalt surfacing an overlay increases bridge dead load and is not the correct solution. As a temporary solution, potholes can be filled with asphalt. If appropriate, cracks can be filled following the methods described in chapter 6.

The concrete wearing surface is an integral part of the deck superstructure in a number of the steel beam/concrete deck composite bridges along the Prithvi Highway constructed under Chinese aid. The likely reason for this is the lively nature of the structural form which would increase the possibility of de-bonding of a surface layer. It is not known at present what the original thickness of these decks was and at what stage deck reconstruction is advised. This would need to be the subject of detailed investigation and assessment.

Spalling, cracks or apparent pothole formations in a concrete deck without surfacing should be treated with caution as there is the potential for a more serious problem affecting the structural performance of the bridge. Any damage observed through the deck, i.e. observed both on the surface and underneath must be reported for investigation. Spalling and de-lamination of the top part of the concrete could be caused by reinforcement corrosion. Expert review should be sought to determine the exact nature of the problem.

The thickness of the deck of the Karnali Bridge was increased to allow for a wearing surface. This is to be reconstructed at a time when the surfacing is worn down to a measurable depth given in the maintenance manual for this bridge. The rate of wear of the deck is primarily related to traffic. Deck reconstruction of the Karnali not happen for some considerable time. There are other bridges where the concrete deck acts as the wearing surface and which are subjected to significant traffic intensity e.g. the Prithvi highway steel/concrete composite bridges. The decks here must be monitored for excessive wear. Excessive rutting or exposure of reinforcement will indicate the need for re-construction of the deck.

4.2.3 Timber Wearing Surface and Timber Decks

Timber is used as a wearing surface in the form of running strips spiked to a timber deck. Some of the old bridges on Tribhuvan highway and postal road use this surface. However, new bridges do not use this type of surface. As with the timber deck they deteriorate with time due to abrasion, impact and rot. Lift off and loosening of the running strips is a continuous problem on a lively bridge. The solution is to re-spike the running strips. Increased performance is obtained using coach bolts in drilling through the timber and through bolting.

The timber deck usually transmits the local wheel loads to the main structural configuration, which may be timber, steel beams or steel truss. It may span longitudinally between transoms or transversely across stringers. The capacity of the timber deck is dependent upon the type of timber used, and other factors, effective span and section properties. Behaviour of timber under wheel loads is improved by transverse bolting of a number of timber beams to form panels as at Mugling and [illegible] bridges. Asphalt surfacing is sometimes laid over the timber, however the life of the surfacing is affected by the amount of deflection of the timber decking and is often short. The practice of overlaying is of little benefit and only extends the life of the surfacing by a short time as well as adds to the bridge dead load. It is not recommended for use.

All timber whether treated or untreated will decay due to moisture penetration, especially around nails, at bolt holes, notches and saw cuts. Affected timber should be replaced with treated timber then sealed around the more sensitive areas with a sealing compound. Draining of water quickly from the deck and preventing water from standing on the deck extends the bridge life.

4.1.6 Steel Bridge Decks

Steel is not normally used as a separate wearing surface but is generally part of the deck. The exceptions are where steel running strips are fitted to timber decks in the form of an open textured grid, or on occasion as a temporary expedient such as to the deck of the Bijayapur Khola Bridge at Pokhara. Unless correctly textured, steel surfacing can be slippery. A weld pattern can provide a textured surface. Specially applied epoxy coatings containing grit can provide a non-slip finish. Steel is an expensive solution as a wearing surface. If steel plate is is subjected to excessive flexure, fatigue cracking soon occurs. Steel wearing coat is not found in use except on very few steel decks.

4.2. BRIDGE SUPERSTRUCTURE CONFIGURATION

There are a great number of bridge superstructure options available to the bridge engineer of which there are many examples in operation in Nepal. The objectives of this section is to review the maintenance aspects and considerations of those normally found in Nepal. By far the most predominant structural form is concrete, usually reinforced and placed in-situ, but also pre-cast (e.g. Russian bridges of E-W Highway) and occasionally incorporating pre-stressing (Indian Divisions of the EW highway constructed by [illegible] Ltd and many other bridges of Indian Construction). Steel beam and concrete composite construction has been in use for some time (Older bridges constructed under Chinese aid along the Prithivi Highway and recent bridges built under Japanese aid in Kathmandu valley and under UK aid as replacements to bridges washed out along the Prithivi Highway). Masonry and PCC block arch construction can be found in a number of locations with arches spanning up to 60 m. Approximately 14% of the bridge stock on the strategic network incorporate steel either in the form of beams or truss. There are some timber bridges but these are likely to be replaced very soon under re-construction programmes. At present there are five bridges classified as special structures, three of which are 125m span suspension bridges (Mugling, Marsyangdi and Bheri) and one cable-stay bridge of 500m overall length (Karnali). Please refer to the specific manual for guidelines on the inspection and maintenance of suspension bridges. The information given in the Maintenance Manual for the Suspension Bridges can be of assistance to the inspection staff maintenance of other bridges. There are a few other minor structural configurations to be found on the Strategic Road Network such as corrugated metal pipe culverts (CMP), Hume pipe culverts etc.

4.2.1 The Karnali Cable Stay Bridge

This is a special structure which is maintained in accordance with the Maintenance Manual prepared specifically for this bridge. All operations must be carried out in accordance with the Maintenance Manual. Specialist advice may be necessary for some of the operations. Where the maintaining authority requires assistance, initial advice can be obtained from the Bridge Unit.

4.2.2 Concrete Bridge Superstructures

Minor repairs to concrete bridge superstructures must be carried out correctly in order to be effective. A poor repair will eventually have to be broken out and re-constructed correctly. Concrete repair can be a fairly intricate subject. Chapter 8 form background information and concrete repair methodology. For Major repair works and prestressed concrete bridge repairs, the problem should be referred to specialist consultant as these may need special investigation and procedures.

The common problems with concrete bridges are cracks in the structure and/or concrete spalling, impact damage, deterioration due to the effects of water or chemical effects, inherent material defects, overload and poor construction. Other damage may result from earthquake effects or flood. Concrete bridges will deteriorate with time, particularly in the presence of water. It is most important to protect the bridge from the effects of water by ensuring that the bridge joints and drainage are working properly. Many bridges have earthquake resistant devices built into the structural system to control the effects of seismic overload on the bridge. If these devices are not working properly the probability of structural damage to the bridge will increase. Bearings must function properly. If restrained, local damage will occur around bearings and at ends of the bridge. (Chapter 5 deals with bearings, earthquake restraints, joints and drainage, etc. The cause of each problem must be identified and the correct course of action decided. Any situation involving loss of bond between concrete and reinforcement due to spalling, corrosion, impact damage or wear, reduces the load capacity of the structure. The extent of loss depends on the location and size of the problem.

4.2.2 Steel Bridge Superstructures

The problems related to steel bridge superstructures include corrosion, deformation due to impact damage or overload and fracture due to fatigue or overload.

1. Corrosion of steel members

Corrosion is by far the greatest problem associated with the use of steel as a structural medium, although due to the mild climate in Nepal, corrosion is not as serious as in many other countries. The best way to deal with corrosion is preventative maintenance. Simple cleaning operations give long term benefits. Periodic cleaning and removal of dirt or debris prevents paint deterioration and corrosion. This routine maintenance operation in turn prolongs the life of the total paint system. The collection and accumulation of dirt or debris on a lower flange or chord is widely observed in the steel truss bridge and on the bottom flanges of steel bridge beams. When debris holds water, the dampness causes paint deterioration and eventual corrosion. Dry debris can be removed using brooms. Brushes and trowels are useful for wet materials. A water pump can be used to remove debris and clean paint surfaces. Blocked drains should be cleared.

One of the most common deficiencies in steel bridges is the paint deterioration and its resultant corrosion. In general, a steel member is painted or galvanized to prevent corrosion. A good galvanizing protection has a particularly long life in Nepal. However, paint and even galvanization deteriorates and breaks down due to the presence of air, water and other contaminants such as faecal deposits and bird droppings. Later the steel member starts to corrode from the surface. If corrosion is advanced the edge of the steel plate can look as if it has split into thin layers. This phenomenon is called "Lamination". Under such condition, the steel has almost no structural strength left and the reduction in thickness of the parent metal is called "Section loss". De-laminated steel often looks worse than it is as the expanded de-lamination is usually some seven times the thickness of parent steel. A de-laminated steel section expands however, and this can cause tension failure of bolts and/or rivets in a connection due to the expansive forces of corrosion.

Corrosion control by repainting is the most prevalent maintenance operation to prevent advanced corrosion and costly rehabilitation to the steel bridges. It also restores the appearance of the bridge. Even though the deficient area is isolated or scattered, it is appropriate to repaint the steel member without delay. In the repainting operation the old paint is first thoroughly cleaned to entirely remove the rust. Suitable paint materials are then applied.

A regular programme of washing dirt and debris from the structure seats, pier tops, lower flanges of girders and truss members will prolong the life of a paint system. Spot painting of localized areas of rapid paint failure, particularly at the bridge ends or bridge connections, prolong the life of the total paint system.

Corrosion left un-corrected and resulting in serious section loss will need section reconstruction or replacement. The most susceptible areas where this problem is likely to occur on structures in Nepal is at the ends of truss bridges where contamination accelerates corrosive effects. Water leakage through expansion plates and joints is also a common cause of corrosion of beam ends or at the ends of a truss. Particular attention should be paid on keeping these areas of the bridge clean and well painted. At the truss or beam ends a stiffener and/or patching the flange or web with additional steel plates may suffice. It is rare that an entire member needs to be replaced because of rust but this does depend on the extent of damage. A connective steel plate can usually be attached to transmit the load through the affected area. Where the affected members are at critical locations a designed solution is essential, particularly when the replacement of a member is a possibility.

ii. Deformation of steel members

Local deformation or damage of steel structural elements results due to a collision damage or impact damage often caused by traffic or debris during floods. The steel members on through truss bridges are subject to impact damage from roadway traffic. In most of the cases, the damage is relatively critical as it causes a stress concentration in the deformed member. Repair of collision damage is often very difficult and involves member replacement in most extreme cases. However, minor damage can usually be repaired by straightening using a strong back with jacks or by heat straightening. Fractured members require partial or total replacement. Minor nicks and gouges due to accidents should not be allowed to remain as they can cause stress locally and often propagate cracks.

Strengthening by reinforcing the member is another technique which can be accomplished by drilling and bolting additional steel plates or sections to the member. Welding of additional steel is appropriate. Care needs to be taken with either method. Drilling of the existing member, prior to fixing additional steel, will weaken the section. Similarly the application of heat during the welding process could cause a highly stressed member to buckle. Hence designed approach is required in such cases.

Deformation of steel members under load has to be quantified. Deflection that is recovered when loading is removed is a part of the normal function of the structure. When the deflection results in a permanent set or buckling of truss members or flanges occur, the problem is of serious nature and calls for detailed investigation.

iii. Member Replacement in a Truss Bridge

The bridge is normally closed to traffic during the member replacement. Closures must employ positive control with barriers placed at the ends of the bridge. The most likely member to be replaced will be a vertical or diagonal brace damaged by impact. Where corroded members are the subject of the replacement consider that any of the members can be involved.

Distorted compression members are more serious than distorted tension members like bottom chord. Damage to lower chords, stringers or transoms are often difficult to repair. A slightly bent or deformed lower chord (resulting from impact) will usually not require repair unless there is a sharp bend creating a stress concentration. A fractured (or seriously corroded) lower chord however may require partial or total replacement. Replacement of lower chords, and especially stringers and transoms may require removal of the decking in the affected area.

Whenever a member is to be replaced extreme care is necessary to avoid serious deflection or distortion of the truss or even collapse. The bridge must be braced, propped or strapped with temporary steelwork or cables to support the structure during the replacement. The temporary members must be capable of carrying the loads equivalent to the section to be replaced and in such a way as to transmit the forces through the nodes of the truss. Temporary members must be adjustable. This can be accomplished by using proprietary adjustable props with screw threaded ends. Another technique is to fit a hydraulic jack into the system and applying pre-determined forces controlled both by load gauge readings. Straps can be used for tension members. These can be in the form of steel ropes incorporating a turnbuckle system to apply tension to the ropes. Once the truss is adequately braced the old member is removed. New bolts must always be used, or new bolts used to replace rivets. The replacing member must be of the Correct dimensions and precisely pre-drilled. Site drilling and particularly site welding should be kept to a minimum for quality control.

Struts can be placed to reinforce damaged compression members as a temporary solution. Similarly cables with a turnbuckle arrangement can be used to take off part of the load from a damaged tension member.

The truss is a fairly simple super-structure system with constant loads carried on two bearings at either end of the bridge. Theoretically the bearings at each end carry equal loading. In practice this varies due to mal-distribution of loading and within reasonable levels, this is not a problem. In the event that one of the truss members is badly damaged following a vehicular collision it is not unusual for considerable redistribution of load to be transferred from the damaged truss to the good truss. This depends on the torsion stiffness of the super-structure configuration and can result in one bearing carrying most of the vertical load. It has been known for the bearing on the damaged side to lift off its bearing seating. It may be necessary to check the reactions of the bridge after it has been repaired, by using jacks to weigh the structure. Where the difference in reactions is unacceptable the bearings will need to be re-set to Carry equal loads. This is accomplished by balancing the jacking loads then re-grouting the bearing plinth.

b. Cracks and Fatigue in Steel Bridges

Any crack or fracture in a steel member should be considered as a sign of serious distress and immediate corrective action needs to be taken. Very often when the crack is visible the member is close to failure. If the crack is large or in a critical position it may be necessary to restrict traffic or close the bridge until the member can be repaired or replaced. The engineer must always consider the effect of the failure of the member under question and whether local or global collapse will result. A certain amount of tolerance can be exercised where failure will not endanger life, property or the structure as a whole.

Cracking that occurs or develops in structures subjected to the repetitious effects of live load is referred to as fatigue damage. The cause of fatigue must be investigated carefully and appropriate solution determined. Global and local fatigue damage can be attributable to a number of causes: frequent overload exceeding the design load; stress levels occurring exceeding the level of design stress; poor detailing; defective welding; local damage instigating high stress levels.

The subject of cracks and fatigue phenomenon in bridges can be quite extensive. It is important for the engineer to recognise the principal causes of such occurrences. Beams or girders are susceptible to cracking at points where local concentrations of stress can occur. These are referred to as stress raisers. Examples are where joints or connections are welded, or where certain types of design details are used which give rise to stress raisers, such as sharp corners, the ends of weld runs or where cantilever brackets are used. Locations where flange plates change section width or thickness are a problem area of fracture. They must be closely watched as a very small crack can develop rapidly.

Initial cracking can develop from fatigue induced by excessive reversals of stress outside of the fatigue life of a member. They can also be initiated by excessive overload or structural damage/impact. Cracks are usually associated with welds. They tend to propagate at the ends of welds or at weld defects such as slag inclusions or undercutting. Other defects include the use of incorrect weld electrodes or errors occurring from the welding procedures themselves such as alteration of the parent material within the heat affected zone (HAZ).

Sometimes it may be enough to drill a hole at the end of a crack to prevent further propagation. Welded repairs are a consideration. Before making any weld repairs the chemistry of the base metal must be compatible with the welding procedure. Many modern bridges using high tensile steels require low hydrogen electrodes for welding. It must be noted that weld repair procedures only apply to the particular circumstances for which they are designed.

Where nicks and gouges due to impact should not be allowed to remain as they can cause stresses locally and give rise to cracks.

- **Bolted, Riveted and Welded Connections in Structural Steelwork**

The main problems associated with connections in steel bridges in Nepal emanate from corrosion taking place in these areas. Accordingly it is important to take preventative action against the occurrence of corrosion. Another problem that has been noted in some bridges is with loose or missing bolts, or bolts that are too short and do not fully engage the nut. Obviously in the latter instance this is a problem that should have been rectified at construction. As a guide the minimum length that a bolt should protrude from the nut is one and a half threads.

The engineer must be aware of the types of bolts that are available and the mode of operation of the connections. Bolts can be designed to act in the bearing mode, where loads are transmitted in shear. In this case the connection is acting as a pin and the bolts do not need to be tightened to any appreciable extent other than to ensure that the nut does not wind off the bolt during service. Bolts in this instance are usually 'Snug tight' tensioned, but acting in the bearing mode. To fit a bolt fully tensioned it is tightened using a standard spanner. All spanners have a length which varies according to the bolt head size and type of bolt that is being tightened. The length of the spanner is based on the force that can be applied by a man without breaking the bolt. Hence a spanner for a 20mm bolt will be longer than for a 16mm bolt. Generally, depending on the design, a mild steel bolt (Grade 4.6) could be used. In practice high tensile bolts are used (Typically Grade 6.8, 8.8 and 10.9) to reduce the risk of over-tightening causing the bolts to break, and sometimes to accommodate tensile or combined stresses.

The other common bolted connection design utilises a high strength friction grip (HSFG) bolt. In this case forces in the connection are transmitted through friction between the steel members when the members are clamped together. The member then behaves as a fixed connection, not a pinned connection.

Appendix B details methods of how to tighten high strength friction grip bolts by the torque control and part-turn methods and describes the tightening difficulties that may be encountered. This appendix may help to understand bolt behaviour. The tightening method using load-indicating washers is not described in the appendix however this has been used in Nepal in erecting Callender-Hamilton Bridges. The bolted connections for Callender-Hamilton Bridges however are not HSFG connections but fully tensioned designed in the bearing mode.

The problem of loose or missing bolts is generally caused by vibration or vandalism. On occasion it is caused by bolt failure (overload causing it to yield or break). Loose bolts should not occur in HSFG connections and this occurrence is indicative of a more serious problem. Loose or missing bolts must be replaced using new bolts. Old bolts must not be reused as they may have yielded or be otherwise be defective. New bolts must be fitted following the manufacturer's or designer's recommendations to reflect the behaviour of the member.

vi. Steel and Concrete Composite Bridge Superstructures

A bridge superstructure comprising steel beams acting compositely with a concrete deck is a popular and often economic structural form. The concrete deck can also be designed to act compositely with a steel truss support rather than beams. The resultant design is lighter and less stiff than a concrete solution. Construction is normally easier as there is less falsework and formwork involved. Obviously there are cost implications with imported steel. Detailed correctly and with simple spans there are few problems with this type of superstructure other than corrosion of the steel beams and wear of the surface. A good corrosion protection regime and regular cleaning of the bridge will safeguard the life of the steelwork.

It is not uncommon for the deck to act as the wearing surface therefore re-construction of the deck surfacing after excessive wear requires some care. This is typical of the bridges along the Prithvi highway constructed under aid from the People's Republic of China. These bridges tend to have lightly reinforced cantilevered footpaths which can collapse under accidental wheel loading, and the parapets are not designed to restrain a vehicle. These are design deficiencies and the Design Section Bridge Unit has developed repair and rehabilitation solutions. The other problem area, along with many other bridges, is with deteriorating road joints that have exceeded their normal design life. A design for joint replacement was developed by the Bridge Unit and is enclosed in Appendix.

vii. Masonry and Concrete Arch Construction

This structural form continues to be used in Nepal for certain Road projects, such as Pokhara to Baglung built under aid from the People's Republic of China. There are a number of examples of this type of bridge in operation on the Strategic Road Network. The recent Condition Surveys found that these structures were performing satisfactorily and will continue to do so as long as the foundations remains secure from the effects of scour. Arch bridges along the Kodari Highway illustrated minor structural cracks in the abutments attributed to seismic damage. Leakage of water through the arch leaving leachate deposits and staining are observed due to difficulties in dealing with drainage. Arsandi arch bridge in Pokhara Baglung highway and stone bridge at Km. 21+750 of Mugling Narayanghat highway suffered serious cracks due to impact and settlement.

Arches are able to sustain substantial cracking, deformation and movement before they reach the point of collapse. Cracks in the arch barrel can often be repaired by grouting or crack stitching. Undermining by floods/scour remains the greatest risk to the arch, followed by seismic overload and vehicle overload. Most arch bridges in Nepal appear to be constructed on good foundations. Where the extent of damage or deterioration to all arch structures is of concern a detailed investigation must be carried.

Should it become necessary to strengthen an arch barrel a common approach is to cover the barrel with a reinforced concrete saddle or relieving arch. This strengthens the arch, improves load distribution and ties together any cracked sections. The dimensions of the concrete saddle are determined from analysis and vary according to each particular circumstance such as extent of deterioration, span etc.

The parapets on some arch bridges may not be sufficiently strong to retain vehicles. There may be other locations where the bridge is too narrow. The Design Section Bridge Unit has completed a demonstration contract improving the parapet on a typical masonry arch bridge. The detail is enclosed in Appendix.

Improvements to arch bridge drainage can reduce water leakage through the barrel. In some circumstances the solution is to the [illegible] to fill the crack. The water will however then find another place within the barrel to leak out of the structure. It is better to try to prevent water from entering the arch structure wherever possible.

viii. Special Structural Configurations – Half Joints

There are some superstructure configurations incorporating half-joints. Half joints are commonly difficult to maintain and can give rise to serious problems even in Nepal where conditions are less aggressive than in many other countries. Access is essential to maintain the bearing areas and bearings, especially when steel bearings are used. Any significant deterioration of concrete at half joints will result in a major reconstruction exercise involving supporting or jacking of the bridge deck.

4.5. BRIDGE DECK DRAINAGE

A good drainage system is the best preventive maintenance, since trapping, ponding and splashing of water can cause damage to various elements of the bridges over a period of time and represent serious traffic hazards, particularly during the rainy season in Nepal. The effects of water and water borne contaminants contribute to the long term bridge deterioration to the extent where reduction in service life becomes appreciable. Where gullies discharge water onto other parts of the bridge the drainage chutes should be modified. In some cases it may be necessary to completely break out the old gully especially where it is observed that they are undersize or badly fitted. Where bridge joints are open and water ingress can cause long term damage to the bearing shelf or bearings a positive drainage system, such as guttering, should be considered.

4.5.1 Surface Drainage

The main components of the drainage system are surface inlets, drainage pipes and surface gutters along curbs. In the drainage system accumulation of dirt and debris is a main reason for damage. It is important that water is quickly and adequately drained from the bridge deck to avoid standing water and any staining and dampness associated with poor drainage details.

Gutters run along the edge of the carriageway on the bridge surface. Accumulation of dirt, debris and other foreign materials in the gutters are frequently observed due to lack of regular maintenance. This defect

causes ponding of water on the bridge surface which is a traffic hazard. As the water is impounded on the surface it makes the pavement slippery and causes inconvenience and a safety hazard for motorists and pedestrians. Moreover, since cracks are inherent in flexible pavements the ponded water can penetrate through the cracks into the deck. Pore water pressures developed from vehicle tyres then contribute to disruption of the surface, potholing and larger cracks. The sediment must be removed from the gutter drains and then the gutters cleaned thoroughly. The gutter cleaning works should be carried out at the same time as roadway maintenance in order to provide a free flow of the water.
Surface inlets blocked due to the accumulation of dirt, debris and other materials obstruct free water drainage. Outlets must be kept clear of debris. The problem is avoided with routine preventative maintenance. Any dirt or debris must be removed and damaged inlets should be replaced. The most important preventive measure is a regular and frequent cleaning of the surface inlets in order to avoid any accumulation of dirt debris.

4.3.2 Drainage Pipes

Drainage pipes are often of inadequate length or even missing. Inadequate length of drainage pipe or missing pipes cause water drained from the deck to splash directly onto some structural elements of the bridge. Without appropriate and timely maintenance this defect can cause deterioration leading to steel corrosion or scaling and flaking of concrete elements. The inadequate pipe length shall be extended approximately 300 mm beyond the bottom of the beams using PVC or an appropriate material. Alternatively a new drainage pipe with an adequate length shall be installed if the pipe is missing.

4.3.3 Sub-Surface Drainage

A technique, less commonly used in Nepal. This consists of a sub-surface system to remove water that has percolated through the surfacing. It can be micro drains in the form of a membrane or a drainage pipe fitted to the low spots in a deck below the surfacing. Their objective is to remove water, especially contaminated water, from below the surfacing and to reduce pore water pressure and the risk of damage to the deck from the water.

4.4. BRIDGE DECK WATERPROOFING MEMBRANES

In some situations a waterproofing layer is incorporated beneath asphalt or concrete surfacing which can protect the superstructure or act as a de-bonding layer. Whenever work is undertaken on bridge surfacing it is important to know if a waterproofing layer is present. Although not widely used existing membranes should be maintained and new membranes are always a consideration for the Bridge Designer. Waterproofing layers of mastic asphalt are found in some Chinese, Russian and Indian aided bridges in Nepal. If a waterproofing layer is present it must be properly reinstated with damages that can occur to it during a re-surfacing operation.

Older mastic asphalt membranes tend to become brittle with age. They lack flexibility and can crack easily under local deflection or differential movement. Examples of such local failures is observed in some Russian Series Bridges of the East West Highway where water leakage occurs between pre-cast concrete bridge beams. This is where the asphalt has cracked. Replacing or repairing these membranes may be better achieved using more modern materials such as a sheet membrane. In this system the deck is first primed and a proprietary waterproofing membrane rolled out to cover the deck. Adjoining joints are overlapped and sealed. These systems give a much better performance than mastic asphalt. It must be remembered that if the problem emanates from the structure, such as excessive deflection of adjacent pre-cast concrete deck units, it is unlikely that new waterproofing will solve the problem permanently.

5. COMPONENTS, ANCILLARY ITEMS AND PROTECTIVE SYSTEMS

5. COMPONENTS, ANCILLARY ITEMS AND PROTECTIVE SYSTEMS

5.1. GENERAL

The life of bridge components, ancillary items, protective systems, and many other constituent parts associated with the bridge structure, are all less than the design life of the basic bridge structure. Many elements are to be replaced or renewed on a number of occasions during the life of the bridge itself. It is better for this replacement to be carried out in a planned and structured fashion rather than 'on demand' or crisis management when the item has failed. When a specific item exceeds its design life or working life the damage may spread beyond the component affecting other parts of the structure. Additional cost then incurs which when combined with the additional costs of 're-active' measures rather than 'pro-active' places an additional burden on the maintenance programme disrupting the planning schedule.

5.2. Expansion Joints and Bridge Joint Systems

These are joints placed in the gaps between the deck ends or the deck end and the back-wall. The purpose of the joint is to permit free movement of the bridge due to thermal effect and structural articulation, to prevent cracking in the surface layer by effectively supporting the surfacing and to prevent water and water-borne contaminants from entering the bearing area and substructure. The efficacy of the joint is therefore most important, especially with metallic bearings. By forming an effective barrier to water and the like, the life of the bridge structure and component items are maintained. Failure of an expansion joint can create a serious hazard to traffic. Planned inspection and replacement is therefore important. Replacement is expensive due to the cost of traffic management, therefore bridge joint replacement is best carried out together with carriageway re-surfacing operations.

Many bridges in Nepal have defective expansion joints. Replacement of expansion joints, and bridge repairs are very often neglected in road projects. This must be redressed so as to achieve their design life without costly rehabilitation in later years.

5.2.1 Modern Design Approach to Bridge Joints

Joints with neoprene inserts perform better than previous generation joints. In the short span bridges with spans less than 12 m., expansion joints are not necessary. The modern trend is to reduce the number of bridge joints to an absolute minimum, and preferably none at all, by improving deck continuity with deck integral with the sub-structure. It will be some time before this approach is adopted as standard practice. Until then the best approach is to utilize these modern neoprene materials for the movement joint. Where possible, consider 'fixing' the fixed end joint or installing a buried joint over which the asphalt surface passes. This approach applies equally to new bridges as well as those under rehabilitation.

5.2.2 Expansion Joints used in Nepal

There are various types of expansion joints presently in use in Nepal.

- Sliding Steel Plate type spanning at the top of deck or bottom of deck slab
- Compression Seal type with or without steel angles
- Clear Gap
- Elastomeric joints

The sliding steel plate, compression seal type and elastomeric bearing have been found commonly used. The finger plate joint is generally applied for long span bridges. Elastomeric segmental joints are incorporated into newer bridges of modern design. Few detailed drawings of existing structures are available therefore it is difficult to analyse and design an appropriate repair. Existing structural details often remain subjective and [illegible] of the concrete to construct the joints.

5.2.3 Problems with Bridge Joints

Water leakage is a problem because of the destructive effect on the bridge elements beneath the joints. This is [illegible] due to blocked drainage troughs and missing and defective drainage devices permitting water to reach structural elements beneath. Many of the older steel plate joints do not prevent the passage of water, although some have rudimentary drainage channels.

It is commonly observed that many joints have been overlaid by asphalt concrete surfacing. Open cracks, potholes or [illegible] are common at the bridge joint. This defect causes the intrusion of dirt and grit as well as water ingress and the accumulation of debris on the bridge structure and bearing seats. These deposits collect and hold moisture resulting in rusting of the steel members and deterioration of the bearings and the concrete surfaces.

Often the bridge joint nosing is damaged. This defect is defined as a cracking and flaking of the slab concrete and asphalt surface adjacent to the expansion joint device. The failure is likely caused by increased loads or surface [illegible] under traffic loading, improper construction material or poor workmanship. Most often the joint has exceeded its service life and the anchorage failed in fatigue. This is usually accompanied by abnormal noise. Here the expansion plate or cover plates break loose or wobble producing rattling noise and a traffic hazard. Such failure will rapidly induce total expansion joint failure as well as critical damage of the edge concrete. This is observed in a number of bridges along the Prithvi Highway.

Minor problems include dense vegetation and debris obstructions in the joints. Dense vegetation will produce a closing of the bridge joint or a water channel blockage by plant accumulation.

5.2.4 Sliding Steel Plate Type Joints

Along the Prithvi Highway existing joints are typically 100 x 100 steel angles cast into the deck and ballast wall with steel anchors at 450 centres which themselves appear to be welded to reinforcing steel. (Minimum reinforcing should not be less than 1000 mm²/m length with anchor bar spacing not more than 250 mm centres). A 200 wide steel cover plate is welded to the steel angle on one side of the joint. The joint is a simple design permitting movement and rotation, restricting entry of stone and debris into the joint, but not water. A small steel drainage channel is incorporated into the detail to carry water away from the bearing shelf. Movement joint gaps were observed to be of the order of 50mm with no difference between fixed and free ends of the bridge. (Note that in some of the bridges along the Mahendra Highway gaps can be considerably wider and are over-spanned by the joint plates.)

Sliding steel plate bridge joints in Nepal have the following faults in general:

- Loose steel top plate lifting and rattling during vehicle movement.
- Missing top plate.
- Loose angles, lifting and moving.

- Missing angles.
- Adjacent concrete deck and ballast wall cracking and breaking up with ballast wall reinforcement exposed.

The likely mode of failure is that fatigue occurs in the top plate weld fixing. At this stage re-welding the top plate can prolong the life of the joint. In many areas the top plate is broken off or missing. With repeated hammer action of the top plate on the skid angle, the steel angle works loose, accompanied by as with fatigue failure of the anchorage. Continued impact of the top plate and angles cause the bedding concrete to crush. The larger the pot hole that develops, the greater the impact load and the faster the break up of the joint.

In some locations the deterioration is increasing rapidly and it can be concluded that some of the joints are in a dangerous condition. Though risk to the structure tends to be restricted to local damage, risk to the bridge user is high. Repair costs will escalate where the joints are left unattended.

5.2.5 Bridge Joint Repairs

In dealing with water leakage, if a drain trough is installed beneath the joint cleaning and flushing of the drain trough will help to prevent clogging. For open joints, sealing the joint against leakage should be carried out periodically. The installation of drain troughs or sheet metal deflectors is a permanent counter measure for the joint without a drainage system. Remember to clean down around the bearings and bearing shelves during the exercise.

To investigate the extent of damage and to identify the type of expansion joint, asphalt overlays removed. If the defect is only local then reposition loose cover plates and re-weld or replace of the loose or faulty bolts, reposition the joint, re-bolt or re-weld back in place. In case of an open joint, sealing the joint against leakage is essential, especially with metal bearing. A compression joint sealant or a liquid polyurethane joint sealant may be utilized to waterproof the joint. If localised concrete edge cracking is observed, the damaged portion is broken back and patched using rapid hardening concrete.

Removal of vegetation, debris and stones from the joint is a routine maintenance activity.

5.2.6 Discussion of Common Alternative Replacement Joint Types

Some Expansion Joints as illustrated by Bridge Joint Association, Typical DoR Standard design and some other commonly used typical joints are shown in figures in Appendix.

'Nosing' type joint and asphaltic buried joint among the joints from the Bridge Joint Association are simpler in installation and maintenance but these call for use of proprietary compounds as well making the works costlier. Nosing type joint has the benefit of not needing steel armoring and associated fixings. It is considered that the nosing can be cast with a high strength concrete.

The important factors for consideration in the selection of an appropriate replacement joint are:

- traffic type and volume
- ease of installation
- time for installation

- Local sustainability, meaning minimum imported materials
- cost
- Different solutions for fixed and free joints

5.2.7 Typical Trial Joint Replacement Details

In Nepal, the treatment of expansion joint failures have been by filling the damaged expansion gap with asphalt or similar material to adhere them. The bridge component of DFID funded Road Maintenance Project carried out several demonstration works on expansion joint replacement with the Sliding Steel plate type as shown in fig 13 in Butwal Narayanghat section. These joints actually are even having the similar Sliding Steel plate type. Some demonstration contracts were carried out as compression seal type expansion joint as in fig 12 in Prithvi Highway. However these replacements did not last long and thus not found to be very successful.

Another DFID funded Bridge Upgrading and Maintenance Project carried out Compression Seal type expansion joints as shown in fig 14 in East West Highway and Prithvi Highway. An expansion joint without any steel angles was also carried out as a trial.

The Compression type expansion joint has following advantages:

- The joint angles can be installed in short lengths allowing half carriage way working.
- The compression seal can be installed across the whole joint at one go after the casting is complete.
- Installation is fairly simple.
- The seal width can be selected to cater for a wide range of joint gaps that are found on the existing bridges.
- The joint is unaffected even if the deck is jacked up for some other purposes.

The disadvantages are that the seal may be displaced, the anchorages to steel angles and the concrete around it may break under the traffic loading.

The deck must be broken out carefully to avoid breaking through the deck soffit. The replacement joint requires the complete break out of the old joints. Formwork is necessary to fix the new joints and cast in the position. The steel angles for the replacement are either tack welded or preferably tied up with the deck reinforcement and the angles are correctly set to the correct finished level. Replacement concrete is to be a designed high strength mix with additives to improve workability, reduce water demand and increase the rate of gain of strength. A bonding agent is recommended for the deck repair.

During the reinstallation work, it is very important to use a low shrinkage concrete with a high early strengthening agent and to minimise any vibration during the concreting. The joints often need to be cast in two halves to maintain the road open, with the deck repair cast first. Positive traffic control is essential to safe operation and will include advance signing, coning and traffic lights, with a publicity programme.

5.2.8 Immediate/Emergency contingency Action

As a temporary measure, asphalt patching work shall be carried out to prevent further deterioration after removal of the cracked asphalt concrete and concrete and thoroughly cleaning the exposed surface. Permanent measures must be programmed to reinstall the expansion joint. Pending replacement of the joints the following action is recommended:

- Remove all loose material and fittings. This includes loose stones and debris, loose top plates and angles. These joints are past their useful life and a loose angle causes more damage to the joint than would happen to the joint with the angles removed.
- Pack the top of the movement joint with any compressible material, preferably bitumen mastic, to seal the joint.
- Fill areas of broken concrete and pot holes with premix.
- Saw cut the premix along the line of the joint and fill the saw cut with hot poured bitumen.

5.3. BEARINGS

The function of bearings is mainly to transmit the superstructure load to the substructure and to permit bridge articulation; provide for longitudinal and rotational movement. Sliding plate, rocker and roller types are among steel bearings used on long span bridges while the elastomeric bearing, using natural rubber and steel plates, is commonly used on the intermediate span bridges. In short span bridges, less than 12 metres, bearings need not be installed, or may be of a very simple form such as a bitumen or felt strip acting more as a de-bonding layer. Bridge bearings are of vital importance to the function of the structure. If they are not kept in good working order, very high stresses may be induced in the structure with resulting damage. As with bridge joints, bearings are not expected to last as long as the bridge therefore bearing need to be replaced. Careful inspection and maintenance can extend the service life of bearings.

5.3.1 Problems with Bearings

Bridge bearings are designed to transmit loads to the substructure and to permit a certain amount of movement. Any restriction to bearing movement will lead to the forces between sub-structure and superstructure which would otherwise have been released. Common defects in bearings result from:

- defective manufacture and/or materials
- inadequate design
- poor installation
- lack of or no maintenance

Of the above problems, improper installation and inadequate maintenance are the greatest problems in Nepal. The excessive friction forces placed upon the bearings due to dirt and debris accumulation and corrosion cause excessive damage to the girders or the bridge seat.

Some of the early observable defects are corrosion, accumulation of dirt, debris and standing water, jamming, dislocation and physical damage. Poor concrete or loss of concrete support to the bedding material is an associated construction defect. Displacement resulting from seismic forces has also been observed in the Eastern Region.

5.3.2 Corrective Action

Routine cleaning works on and around the bearings i.e. removal of dirt and debris is essential to prolong the function of the bearings. More advanced defects call for detailed investigation prior to corrective action. Repairs or replacement may require traffic restriction or temporary diversion, although it is not unusual to permit usual traffic with properly designed falsework. The bridge will need to be lifted in the course of replacement or more extensive rehabilitation with appropriate jacking system and temporary supports. The Design Section Bridge Unit has a set of jacks that can be applied in most circumstances. The lifting of bridge decks is described in Appendix C.

5.5.3 Elastomeric Bearings

Elastomeric bearings are found in a number of bridges in Nepal, including the long span Pattani Bridge on the [illegible] Rajpath. They are a competent bearing and resistant to corrosion, readily available from a number of sources in India. Premature failures, observed as cracks, splits, tears in the neoprene materials and excessive deformation are common. Once damaged there is little that can be done in the way of maintenance other than replacement.

Common defects are:

- Displacement of bearing pad
- Rusting of steel laminations
- Debonding of steel elastomer
- Excessive deformation or bulging of elastomer
- Splitting of elastomer
- Embrittlement of elastomer from effects of poor manufacture or contamination
- Cracking of plinths due to overstress
- Cracking of bearing plinths from corrosion of reinforcing steel.

5.5.4 Sliding Bearings

Sliding bearings tend to be found on older bridges. The metal on metal interface is not particularly efficient due to a coefficient of friction at the higher end of the bearing design spectrum. This is exacerbated in the presence of water and other contaminants where the occurrence of corrosion on the contact surfaces can render them virtually ineffective. With the development of this type of bearing improvements are observed where one of the plates is given a curved contact surface, allowing rotational capability. When the steel plates are dowelled they form the fixed end however some bridges are observed un-dowelled at both ends with movement taking place at the end where the least frictional resistance is developed. A copper, stainless steel or PTFE layer interface or coating to the steel plates is much more efficient with greater corrosion resistance.

For sliding plates, lubricant should be applied after the bearings have been cleaned. External bearing surfaces should be repainted. It can be difficult to apply grease to mating surfaces therefore a lighter grade lubricant should be applied first. Bearing replacement should not be undertaken without first trying to free a corroded bearing by lubrication. Copious oiling should be allowed to soak into the contact interface and the bearing observed over a reasonable temperature to see if it releases. Lifting the bridge, separating and cleaning and lubricating the contact surfaces should be tried next before replacement. As a general rule only consider replacing bearings where restricted movement is causing structural damage. These bearings are better enclosed in a grease box to keep them clean.

Common defects are:

- Rusting of the bottom plate
- Delamination of the bottom plate
- Disintegration of anchorage bolts

- Unauthorized removal of bolts, straps, earthquake restraint straps or other elements
- Cracking of bearing plinths from corrosion of reinforcing steel
- Cracking of plinths due to overstress

5.3.4. Steel Roller Bearings

Roller bearing are capable of transmitting large vertical loads with minimal horizontal forces. They have a very low frictional coefficient and permit longitudinal rotation. The drawback are that they are rarely installed properly and regularly jam thus completely defeating the purpose for which they were installed. It may result, in rare cases, due to excessive loading or poor material. Local damage due to incompetent installation is widespread. Damage is evident in buckling and chipping of bearing guides and damage of fittings such as bolts, rack and pinions, guides, plates, pins and lugs etc.

Corrosion of roller bearings can also be a problem although they often look worse than they actually are. The contact plates and rollers are usually a little higher than the surrounding dirt and debris and cleaning and a coating of ordinary grease on steel contact surfaces and rollers can usually restore them. They are often enclosed in grease boxes and the premature corrosion of the grease boxes can give a misleading impression of the bearing condition inside the corroded box.

Correct installation of roller bearings is essential. They must be set out accurately to reflect the movement of the bridge, both sub-structure and superstructure, to ensure that the bearings move properly along the guides. Jammed roller bearings can be observed at the Sunkosi Bridge on the Kodari highway in the Eastern Development region. Here, bridge movement takes place in deflection of the slim piers. Loss of bedding mortar has occurred on some of the roller bearings on the main suspension bridges. The consequences of poor quality bedding mortar is a costly repair process.

Common defects are:

- Rusting of the roller surfaces and the bottom plate
- Delamination of rollers and bottom plates
- Debris under and around roller preventing movement
- Disintegration of anchorage bolts
- Unauthorized removal of bolts, straps, earthquake restraint straps
- Cracking of bearing plinth due to corrosion of reinforcement or overstress

5.3.5 Special Bearings PTFE etc.

A number of special bearings have been used in Nepal, generally to suit special circumstances. The notable structure is the Karnali Bridge where the multi-directional bearing is unique. Bearing details are addressed in the maintenance manual for the Karnali bridge. This type of bearing has been provided in Pedo Khola of Kodari highway as part of rehabilitation exercise to accommodate excessive ground movement. These bearings have a stainless steel/PTFE interface and are permanently lubricated. Excessive movement and deflection seals are indicative of problems in this type of bearing.

Other steel bearings include knuckle type, linked rocker and pinned types. The latter are incorporated in some arch bridges to permit two-pin and three-pin articulation.

Reference should be made to the manufacturers instructions and maintenance manuals for bearings where these are available. Bailey bridges and Callender Hamilton have their own type of bearing, both galvanised for long service life. The Bailey bearing is a fairly simple type as main bridge articulation occurs in the pinned truss connections.

5.4 EARTHQUAKE RESTRAINTS

Earthquake or seismic restraints are often used with the bearing installation. Their purpose is similar to that of the bearing, to control the imposed seismic force effects between deck and sub-structure. They go a little further in that they also act as a fail-safe device to prevent displacement of the deck.

They are found in the form of a simple and rudimentary holding down arrangement, either steel strap or channel, to restrict effects of vertical acceleration. Similarly lateral stops restrict the effects of lateral acceleration. The stops are in the form of concrete blocks, steel brackets or elastomeric pads. Modern designs may use proprietary Shock Transmission Units, or STU's.

In Nepal there is a big gap in the maintenance of earthquake restraints. Many are corroded out at the base and others are noted to be partially dismantled or damaged. Accordingly, the immunity of bridge structures from the effects of seismic activity is much reduced. This can manifest itself in structural damage due to excessive movement of the bridge. Rectification of corroded holding down straps usually requires breaking out of the corroded strap and installing a new fitting. This is not an easy operation due to the extent of the required break-out. The prevention of corrosion by simple cleaning and painting is the best course of action.

5.5 BRIDGE PARAPETS

Parapets are barriers built at the outer-most edge of the roadway or footpath to guard against accidents and guide the movement of both pedestrian and vehicular traffic. Parapets normally do not contribute to the structural strength of the bridge. Their absence could have a very high risk of public safety. The typical types in Nepal are reinforced concrete and steel rail/tube rail. Some timber parapets are used on older timber bridges on feeder roads.

5.5.1 Parapet Design

Parapet design rules vary significantly throughout many countries. In Europe and America where the cost of motor vehicle accidents on major highways are appreciable and road safety standards strictly applied, parapets are designed to withstand stated levels of vehicular collision. The design level varies with road standard and location and systems vary between steel post and steel rail to solid concrete barriers. Bridge approaches are often augmented with metal safety barriers. A different standard is applied in other countries with a concrete kerb up-stand of the order of 225 to 250 mm used either at the road edge or along the railing line to retain vehicles.

5.5.2 Parapets in Nepal

Parapets used in Nepal reflect the applied standard of the donor country. Concrete is the predominant structural medium particularly with pre-cast railings. On the whole the parapets are not particularly effective at restraining vehicles. In some examples such as the tubular steel railings used along the Prithvi Highway, many of which are in high risk locations, they are virtually useless in retaining vehicles. A more successful form of barrier is the use of the raised kerb along the road edge line. This can effectively protect the footpath and often minimise serious damage to the handrail. Better quality parapets are observed in the more ancient bridges, the prestigious [illegible] Bridge having steel posts and rail with stainless steel fittings. Wherever a high motor vehicle accident frequency occurs it is imperative that the parapet design be reconsidered and suspect parapets be replaced with competent barriers. The Design Section Bridge Unit and Traffic Engineering Safety Unit have developed a number of parapet replacement improvement details some of which were implemented in demonstration contracts.

5.5.3 Typical Problems with Concrete Parapets

Local defects in the concrete railing are broadly divided into two categories: minor defects including concrete cracks, rebar exposure, honeycombing, and major defects, mainly caused by vehicle collisions, large scale delamination, rebar exposure and broken posts. To this end the major defects threaten the safety of traffic and pedestrian.

5.5.4 Typical Problems with Steel Parapets

Local deformations and/or rupture caused by vehicle impact is the main reason for local deformation and more serious damage. In the worst case, safety of traffic and pedestrian flow on the bridge will be threatened.

Paint deterioration is widely observed since the railings are exposed to impact and collision of vehicles, weathering and other environmental agents. It should be noted that paint quality and cover thickness are determinant factors for the service life of steel railings. Internal corrosion of the rail was observed in at least one instance where a galvanised tube railing was installed. Hollow sections should either be sealed or have drain holes drilled, or both.

Steel parapets can deform if no allowance is made for temperature movement. Expansion joints have to be made in parapets and should reflect the movement in the bridge deck. The parapet expansion joint must be designed to transmit applied forces and not be a point of weakness.

5.5.5 Parapet Repairs

Minor concrete damage and local defects can be repaired by component patching. In the case of major local defects they need to be repaired by removing and replacing the damaged parts and could require reconstruction. Further details on concrete repairs are detailed in Chapter 6. Reshaping of the deformed steel can be considered for minor deformation. However, in order to ensure the safety of both vehicular and pedestrian traffic, more seriously damaged or ruptured railing parts must be replaced by appropriate steel sections or suitably reinforced with additional steel. Loose, corroded or lost nuts or bolts and connections must be repaired or replaced. The deteriorated parts must be re-painted. For this purpose, defective painting and, rusted or corroded surfaces should be thoroughly cleaned and the coating renewed in accordance with the Paint Specification.

It will be an advantage to the Divisional Engineer to carry some stocks of replacement parapet sections, both steel and pre-cast concrete for the types of parapets used within the Division.

5.5.6 Emergency Repairs

In the instance of replacement sections in stock a temporary repair is essential. This might comprise temporary shoring but the use of high visibility markers and warning signs are also recommended to alert road users of the problem. A Gabion basket can effect a reasonable temporary repair where access permits. A traffic speed restriction may need to be applied.

5.6. FOOTPATHS AND CURBS

Footpaths are the portion of the bridge serving the pedestrian traffic. They are commonly elevated above carriage way level to provide safety to users and to separate the designated areas. On narrow bridges and bridges with low traffic usage, the whole carriageway area may be shared or the pedestrian area may be designated by road lines.

Kerbs are barriers usually constructed parallel to the side edge of the carriageway to guide the movement of vehicle wheels and safeguard parapets, hand-railing, truss chords or other appurtenances existing outside the carriageway limits. They protect the pedestrian from injury due to vehicle hit.

5.6.1 Kerb and Footpath Design

Kerb and footpath may serve a design purpose in containing the highway vehicle loading within the main bridge deck area thereby restricting the occurrence of high edge moments. Notwithstanding this the footpath must be designed for accidental wheel loading unless the traffic is physically restrained by a restraining parapet along the road edge. There are indications of sub-standard footpath design in locations along the Prithvi Highway and Arniko Highway in some of the older bridges where the footpaths (and parapets) have collapsed. In these circumstances under-reinforced footpaths are cantilevered from the bridge. The Design Section Bridge Unit designed a combined parapet and footpath repair improvement to rectify the deficiency. A typical detail is given in Appendix which is to be used as a demonstration contract.

5.6.2 Kerb and Footpath Construction

Concrete footpaths and kerbs are common in Nepal. They are usually placed on top of the concrete bridge deck, or may also be a part of the wearing course or deck itself. Both in-situ and pre-cast concrete are used. On truss bridges with timber decks a timber kerb may be located alongside the truss member to reduce the possibility of vehicular impact with the truss. Proprietary steel kerbs and footpaths are supplied with modular steel bridge systems such as Mabey and Johnson Bailey Bridges.

5.6.3 Problems related to Kerb and Footpath

Pre-cast panel footpath slabs usually damage as the result of wheel loading. Loose slabs can occur due to improper construction techniques creating hazards to pedestrians. Minor damages such as edge flaking and other concrete defects can be corrected by patching work while loose slabs can be re-set. Major damage such as broken or missing slabs have to be replaced with a new unit. It is always useful to maintain the footpath area and remove vegetation.

Kerbs can be displaced by impact or vehicle collision. Serious defects such as missing kerb units or seriously fractured units must be reset or replaced otherwise they can become a serious safety hazard.

5.7. BRIDGE APPROACHES

Bridge approaches can be in embankment or in cut depending on the topography of the location. As well as the approach construction, the approach alignment is an important factor in how well the bridge will function. Generally there is little that can be done to rectify the poor alignment at a particular steeply sloping location, although improvements made be necessary. Road furniture and road markings can serve to improve safety against and protect the bridge user. The approach road construction defects are often more of a problem.

5.7.1 Problems in Bridge Approach

Settlement or surface distortion mainly due to soil consolidation or compaction causes bumps and uneven approaches. This tends to be greater between bridge surface and approach road where impact forces enhance the problem both on the bridge deck as well as the adjacent approach.

Piping failures create local depressions and deep holes in the embankment behind the abutment as soil material is washed out. Piping failures are mainly caused by water flow concentration. Surface water, if not channelled and controlled, lead to erosion damage and flanking of the road edge. Both phenomena are a danger to the road user and can lead to rapid deterioration in bridge serviceability if left uncorrected.

5.7.2 Correction of Defects

Minor potholes on the bridge approach are treated by pot hole patching. A square or rectangular cut should be made to confine the pothole area and a bituminous tack coating applied before placing asphaltic concrete and compacting. Too many small potholes give a poor riding surface and it is considered that the more significant areas of damage along main Highways should be reconstructed to a full lane width and a minimum of one metre in length. Where the pothole number or size are considered excessive (compared to the total paved area), the pavement must be scarified and replaced by an overlay.

In the bridge maintenance operation where the maximum settlement depth on the approach is not more than about 20cm the distorted area can be overlain with asphalt concrete. Where the settlement depth is more than 20cm, total replacement including excavation, embankment, base and sub-base course work and surfacing may be carried out under road maintenance.

The piping defect is basically repaired by filling with adequate compaction. Small scale piping can be repaired under the bridge maintenance operation. The work sequence is excavation, filling with compaction sub-base, base course work and surfacing. Large scale piping should be rehabilitated under road maintenance. Particular attention should be placed on improving drainage to eliminate surface water erosion and/or piping action.

5.8. BRIDGE SIGNS AND BRIDGE MARKINGS

Standards for Bridge Signs and Bridge Markings have been developed by the Planning and Design Section. Wherever possible, damaged, deteriorated or defective signs and markings should be remedied to the standard.

5.8 PROTECTIVE SYSTEMS

A Specification for the Protection of Steelwork against Corrosion is given in the DOR Standard Specification for Road and Bridge Works.

5.8.1 Bridge Re-painting

As the environment in Nepal is fairly mild, corrosion of steelwork is not as significant as in many other industrial countries or countries with a marine environment. Paint protection therefore has a reasonable service life before breakdown of the paint system starts. The service life depends on the standard of the initial protection. Nevertheless, a paint system without any maintenance will eventually break down and corrosion will develop. Bridge re-painting therefore remains an important maintenance activity.

Tamor Bridge, in the Eastern Development Region, was re-painted, to a particularly high standard. Poor surface preparation and limited availability of industrial standard coatings resulted in maintenance paint systems breaking down after a short period of time. Painting Specification has been included in the DOR standard specification.

5.8.2 Galvanised Protective Systems

Some proprietary modular steel bridge systems are supplied with a galvanised protective coating system. Such a system can be observed on Callender Hamilton Bridges and most of the newer type of Bailey Bridges. (The older Bailey Bridges and some from sources other than the UK are painted). The galvanised protection will have an excellent service life, well in excess of 20 years before first maintenance is required. If minor touch up to the galvanised coating is required to areas of local damage, two coats of a zinc rich paint, such as Galvafroid, should be applied.

5.8.3 Protection of Miscellaneous Structural Steel Element

The protective systems to typical structural steel elements such as steel cables, bridge bearings and steel connectors and hangers used on suspension bridges are given in the DOR standard specification. Protection to the elements is usually provided by a coating of ordinary grease. A high performance grease, such as that used for mechanical moving parts in plant and vehicles is suitable but tends to be more expensive than an ordinary grease available from the local market. Obviously the items must be cleaned first to remove dirt and other deleterious substances before the application of the grease. On bridge bearings, further protection is provided by enclosing the bearing in a simple grease box. Similarly the protective system on suspension bridge cables is enclosed in a protective bituminous felt to provide an outer shield against the elements and the effects of ultra-violet radiation.

4. CONCRETE REPAIRS

6. CONCRETE REPAIRS

6.1. SCOPE

General procedures for the repair of concrete damaged by corrosion of steel reinforcement, poor concrete such as honeycombs and concrete damaged by external impacts such as vehicle impacts are discussed here. The repair methods do not apply to concrete damaged by chemical attack such as by ASR or sulphates.

6.2. APPROACH TO REPAIRS

It is important to identify the reason for the damage and extent of repair that govern the choice of repair methods on the specific situations. The extent of the repair is determined from investigation.

1. No repair work should be done until the reason for failure has been well established. When the reason for failure is because of the ingress of aggressive agent such as chlorides from an external source, preventing further ingress should be the first priority before repairs of damage are contemplated.
2. The implications of the damage and of subsequent repair operations on the stability of the structure must be considered.
3. The most sophisticated and "fool-proof" material or system will not provide a satisfactory repair if improperly used.
4. Repairs should be entrusted only to skilled construction workers who are properly trained and supervised. Normal concreting skills do not completely translate to repair work.
5. A number of materials suppliers provide complete systems for repairs, including premixed mortar or concrete and final coating materials. When these systems are used the manufacturers' specifications should be followed.

6.3. INVESTIGATION OF DAMAGE

The symptoms are investigated in detail. Many are visible such as cracking, spalling and rust stains however some are not visible such as pitting corrosion. Cracking due to corrosion generally follows the line of the reinforcement. Cracking may originate from other factors, natural structural response, thermal or shrinkage, ASR etc.

Sufficient investigation should be made to identify the cause and extent of any problem. In many cases the cost of a full survey, completely separate from the repair operations, will be prohibitive. For example, it may be wrong to recommend full scaffolding to facilitate a survey when subsequent repair work will also require full access to the structure. In these cases the specification may be one where the two operations are combined. Field investigations may need to be supported by in-situ and laboratory tests depending on the importance of the investigation. The investigation could be part of a separate consultancy contract.

Specifications for concrete repair are given in the Standard Specifications for Road and Bridge Works: 2700 Repair of Structures. Special or additional specifications are prepared by using the results of the investigation. Some times a proper specification based on bills of quantities should be followed. Structural repair operations are however much different from new works. Often the problems are only truly revealed in the course of the remedial work. It is necessary therefore to have a workable Variation Order procedure in operation to prevent undue delay and disruption caused by late instruction and payment and seeking the authorization.

The investigation or survey should indicate the following:

1. Inadequate cover where carbonation has reached the steel. Inadequate cover may be poor quality concrete or low depths of cover (or both). The survey should establish depths of carbonation and cover to the steel. The specification may call for a full cover-meter survey with all concrete having less than a (minimum) cover being treated.

2. The extent of the problem. All physical damage is recorded. In many cases it may prove that the visually obvious damage is all that requires attention but usually the survey will indicate areas of low cover, high chloride etc. which may cause problems in the near future if not attended to.

3. The presence of appreciable amounts of chloride ion in the concrete. Levels of more than 0.3% Cl ion by mass of cement (say 0.05% Cl by mass of concrete) may be taken to present a risk.

It should be stressed that if the presence of chloride is the cause of failure, further damage to areas close to the repairs may occur. In many cases local patching with the acceptance that further work may be required in the future is the most economical solution.

Cladding panels or concrete rendering (plaster) sometimes represent visual indication of serious underlying problems. It is most important that the investigation pays particular attention to the fixings and their surrounding concrete in the case of panels and the concrete under the render where this is used.

6.4. REPAIR METHODOLOGY

The repair methods can be divided in to three categories: (a) Patching by plaster or micro concrete (b) Casting the damaged portion (c) Injection the cracks. Resin mortars are more appropriate to small repairs whereas larger volumes may call for re casting or sprayed concrete. Cementitious or polymer modified cementitious materials are used for more extensive patch repairs. Where there is the possibility that resin mortars will de-bond and where the additional layer is to be greater than 12 mm a polymer modified cementitious material should be considered. In the case of stressed structural members, cutting out concrete behind the reinforcement can lead to the need for extensive propping.

6.4.1. Cutting Back the Concrete

The concrete should be cleaned, preferably by water jetting. All defective concrete must be removed off. Cut back additional concrete to an un-carbonated zone (established by spraying with phenolphthalein) and to expose all the corroded metal. Except when it is forbidden by structural considerations, the cutting back should be to a level behind the steel so as to permit access of cleaning tools to its back surface. Generally concrete should be cut back to a minimum depth of 25 mm behind the reinforcement in order to provide adequate room for new compacted concrete.

Ensure that the areas to be repaired have clean cut edges and particularly avoid "feather edges". It can be sometimes be useful to get an even face, but the faces of the saw cuts must be thoroughly roughened before reinstatement. Where the "excavated area" has a depth of less than 10mm cementitious repairs should not be recommended.

6.4.2. Cleaning the Exposed Steel

It is essential that all loose and flaky rust is removed. If chlorides is implicated then removal of all corrosion products is recommended. The steel should be cleaned to a standard compatible with the repair materials paying equal attention to the rear surfaces of the bars. Sand blasting is the preferred method, but high pressure water jetting or mechanical devices have been successfully used. In the absence of chlorides sand blasting of the reinforcement will be adequate, particularly for resin based repairs. For hand cleaning use scrapers. Wire brushing is not recommended, generally only producing a burnished finish. The use of "rust converters" appears to be deprecated by many authorities. However, some specialist repair firms advocate their use particularly when the steel cannot easily be cleaned to the required standard. In these cases only approved materials for concrete repair should be used. The manufacturer's recommendations must be followed. It is recommended that only materials based on phosphoric acid which are free from chlorides should be used and then only by specialists who are familiar with their successful use.

Make arrangements for inserting new steel if this is required to restore the engineering properties of the structure. Steel may be inserted into the exposed surface of the broken out concrete to give a mechanical key to the repair. This is particularly appropriate when, for example, corners are to be made good at the soffit return.

Where defective steel is removed by cutting out, replacement steel is lapped in. Often the area of the breakout is increased in order to obtain adequate lap lengths. In some cases new steel is welded onto existing steel remain after the defective areas are cut away. This practice is not recommended. Strict site control of the welding operation is necessary and the welded areas can give rise to high stress concentrations in service. Sometimes however where it is not possible to lap in new bars, welding may be permitted.

6.4.3. Coating the Steel

Coating the steel with an impermeable material is recommended by some authorities when the concrete contains high levels of chloride which may migrate back through the repair and also when very low cover to the steel is the initial cause of damage and the cover cannot be increased after repair. In general coating is not required as an anti-corrosive treatment with cement based materials which themselves are able to passivate the steel. Reference should be made to the manufacturer's instructions for resin based materials.

When adequate cover can be provided to the steel with a cementitious repair and when chlorides are not present, coatings are not strictly necessary, but may still be preferred. Often the passivity of new concrete is adequate to obviate the need for coating and the extent of the breakout should mitigate against a repeat of contamination.

Where coatings are used it would be an unreasonable responsibility on repair workers to specify coatings in some defined situations and not others. It is more realistic to specify coating all the exposed steel. It is important that the rear surfaces of the exposed steel also receive the coatings.

When resin coatings are used the manufacturer's assurance that they are compatible with other elements of the repair system should be obtained. Resin and latex coatings may incorporate cement. It is helpful to apply coarse grit to the final coat to assist bonding of the repair mortar.

4.4.4. Bond Coats

The purpose of the bond coat is to achieve effective adhesion between the repair and the old concrete. It should be noted that if used inappropriately, it can provide worse adhesion than if nothing had been used. It is essential that the repair material must be applied before adhesion properties begin to go off.

Latex and polymer emulsions, epoxy resins and cement-water slurries have all been used. Water sensitive materials such as PVA should not be used. Latex and polymer emulsions are widely used in many industries. It is essential that the material used for concrete repair has been properly formulated for the purpose. Emulsions are usually stabilised with surface active agents and if these are not compensated for by [illegible] a "frothy" joint which has little strength may result.

Many formulations specify that emulsions should be mixed with sand and cement to provide the best bond and the manufacturer's recommendations should be followed. The material used should be compatible with any modifier used in the repair mortar.

Bond coats which also act as barriers to the migration of chlorides from the concrete back into the repair material are doubly useful. Where the repair does not incorporate a bond coat the parent concrete is generally soaked with water for 24 hours prior to the repair.

4.4.5. The Repair Mortar or Concrete

An aggregate/cement ratio of about 4:1 by mass is preferred but the grading of the aggregate must be such that a minimum water content is required to produce a workable material. The sand should have an acceptable grading and for fine concrete, coarse aggregate up to 10mm nominal size should be used in minimum depth repairs and 20mm for larger repairs. Washed aggregates free from silty material should be specified. Ordinary Portland cement is preferred. There is not likely to be any advantage in using rapid hardening Portland cement. Only sufficient water to make the concrete/mortar cohesive should be added. Forced action mixers are preferred although efficient hand mixing may be satisfactory. Minimum amounts of water are necessary to reduce drying shrinkage of the repair. The final strength of replacement concrete should be as close as possible to the parent material to promote homogeneous action. The existing concrete strength should be determined during the investigation.

Drum mixers should not be used. Some specialists hand mix and then pass the mortar/concrete through the appropriate aperture sieve to break up agglomerates and then re-mix. Modifiers such as acrylic or latex polymers or waterproofers added to the repair material are recommended and should be added with the mixing water. Materials designed for the job should be used and should be compatible with bond coat used.

With mortars, the repair mortar must be firmly applied by hand or trowel and pressed to give full contact with the base concrete and with all surfaces of the steel. Pay particular attention to the volume behind the steel. Apply mortar in layers 10–15mm thick, each layer being applied while the previous layer is plastic. Particular care should be taken with the interface between the repair and the sides of the "break-out". The mortar should be used within the recommended time from mixing and must not be re-tempered with extra water. The final layer is finished to the required profile and the repair is then cured. Close wrapping with plastic is used initially, but most systems require air-curing after 1 or 2 days. When specialist materials are used the manufacturers' instructions must be followed.

Some jobs which require the application of large amounts of repair concrete are better suited to rigging up formwork and pouring in a free flowing mortar grout or concrete. To achieve this flowing properties while maintaining a low water content probably calls for the use of Super-plasticisers, but it is best to use proprietary materials in this instance. Small sprayers have been used to apply wet mortar or concrete for patch repairs, but in general sprayed concrete is used for refurbishing operations. Sprayed concrete should only be applied by specialist contractors experienced in its usage.

6.4.6. Final Coating

It is not generally possible to apply a repair which so matches the surrounding concrete that it will remain 'invisible' for the life of the structure, so a coating is recommended if a good visual appearance is desired. If carbonation is the cause of failure it is sensible to coat not only the repair but also the rest of the structure. The coating should be waterproof but allow the transmission of water vapour. Some coatings are claimed to permit the passage of water vapour but no CO2, the latter molecule being larger.

The structure should be cleaned before the application of the coating but this should have been done before the repair work started. Some coatings require that the concrete is finished with a thin trowel applied material before coating. This is to present a smooth finish with no blow-holes or other imperfections so that the final coating can be applied as a continuous film. This type of coating should not be used without this skim coat. There 'high-build' coatings are available which may make the skim-coat unnecessary. Coatings should not be applied to structures affected by chlorides.

6.4.7. Operational Factors and Restrictions

The following operation factors may affect the design and specification of the repair:

- possession of the site, whether this is un-interrupted or restricted
- the effect of vibrations on the structure on the repairs themselves
- access limitations where part of the structure is used by through traffic and restrictions over rivers
- the amount of scaffolding needed to access the repair
- temporary diversion for drainage, services etc.
- removal of road furniture
- maintaining access for the public
- effect of noise, dust, spray, grit blasting from breaking out the concrete
- weather restrictions, hot, cold, wet, windy

6.5. REPAIR MATERIALS

6.5.1. Resin Mortars:-

Polyester resin, epoxy resin, modified epoxy resin

Although cementitious mortars are usually preferred, resin mortars have following advantages:

i) Ability to be applied in thin sections

ii) Rapid development of high strength.

iii) Ability to cure/harden under environmental conditions outside of the range of cementitious mortars.

Both polyester and epoxy resin binders are fine syrupy liquids which remain stable for long periods under normal storage conditions. They harden rapidly by a chemical reaction when a second component, the hardener, is added.

Polyester Resin
The hardener is the filler, a powdered catalyst, the precise quantity of which is not very critical. This facilitates scope for adjustment of the filler content to suit the work in hand i.e. semi-fluid grout, trowel able mortar, or stiff mix to be rammed into place. The material is capable of rapid reaction but then incurs a high degree of shrinkage. Care is required.

Epoxy Resins
These harden by an additive chemical reaction, i.e. the addition of a reactive hardener, not a catalytic one. Accurate quantities must be matched for proper strength development. Some thermal contraction occurs contraction on cooling.

Resin mortars are commonly confined to small works. Shrinkage may be as low as 20 micro-strain in well formulated epoxy resins although the effect of bulk upon the build up of exothermic heat must always be considered. Polyester mortars generally do not need a surface primer, however, a separate primer may well be required with the epoxy resin.

Strength attained is generally in the range of 50–100 N/mm².

Disadvantages of resin mortars

- Shrinkage movement.
- Co-efficient of thermal expansion 65×10^{-6} per °C compared with concrete at 12×10^{-6} per °C.

Mineral filler reduces this to about 2.5 differential. Therefore there is a risk of differential thermal movement at bond line which can disrupt the joint.
Care is required to avoid a mismatch in properties between the repair system and the substrate.

6.5.2. Cementitious Repair Packages

A great variety of systems are available from specialist formulators. They range from prebatched grouts and mortars to multi-part systems incorporating bond coats, and corrosion primer for rebar, specialist mortar, levelling mortars (finishing coats) and anti-carbonation coating applied over whole structure after repair.

6.5.3 High Slump Concrete or Superfluid Micro Concrete

The repair concrete often needs to be cast in narrow spaces and places congested with the reinforcement. The demands for free flowing concrete of smaller size aggregates. High slump concrete with water cement ratio less than 0.42 can be obtained by mixing super plasticizer. Appropriate mix can be obtained by various trial mixes on site with slump as high as 200 mm. The concrete can be placed by simply pouring or pumping. It can be cast to the soffit of slabs by placing through drill holes. Bleed holes are provided to allow air to escape.

6.5.4 Materials for treatments of Rusty Steel

Applications of corrosion inhibitors are a possible method of overcoming the necessity of removing corrosion products from rebars but ample care is required in their selection and further research may be required to determine if the application has any adverse effect on steelwork outside of the repair area by intensifying the corrosion reaction in that area.

Cementitious Coating to steel reinforcement with the incorporation of polymers are intended to assist in developing the bond between the rebar and the repair mortar. This treatment is questionable about that it may reduce the alkaline benefit to the steel.

Epoxy Resin Coatings have a long history of success in the protection of external steelworks. They have also proven good performance in protecting steel reinforcing when factory coated prior to incorporation in reinforced concrete. However, it may be unwise to apply coatings when only a limited length of bar is exposed.

Zinc rich epoxy coatings are accredited with keeping the reinforcing in the repair zone rust free and without affecting the exposed steel outside of the repair zone. These may provide the best solution.

6.5.5 Bonding Coats

A cement slurry of low water cement ratio, as a bonding coat, is found beneficial to prime the previous deepened surface. The addition of a natural rubber latex or synthetic polymer dispersion in lieu of part of the water to the slurry mix can improve adhesive properties.

It is to be noted in both cases that the bond coat is not allowed to dry out before the application of the repair mortar. If it does so a second coat of slurry bonding will not necessarily redress the problem. The only recourse is to scrub back to clean concrete and start again.

Various proprietary bonding coats are also available from the manufacturers.

6.5.6 Fairing Coats

If a concrete structure is to be protected by an anti-carbonation coating it is first necessary to prepare the concrete surface. Preparation, removing all dusts, dirt, algae, grease, laitance, old coatings, traces of mould oil and incompatible curing membranes are of great importance.

A cementitious fairing is needed to bridge larger blowholes. This is sometimes known as a smoothing or levelling coat. A variety of systems are available, some applied thinly and squeezed into defects, and others in the form of a 2-3 mm sand-cement based polymer modified mortar.

6.6. REPAIR TECHNIQUES

The preparations prior to repair have been discussed in the preceding sections. Placing of Repair mortar or concrete will vary with the type of the repair and the system being used. Work methods for mortar patching and normal concrete have been discussed earlier. Special techniques used for Superfluid Microconcrete and Sprayed concrete are described here.

6.6.1 Superfluid Microconcrete

It is placed by pumping or pouring. The speed of placing is important; the material generally retain flow properties for 30 min with agitation.

Vertical Sections:
Use 'bird-beaks' or front chutes. The soffit must be formed sloped and sloped in elevation with vent tubes. This will prevent water from being trapped in the casting and will allow air to escape. Protruding castings are dressed back after removal of formwork.

Soffit Repairs
Drill feed and vent holes through soffit of the slab. The concrete is fed into the area under a head. Thick sections are fed by gravity or pump into formwork. Bleed holes are provided to allow air to escape.

4.6.2 Sprayed Concrete
This is a repair technique that has been used in hydropower stations in Nepal, but not yet is used in bridge repairs. It is used to restore concrete after widespread spalling, e.g. from corrosion or fire damage. As it is a specialist technique the cost of the repair using this process must be carefully balanced against other alternatives. It is likely that for simple work or small structures, this method could be cost prohibitive.

There are two main methods of sprayed concrete:

- Gunite: cementitious material with maximum aggregate size of less than 10 mm.
- Shotcrete: cementitious material with maximum aggregate size greater than 10 mm.

Gunite is a mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto a surface using either a dry or wet process. The force of the jet compacts the material, which normally has a zero slump and can support itself without sagging on a vertical or overhead surface. Cement rich mixes (Aggregate/cement ratio between 1:3 to 1:4) is used.

High strength and density result from the impacting action of individual particles propelled from the gun nozzle at high velocity. Placing the mix in its final position in a single operation permits the use of low w/c ratios with beneficial effects on strengths and density combined with low drying shrinkage. The necessity for a face shutter is eliminated.

Rebound particularly of the larger aggregate particles is a normal feature of placing. The proportion of mix lost in this way depends upon the type and grading of the aggregate used, the plane on which it is placed, overall gunite thickness and operator skill. An overall allowance of at least 25% may be taken as covering losses due to rebound, surface trimming and wastage.

Dry mix guns have the facility to convey the gunite mix up to 80m vertically and 200m horizontally. Gunite is considerably more expensive per unit volume than conventionally placed concrete. Two distinct methods of conveying mortar and concrete exist, the dry mix and the wet mix systems.

Dry Mix System is original type and most common. A mixture of cement, sand and aggregate is fed into a special mechanical feeder. The material is carried by a stream of compressed air to a nozzle equipped with a water injection system. The nozzle converts the incoming streams of dry mix into mortar or concrete of the correct consistency and projects it onto the surface of application. In case of Wet Mix System, all the material, including water are thoroughly mixed before being introduced into a pump. Concrete is then pumped or squeezed along delivery hoses until it reaches the nozzle where pumped concrete is converted to sprayed concrete by the introduction of compressed air.

After sufficient set has been achieved a fine gentle water spray at intervals such as to keep the surface moist for 24 hours after placing. It can support itself of thickness up to 50mm in areas in the overhead without the use of a formwork shutter. The typical strengths are 50 to 54 N/mm2.

6.7. CRACK REPAIRS

Various types of cracks are shown in the volume 1 part 2 Appendix A of this guidelines. Structural cracks are fundamental in the tension zone, and concrete is also liable to crack in both the plastic and hardened states due to stresses intrinsically generated by nature of its constituent materials. Codes of practice establish acceptance limits for the width of cracks in structural concrete. There is no firm evidence that cracks up to 0.5mm will lead to corrosion, and the design limit of 0.3mm in our codes is therefore a visual limit, unconnected with reinforcement corrosion.

There must be a realistic assessment of the possibility of achieving structural restoration of a cracked member. If a structure is disturbed again after repair it will crack again. Following methods are used for crack repairs by injection.

6.7.1 Epoxy resin Injection :

It has high penetration property. Generally it is not practical to inject resins into cracks less than 0.2mm wide at the face. If the crack is of sufficient width to make entry feasible, the low viscosity resin systems are capable of penetrating into fine depths down to limits measured in microns. (Even thixotropic resins can go down to <50 microns). Unfilled epoxy resins are not recommended for cracks over 10mm; it is better to first pack the voids/gaps with single size fine aggregate then inject with unfilled resin. Polyester systems are also very effective.

6.7.2 Cement Grouts

It is used for the repair of wider cracks but normally require shrinkage compensation systems to be effective.

6.7.3 Injection Technique

Fit flanged injection tubes if crack is open, after removing surface dust. If the crack is blocked at the surface a "Vannon Flushed" drill hole is required. For this a hole is drilled at an angle to intersect the crack 50 mm down from blocked surface (this is to avoid missing a non vertical crack with a vertical drill hole). Injection tubes are then sealed into the drill holes. It is possible to check that drilling was successful by blowing air into the hole using a "bubbler". If air goes in then it is likely that it can be resin injected.
The crack is sealed between injection points. Injection point placing 2/3 times the depth of crack (average spacing 250 mm). Use a thixotropic resin if the crack goes right through structure to reduce/prevent resin loss. Stop pumping when resin reaches next injection point. Remove the injection tubes and sealing compound after completion of the operation.

Inject the resin using hand held gun for small jobs or 'mix in the nozzle' equipment for larger jobs (2 line twin volumetric pumps). Other systems use temporary vacuum feed or simply possible low viscosity resins.

6.8. THE SUPPLIERS OF REPAIR MATERIALS

There are various manufacturers worldwide which produce the materials for the concrete repair works. The addresses of some manufacturers are given in this guideline with their contact addresses.

APPENDICES

A Quick Reference Tables
B How to tighten High Strength Friction Bolts
C Lifting of Bridge Decks
D Norms for Recurrent Maintenance of Paved Roads (including Bridges)
E Typical Damage and Repair Details
F Typical Photographs

Appendix A
QUICK REFERENCE TABLES

Table No.	Details of Table
Table 1	Waterway and Bridge Protection Works
Table 2	Concrete Bridge - Typical Defects, Reason for Defect and Repair Method
Table 3	General Characteristics and Effectiveness of Resin Based Repair Material
Table 4	General Relationship Between Repair Material and Repair Method
Table 5	Structural Repair Method - Protection Approach and Corresponding Application Criteria
Table 6	Structural Repair Method - Strengthening Approach and Corresponding Application Criteria
Table 7	Structural Repair Method - Replacement Approach and Corresponding Application Criteria
Table 8	Functional Repair Method and Corresponding Application Criteria
Table 9	List of Manufacturers and Suppliers of Bridge Repair Materials

Table 1 : Waterway and Bridge Protection Works

Repair Plan	Method	Application Criteria
Slope Protection	Stone Masonry	1. Slope 1:0.5-1.5 2. Height: less than 5m 3. Application: Small to medium scale river
	Concrete Block Masonry	1. Slope 1:0.3-1.0 2. Height: less than 5m 3. Application: Stream and small to medium scale river
	Concrete Block Pitching	1. Slope 1:0.5-2.0 2. Height: less than 5m 3. Application: Medium to large rivers
Toe Protection	Dumped Stone	Small to medium rivers on relatively solid foundation
	Wire Mesh Gabion	Small scale river where foundation ground is relatively soft
	Concrete Block Mattress	Medium to large river with rapid flow velocity
	Sheet Pile	Normal water level at slope toe is more than about 1 m and it is difficult to provide base concrete under river bed at slope toe
River Bed Protection	Wire Mesh Gabion	Foundation Protection
	Dumped Stone and Wire Mesh Gabion	Local Scouring
	Spur Dyke by Stone Masonry	Large scale river
River Realignment	Spur Dyke by Concrete Pile	Medium to large scale river
	Embankment	Medium scale river

Table 2 : Concrete Bridge-Typical Defects, Reason for Defect and Repair Method

Defects	Reasons	General Repair Method							
		Injection	Patching	Coating	Surface Coating	Jacketing	Lining	Steel Plate Bonding	Additional Prestressing
Cracks	-Effect of Excessive Load (1)	X	X			X	X	X	
	-Design Deficiencies (2)	X	X			X	X	X	X
	-Improper Construction (3)	X	X	X	X	X	X	X	X
	-Environmental Effect (4)		X	X	X				
	-Disaster (5)	X	X	X	X	X	X		
	-Aggravation of Foundation (6)	X				X	X	X	X
Spalling & Section Loss	-Effect of Excessive Load (1)		X	X		X	X	X	X
	-Design Deficiencies (2)	X	X	X		X	X	X	X
	-Improper Construction (3)		X	X	X				X
	-Environmental Effect (4)		X		X	X	X		X
	-Disaster (5)		X	X		X	X		X
Rebar or PC cable Exposed, Corrosion of rebar or PC cables	-Design Deficiencies (2)			X		X	X	X	X
	-Improper Construction (3)		X	X	X	X	X		
	-Environmental Effect (4)		X	X		X	X		
	-Disaster (5)		X	X		X	X		
Discoloration	-Improper Construction (3)	X		X		X	X		
	-Environmental Effect (4)			X	X	X	X		
	-Disaster (5)				X	X	X		

Notes:

X Generally applicable

(1) Increase of dead and live loads

(2) Inadequate amount of rebars or PC force, inadequate concrete cover, wrong structural analysis or incorrect structural model

(3) Poor concrete quality, inadequate concrete cover, honey comb, poor cold joint, improper supporting or formwork, inadequate PC force

(4) Carbonation, chloride attack, acid attack, sulphate attack, alkali-aggregate reaction, shrinkage

(5) Fire, Collision

(6) Local scouring, reduced bearing capacity, effect of adjacent construction

Table 3: General Characteristic and Effectiveness of Resin Based Repair Material

Item	Epoxy Group	Polyester Group	Polyurethane Group	Rubber (Acrylic) Group
Adhesion	VG	G	G	F
Flexibility	F	F	VG	G
Durability	VG	G	G	B
Workability	G	G	G	VG
Waterproofing	VG	G	G	F
Alkali-Resisting	VG	B	G	F
Shrinkage	NONE	LARGE	SMALL	LARGE
Economy	F	G	G	VG

Note: VG : Very good
G : Good
F : Fair
B : Bad

Table 4: General Relationship between Repair Material and Repair Method

Type of Repair Material		Injection	Patching	Protective Coating	Formwork Grouting
Resin Based Material	Resin Mortar		X		
	Epoxy Resin	X	X		
	Flexible Epoxy Resin	X	X		
	Elastic Sealing Compound		X		
	Coating Elastic Membrane			X	
Cement Based Material	Polymer Cement Slurry	X			
	Polymer Cement Paste			X	
	Polymer Cement Mortar		X		
	Cement Filler Expansive Grout	X		X	
	Micro Concrete				X

Note : X: Means applicable

Table 5: Structural Repair Method-Protection Approach and Corresponding Application Criteria

Repair Plan	Method	Application Criteria
Protection work to Concrete member	Injection	a. Cracks are not active and its surface width is more than 0.2mm but less than 1.0mm. b. Reason of the crack appearance is due to shrinkage, creep of concrete, etc. c. No water leak and no liquid use d. No carbonation and no chloride attack 1) If surface crack width is more than 1.0mm, apply cement paste injection. 2) If crack surface is wet due to water leak apply expansive cement grout.
	Patching	a. Defects such as honeycomb, flaking, cavity etc. are active. b. Reason for these defects are possibly due to inferior concrete or poor workmanship, or due to traffic collision. c. Minimal carbonation, no chloride attack and no water leak d. Adequate concrete cover e. Defective area is localized f. In case that the cavity due to scaling etc., is relatively small and shallow, apply epoxy resin based material as a repair material, but if the cavity is extensive and large, use polymer cement mortar [illegible]
	Sealing	a. Cracks of which surface width is less than 0.20mm and not active b. Concrete is slightly carbonated c. Minimum concrete cover is inadequate d. No water leak (or water leak prevention work has been completed) e. Defective area is extensive
	Protective Coating	a. Crack are not active and surface width is less than 0.2mm b. No water leaks, no scaling, no flaking c. Minimal carbonation and no chloride attack d. Adequate concrete cover
	Waterproofing	a. Water leak, free lime and other associated defects are observed at deck soffit b. Defects that are not active Note: is waterproofing from top of slab through defective concrete or leakage joints between precast members.
	Concrete Lining	a. Minimum concrete cover is inadequate b. Wide longitudinal cracks due to chloride attack or rebar corrosion c. Absence of concrete surface or loss of concrete matrix due to inferior concrete or chemical attack d. Concrete is carbonated
Protection work to steel member	Repainting, Repaintcoating	a. Adequate load carrying capacity b. Rust and/or corrosion c. Paint deterioration
	Adding cover plate	a. Adequate load carrying capacity b. Cracking of steel member due to fatigue damage or stress concentration c. Stress due to total load including additional load is still within allowable stress
	Repainting steel pile	a. Steel surface is slightly corroded but load carrying capacity is still b. Adequate c. Bridge is located at non-severe environmental condition. No chloride attack
	Concrete filling steel	a. Steel surface is considerably corroded but load carrying capacity is still b. Adequate c. Bridge is located at severe environmental condition. Chloride attack is considerable
Protection work to incidental facility	Extension of Drainage Pipe	a. The drainage pipe is too short or missing. b. The water through the pipe which is improperly installed splash the structural members.
	Installation of Drip Check	a. Water stain at soffit of cantilever slab and external face of beam web.

Table 6: Structural Repair Method-Strengthening Approach and corresponding Application Criteria

Repair Plan	Method	Application Criteria
Strengthening work to concrete	Steel Plate Bonding	i) Inadequate load carrying capacity (Inadequate amount of reinforcement) ii) No water leak and no carbonation iii) Active cracks due to bending moment or shear force iv) Adequate concrete cover
	Overlaying with additional rebar	i) Inadequate loading capacity ii) Narrow active cracks iii) Adequate for additional stress in beams and slab due to additional load iv) Bridge is located in relatively severe climatic environment v) Advance carbonation vi) Deflective area is extensive vii) Bridge can be closed at least 3 consecutive days
	Bonding for Concrete Girder/Beams	i) Severe shear cracks due to shear force ii) Deflective area is not extensive iii) Stresses due to total load including additional dead load are within the allowable stress iv) Total load including additional load within allowable stress v) No water leak and no liquid leak vi) No chloride attack
	Pre-packed concrete lining with additional rebar	i) Inadequate loading capacity ii) Various active cracks due to bending moment or shear force iii) Inadequate concrete cover iv) Sufficient salt (chloride) attack or advanced carbonation v) Deflective area is extensive vi) In case that bridge cannot be closed more than 1 hr for less than 1 hr apply high early strength cement mortar vii) Soffit of member such as soffit of beam and slab where it is difficult to pour concrete
	Additional pre-stressing	i) Inadequate load carrying capacity ii) Various active cracks due to bending moment or shear force iii) Working stress of pc members exceeds about 120% of the allowable stress iv) Stress due to total load including additional dead load is within the allowable stress v) Deflective area is extensive
	Concrete lining to pier	i) Inadequate thickness cover of pier [illegible] ii) Abrasion of concrete surface or loss of concrete section due to [illegible] or chemical attack iii) Concrete is deteriorated
	Underpinning with additional piles Sheet piling	i) Progressive settlement of substructure due to inadequate bearing pile capacity ii) Increase of design load due to upgrading of the bridge i) The backfill behind the abutment fill out due to broken parapet wall [illegible] ii) Active bending cracks on concrete piles due to earth pressure
	Extension of bridge seat	i) Inadequate bridge seat width from bearing edge to bridge seat edge ii) Active shear cracks at bridge seat due to heavy concentration iii) Deflective area is not extensive
Strengthening work to steel	Adding Stringer	i) Excess bending stress of deck slab is more than 20% of the allowable stress ii) Stress of main member due to total loading additional dead load is within the allowable stress
	Attachment of Steel Plate	i) Inadequate load carrying capacity ii) Excess bending stress is less than 20% allowable stress iii) [illegible] active corrosion, member deterioration
	Concrete lining with steel	i) Deterioration is considerably extended and the load carrying capacity is inadequate due to section loss ii) Bridge is located in severe environmental condition

Table 7: Structural Repair Method Replacement Approach and Corresponding Application Criteria

Repair Plan	Method	Application Criteria
To (re)place Work of Structural Member and Bridge component	Deck Slab Replacement	(a) Inadequate loading capacity (b) Severe damage of steel girder/deck slab due to steel corrosion (c) Stress of [illegible] due to dead load after repair is within the allowable stress
	Bearing Replacement	(a) Bearing is missing or not functional due to severe damage
	Replacement of Expansion Joint	(a) Critical defects such as water leaking, abnormal noise, difference in level etc. due to damaged expansion joint (b) Recurrent repair of the pavement overlaid on the existing expansion joint (c) Transverse open crack or gap due to existing expansion joint
	Replacement of Steel Truss Member	(a) Inadequate load carrying capacity (b) Critical deformation or rupture of steel member due to vehicle collision (c) Severe section loss due to corrosion

Table 8: Functional Repair Method and Corresponding Application Criteria

Repair Plan	Method	Application Criteria
Functional Repair for Traffic Capacity of Bridge	Widening Carriageway by Cantilever Support Attached to Substructure	(a) Inadequate Carriageway width (b) Adequate loading capacity of existing sub-structure for additional dead load and live loads
	Widening Carriageway by Extension of Both Superstructure and Substructure	(a) Inadequate Carriage width (b) Inadequate load carrying capacity of existing foundation for total load including additional dead and live loads
Functional Repair for Pedestrian Flow Capacity of Bridge	Adding Footpath by Cantilever Support Attached to Superstructure	(a) Absence of sidewalk (b) Adequate loading capacity of both existing superstructure and substructure for total load including additional dead and live loads
	Adding Sidewalk/Footpath by Cantilever Support Attached to Substructure	(a) Absence of sidewalk (b) Adequate loading capacity of existing sub-structure for total load including additional dead and live loads
	Adding Footpath by Construction of an Independent Bridge	(a) Absence of sidewalk (b) Inadequate loading capacity of existing sub-structure for total including additional dead and live loads
Functional Repair for River Flow Capacity of Bridge	Raising of Bridge Deck	(a) Inadequate bridge opening (b) Required raising height is less than 1.0m
	Extension of Bridge Length	(a) Inadequate bridge opening (b) Raising height requirement is more than 1.0m (c) Adequate loading capacity of existing abutment or expansion with the total load including additional loads due to bridge extension

Table 9: List of Manufacturers and Suppliers of Bridge & Concrete Repair Materials

	Manufacturers	The supplier / Local agent
1	Roffex Construction P. Ltd. 47-A, Mittal Tower, Nariman Point, Mumbai Phone: 022-2880284, 6332793	Chalet Enterprises Tripureswor, Kathmandu PO Box 8059
2	Sika Qualcrete Ltd. 628 Diamond Harbour Road Commercial Complex, Calcutta Phone (033) 448 0704 / 447 2449 Fax (033) 468 8608	H & U Enterprises Kamaladi, Kathmandu Phone: 4441172, 4408474 Fax 4445100
3	Bauchemie (India) P. Ltd 201, Vardhaman Chamber Sector 17, Vashi, Navi, Mumbai Phone 7653627, 7653631	New Technical Water Proofing Kupondol, Lalitpur Phone: 4533717 Fax: 4531313
4	Master Builders Technology (MBT) 704, Krishna Govindam Tower 7th Floor Sector 24, Sanpada, Navi, Mumbai Phone: 0091-22-7650827/7619095 Fax: 0091-22-7650542	Indus Trading Concern Dillibazar, Kathmandu Phone: 4220254 Fax: 4225168
5	Pagel Concrete P. Ltd Court Chambers, 3rd Floor New Marine Lines, Mumbai Phone: 0091-22-2081130, 2062144	Himalayan Engineering Associates P. Ltd. Maharajgunj, Kathmandu Phone: 4435259 Fax: 4419212
6		Create Some Associates Pako, New Road, Kathmandu GPO Box 1344 Phone: 4228221, 4243731
7		RSMC Pvt. Ltd Anam Nagar, Kathmandu Tel: 4228780, 4247791

Suppliers for the Bridge Expansion Joint and Bearings	1 2	RSMC Pvt. Ltd Anam Nagar, Kathmandu Tel: 4228780, 4247791 Conset Trading Kathmandu

The above is some of the suppliers, there may be other suppliers and Manufacturers.

Appendix B
HOW TO TIGHTEN STANDARD HIGH STRENGTH FRICTION GRIP BOLTS

(British Manufacture metric only)

i. Part turn method (General grade bolts only)

The most widely used tightening technique for standard high strength bolts and the one which has now become the preferred method of tightening is the 'Part Turn Method'.

Where bolts and nuts in compliance with British Standard BS 4395 are tightened by the part turn method all the bolts are first tightened to a bedding torque. The value of the bedding torque for the preliminary tightening is given below. The purpose of this initial tightening is to bring the joint surfaces into close contact. It will also give a small initial tension in the bolt. It is important to ensure that the joint surfaces are in close contact before continuing with the final tightening. On first assembly of the joint the initial tightening before any bedding torque is applied, is classified as finger tight.

Preliminary Tightening of Nuts	
Nominal Diameter of Bolts (mm)	Bedding Torque (Nm) ±10%
16	80
20	166
22	218
24	270
27	340
30	460

After initial tightening it will be necessary to make a permanent mark on each nut and the protruding end of the bolt to record their relative positions; this mark can be made with paint or by using a cold chisel. Each nut is then finally tightened, preferably with an impact wrench, so that it turns relative to its bolt by the amount given in the table below.

Final tightening of nuts

Nominal size and thread diameter of bolt	Grip of bolt for rotation of the nut (relative to the bolt shank)	
	Not less than than ½ turn	Not less than ¾ turn
M16	Up to 115	
M20	Up to 115	Over 115 to 225
M22	Up to 115	Over 115 to 275
M24	Up to 160	Over 160 to 350
M27	Up to 160	Over 160 to 350
M30	Up to 160	Over 160 to 350
M36	Up to 160	Over 160 to 350

Note:- Higher grade bolts to BS 4395 Pt II 2 must not be tightened using the 'Part Turn Method'. The strain increases are limited by controlled tightening to within a specified range. This limitation is due to the lower ductility of the steel from which the bolts are made.

2. Torque control method

If this method is used a calibrated tightening device is employed. The torque necessary to induce the minimum bolt tension (equal to the proof load) is determined by the actual site conditions. The torque figures are approximate and for guidance only, and for further details of this method, reference should be made to BS 4604. Where there are several bolts in a single joint, the device is re-applied, tightening as bolts previously tightened may have lost tension through tightening of subsequent bolts, until all are finally tightened to the prescribed torque.

3. Load indicating washers

For weather resistant steel, load indicating bolt heads or washers shall not be used. Where bolts or washers with load indicating devices are used as approved, the range of final average gap for each batch (as defined in British Standard BS 4395) shall be established by testing a minimum of three bolt, nut and washer assemblies in a bolt load meter. The bolts shall be tightened in two stages, the sequence and pattern agreed with the Engineer. The range of the average gap after initial tightening shall be agreed by the Engineer. On final tightening of each bolt and nut, the average gap under the bolt head or washer shall be within the agreed final range.

Tightening difficulties

The pre-loads to which high strength bolts are tightened require approximate tightening torque as shown in above tables. These values however, only apply to self-colour bolts in a lightly oiled condition. (As Rieged, unpainted and/or un-coated.) It is possible that self-colour bolts may dry out in storage which can give rise to high thread friction. In order to prevent high torque values, the bolt threads can be lightly oiled after the bolt has been inserted in the steelwork. No lubricant must be allowed to get onto the interfaces of the friction grip joint.

When tightening a large pattern of bolts, whether they be standard high strength, load indicating or waisted bolts it is necessary to tighten in a staggered pattern and, where there are more than four in any one joint, they should be tightened from the centre of the joint outwards. High strength bolts may be used temporarily to facilitate assembly during erection. If after final tightening a bolt or nut is slackened off for any reason, the bolt, nut and washer should be discarded and not re-used.

Bolts of Other Manufacture and Other National Standards

It is important to ascertain the governing National Standards that the bolts comply with. The National Standards when read with the manufacturer's recommendation(s) will give guidelines for the use of the specific bolt. The guidelines and standards will vary with the bolt strength and type and pitch of thread. For example an imperial size bolt of British manufacture will have a vastly different holding torque to a metric bolt of British manufacture. It is strongly advocated that bolt testing be incorporated into specifications to confirm bolt suitability and method of tightening. Notwithstanding this, close monitoring of the site assembly is necessary to ensure that correct procedures are maintained.

Special precautions

Special precaution is to be observed when using protective coating on high strength bolts. (i.e. nut and colour). Any variation in finish on high strength bolts can seriously affect the mechanics of tightening and the methods of tightening can be restricted. Where bolts and nuts are plated there is a tendency for the soft plating metal to collect in the threads as a result of the high pressures generated on the thread surfaces and this can cause the nuts to seize. When this occurs, the energy which is being applied to the nut, to overcome the friction between the threads, is transferred to attempting to twist the bolt. Under extreme frictional conditions this can cause torsion failure of the bolts. This possible condition can be reduced very significantly by the use of a high pressure lubricant on the threads. (Such as copper slip) It is extremely important that the lubrication be applied to the threads of the bolt, after the bolt has been inserted through the steel work, since it is important that no lubricant gets between the plies of the steelwork. To minimize the danger of nuts seizing 'like' metal contacts, such as sherardizing, should be avoided. It has been found that either a hot sprayed galvanized finish on both the bolt and nut (the nut is tapped after galvanizing) or electro-zinc plated bolts and cadmium plated nuts, give the most satisfactory conditions for tightening. When tightening standard high strength bolts with protective finishes, only the 'Part Turn Method' of tightening should be used, as this method is independent of the frictional conditions occurring when the bolts are plated or coated. Neither calibrated torque wrenches or calibrated impact wrenches should be used, as the torque/tension relationship is affected and it is impossible to obtain consistent results.

Tightening the Bolt or Nut

The nut is part that is normally tightened, however it can be preferable to tighten the bolt. The washer is always placed under the part to be rotated.

Appendix C
LIFTING OF BRIDGE DECKS

Introduction

Lifting bridge decks may be required for a number of reasons. Commonly it is to replace bearings but it is also undertaken to re-level the structure to rectify settlement or as part of a repair operation on other elements of the bridge. Sometimes the bridge is moved horizontally involving similar techniques. One reason for moving a bridge deck horizontally is to reset it on its bearings.

Bridge lifting is an intricate operation and working procedures must be developed from a designed approach to minimise stress differentials within the structure. In the past bridge lifting was carried out using labour intensive jacking operations in disregard of the consequences of differential movement between jacking points and to the damage that could result on the structure. Obviously some bridge lifts are easier to resolve than others. Simple two bearing decks with low transverse torsional stiffness should be straightforward to lift however multi-bearing stiff decks should be treated with care.

Lifting Equipment

The design section Bridge Unit has procured a set of four hydraulic jacks, each of 50 tonnes capacity, for use in bridge lifting. They are expected to be sufficiently versatile for most situations however additional jacks can be obtained from the same source for more complex lifts.

Hydraulic jacks are fairly precise in operation and although limited to small lifting movements higher lifts are achieved by repeating the work in a number of staged lifts. The hydraulic jacks are operated by oil pressure with the oil pressure in the jack multiplied by the area of the plunger to produce a given jacking force. The jack system is complete with load gauges for direct reading. By increasing the oil pressure the deck is moved upwards and by releasing the pressure the deck is lowered. Other than the hydraulic operating system the only other main items are packs used to support and spread the loads. These are usually timber hardwood and/or steel plates. Sometimes, to suit an individual circumstance, the steel is fabricated into jacking stools for greater control and stability.

Designing the lifting operation

An assessment is made of the forces involved by calculating the dead load reaction on the bearings. If the bridge is open to traffic during the lifting operation the live load forces are determined. Often the engineer will need to place load or lane restrictions during the operation. The load assessment will confirm that the jacks have adequate capacity. From a site inspection the location of the jacks is selected taking into account the need, if any, to strengthen the bridge (both deck and sub-structure) at the jacking points. Packing plates are used to distribute the applied loading.

The jacks are positioned to give a balanced lift. On beam bridges and other structures with two bearings at the end of the bridge the positioning of the jacks is fairly straightforward. On multi-bearing systems the position of the jacks can be calculated to give even reactions. Bridges with continuous spans need additional care. This is always assuming that there is sufficient room around the bearing to carry out the work or transverse diaphragms are available. If not a special jacking position may need to be designed. This allowance must be made for both rotation, cross- fall and horizontal movement in the lifting operation. It is possible to fit a jacking cam that can accommodate rotations of up to 5 degrees otherwise the rotation is taken out on the jacking packs.

Horizontal movement can dislodge the jacks. This movement is caused by vehicle load and/or temperature. An accurate assessment of temperature movement needs to be determined and this will be dependent upon a number of factors including the time that the bridge is going to be held on the jacks. To allow for horizontal movement the jack may need to sit on stainless steel/PTFE sliding pack.

An analysis of the structure will confirm the allowable differential in height between adjacent jacking points during the lifting operation. The shear and moment capacities, particularly continuous bridges, can be considerably reduced by the introduction of small differential settlements during the lifting operation. This differential must not be exceeded otherwise the bridge may be subjected to local over-stress and damage. Similarly it is important that the bridge is returned to its original level after the work. Sometimes if the bearing rockers are being re-set the final bridge level may be slightly different. Dial gauges will give the best control to check movements. Another technique is to fix Demec markers and monitor the movements with a digital vernier caliper.

The height of the lift is determined from the job to be done. Often a lift of a millimetre or two will be sufficient to dismantle a mechanical bearing.

Typical Jacking Sequence

1. Place jacks at the designed locations with bearing plates and packs between jack and bridge pressure points.
2. Record levels. As a secondary check fix permanent marks.
3. Jack one location at a time to the fixed pre-determined increment. In some cases this may be less than 5mm depending on the structure.
4. When the bridge is in its final position, packs are located as a safety precaution. Some jacks can be locked off with a threaded locking collar.
5. The lift is monitored during the repair /modification work to ensure that all the supports are stable and there is no local damage to the structure.
6. After the work is complete the lowering is a reverse of the lifting procedure.

A sketch illustrating the jacking of a bridge deck is shown in the succeeding appendix.

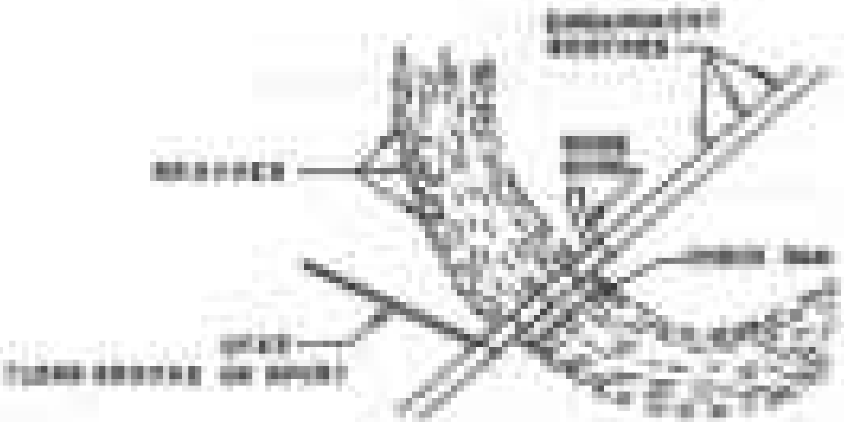
Appendix D

Norms for Recurrent Maintenance of Paved Road Including Bridges

[illegible]

Recommended Cycle			
Traffic (vpd)	Surface Condition		
	Good [illegible]	Fair [illegible]	Poor [illegible]
Low (<250)	1	3	[illegible]
Moderate (250 – 1500)	2	2	
High (>1500)	2	2	

Appendix E
Typical Damage and Repair Details

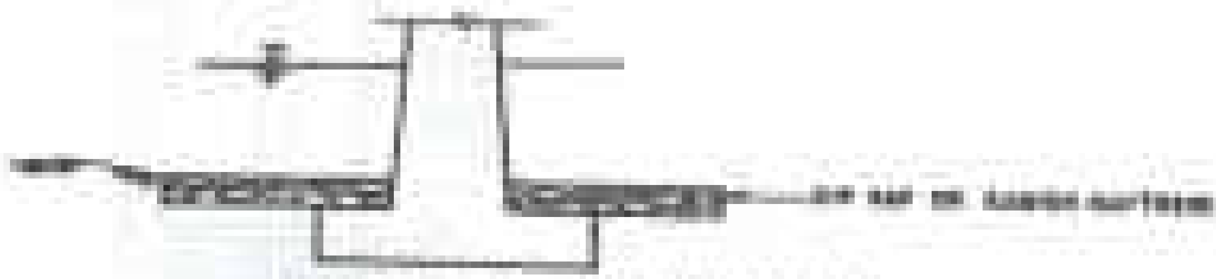


(i) Repelling Groyne

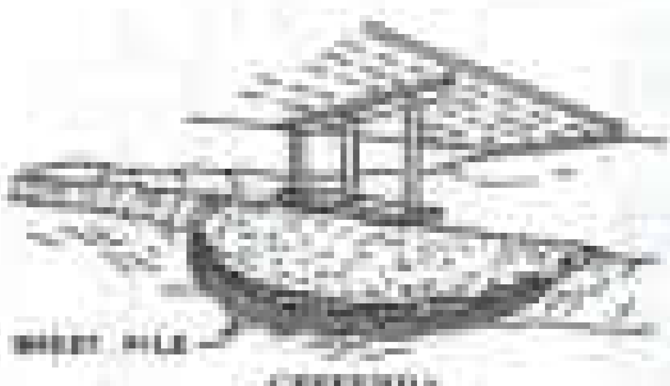
(ii) Attracting Groyne

Fig. 5A TYPICAL WATERWAY & BRIDGE PROTECTION WORKS

REMEDIAL WORKS FOR SCOUR AT PIER

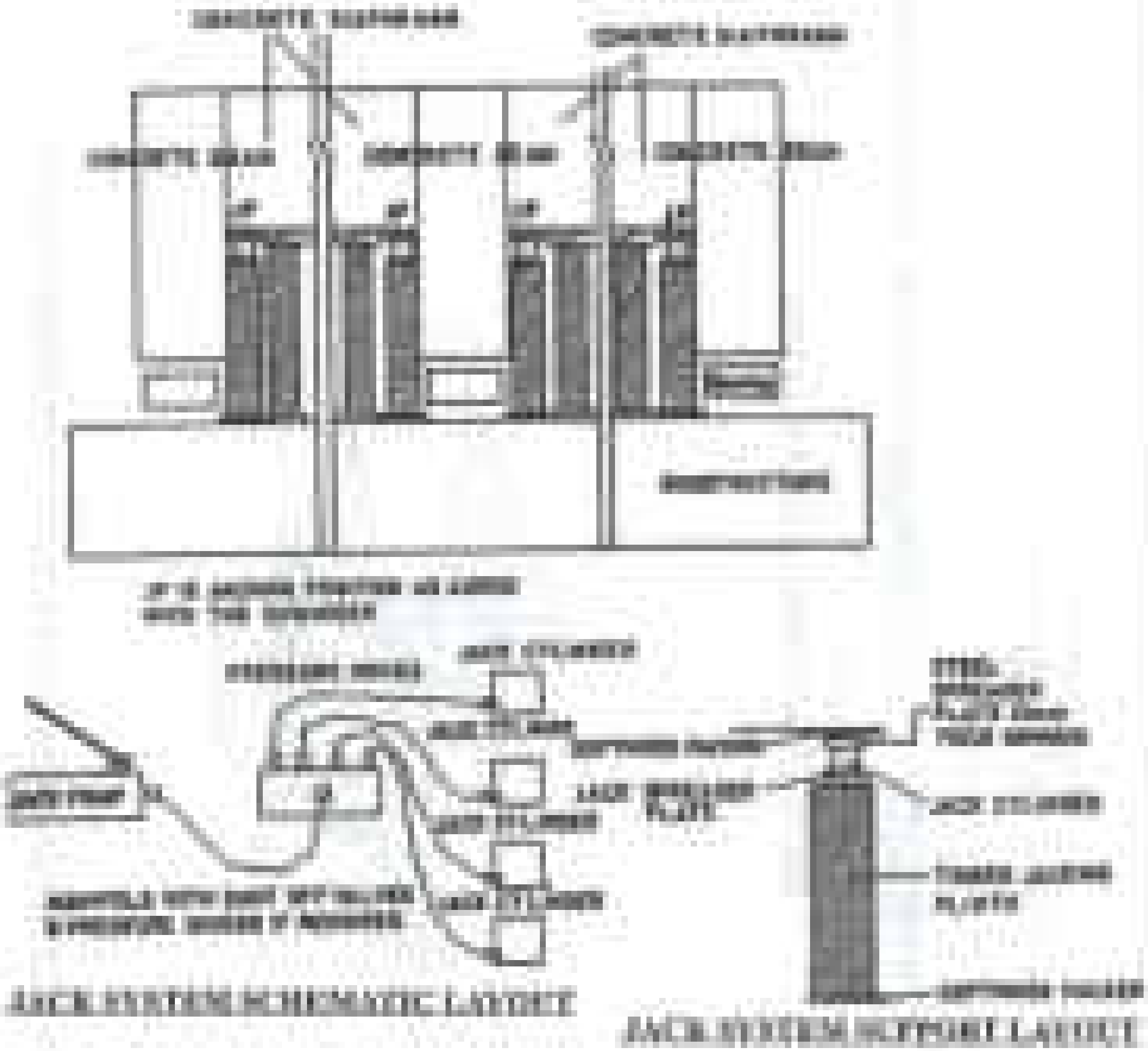


PROTECTION WORKS AGAINST SCOUR



COFFERDAM

Fig. 28 TYPICAL WATERWAY AND BRIDGE PROTECTION WORKS (Contd.)



Notes On Jacking Procedure

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. Stop all traffic.
6. [illegible]
7. [illegible]
8. [illegible]
9. [illegible]
10. [illegible]

Fig. 2 ARRANGEMENT FOR JACKING UP OF BRIDGE DECK (TYPICAL)

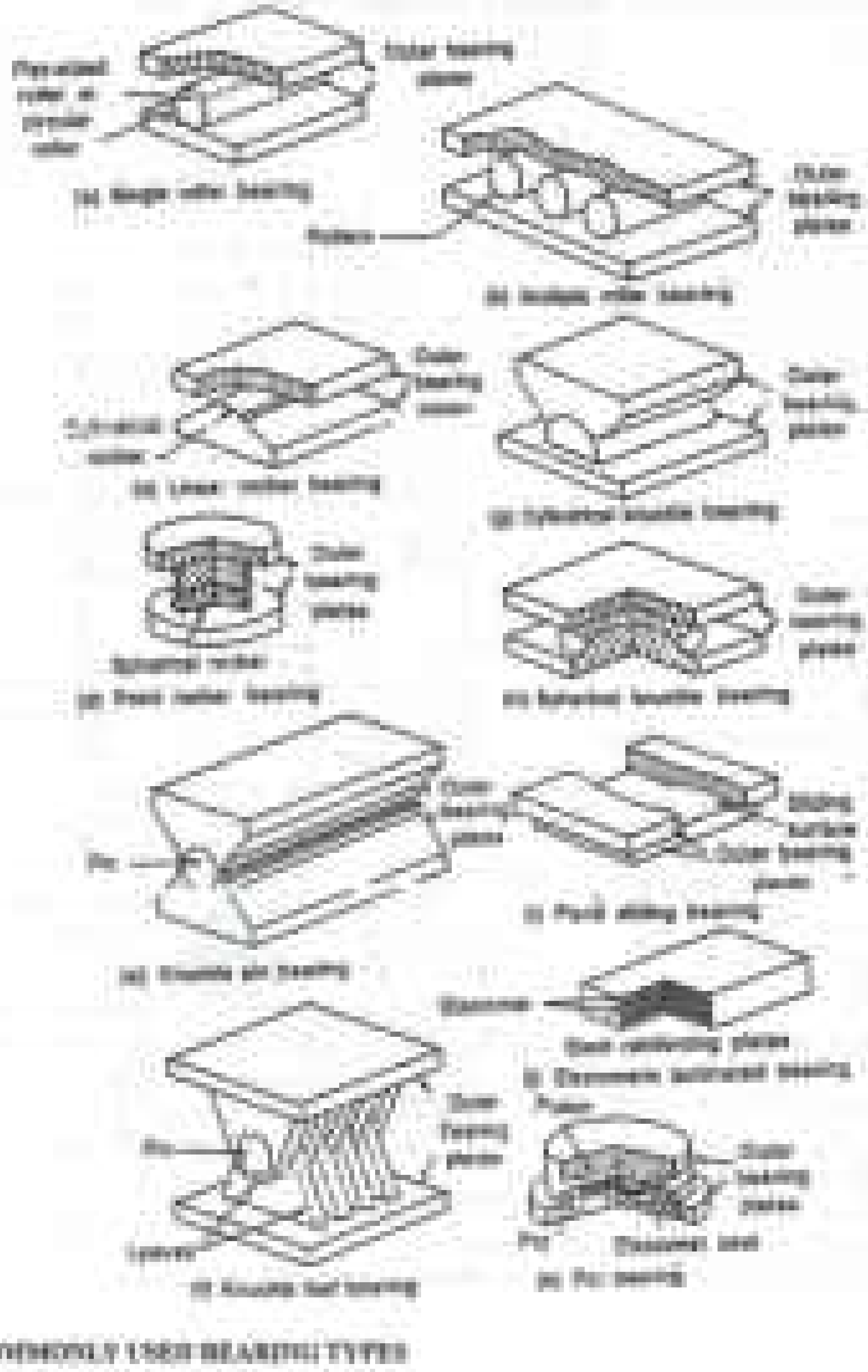


Fig. 1 COMMONLY USED BEARING TYPES

Table 10: Typical Questionnaire On Bearings to be filled While Placing Order

	Bridge Manufacturer's name		Design Data Sheet for Bridge Bearing	
	Client's Name		Client's Reference Date	
	Project Name		Manufacturer's Reference Date	
1	Type of Structure e.g. Bridge, Aqueduct etc.			
2	Span			m
3	No. of Spans			nos
4	No. of Beams per Span			nos
5	Total No. of Bearings required			nos
6	Width of Beam / Girder			mm
7	Space available over pier	Lateral		mm
		Longitudinal		mm
8	Construction material e.g. concrete, steel etc.	Pier		
		Girder		
9	Construction method e.g. Cast in situ, precast, prestressed			
10	Concrete fck	Pier		
		Girder		
11	Direct Vertical Load (Per Bearing)	Dead Load		KN
		Live Load		KN
12	Horizontal Force (Per Bearing)	Seismic	Longitudinal	KN
			Transverse	KN
		Wind	Longitudinal	KN
			Transverse	KN
		Braking	Longitudinal	KN
			Transverse	KN
		Other if any		KN
13	Movement horizontal (per bearing)	Longitudinal		mm
		Lateral		mm
		Other if any		mm
14	End Rotation			rad

Note:

(i) Provide as much as information as readily available.

(ii) In case of road bridge, indicate class of loading and with or without footpaths.

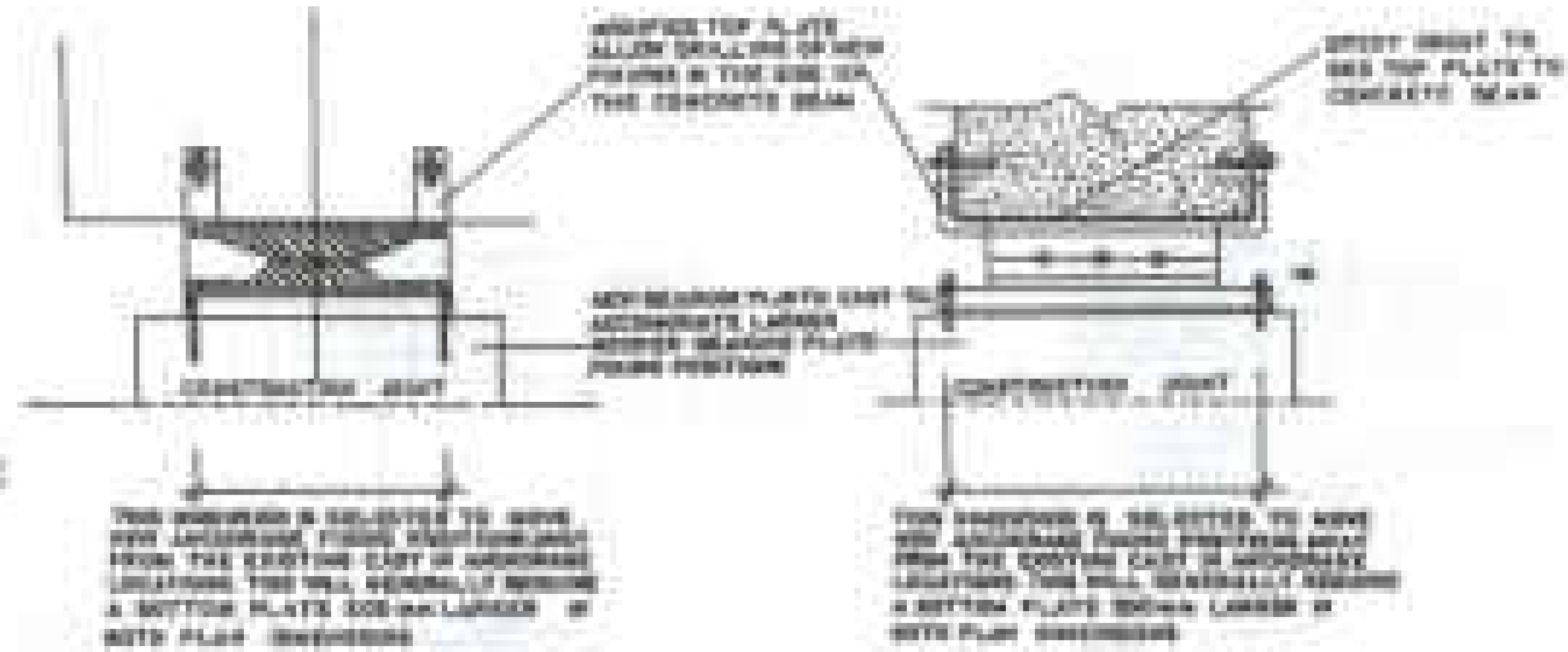


Fig.4 REPLACEMENT ROCKER BEARING (TYPICAL)

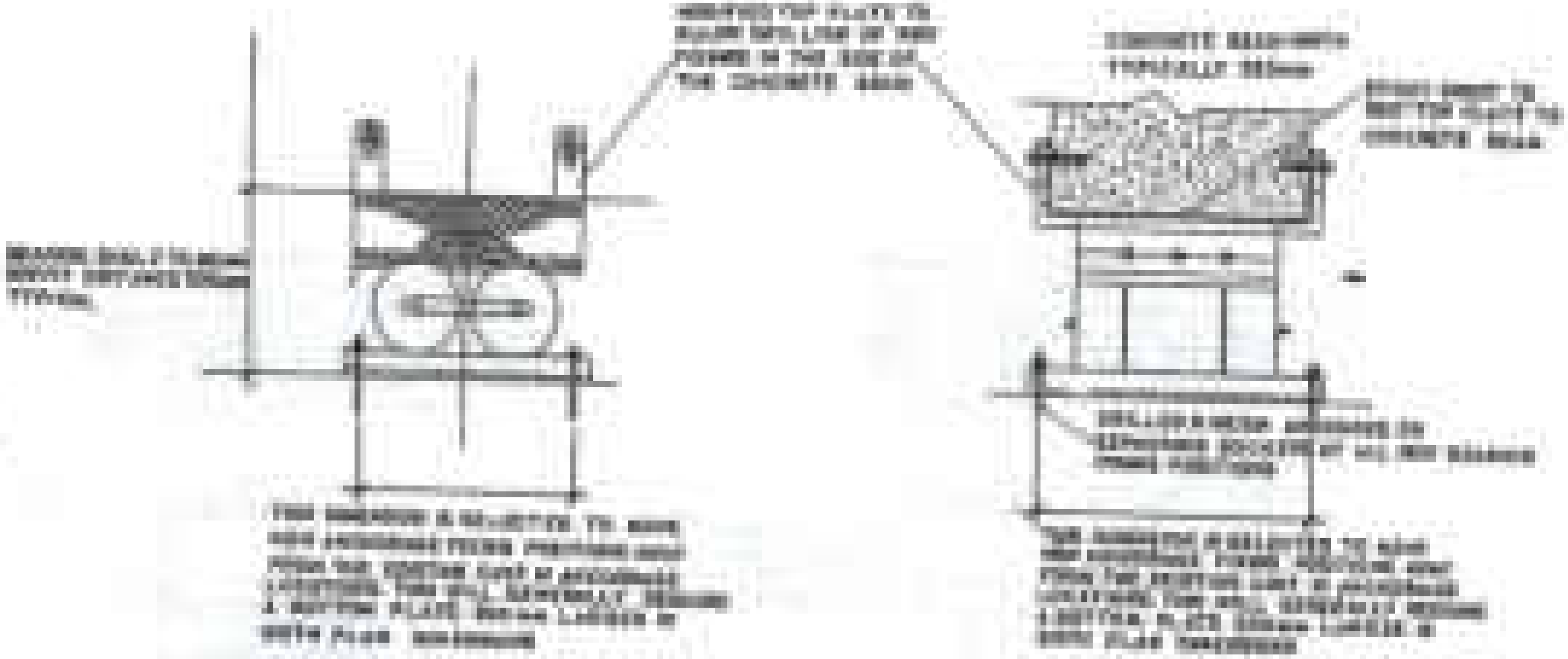
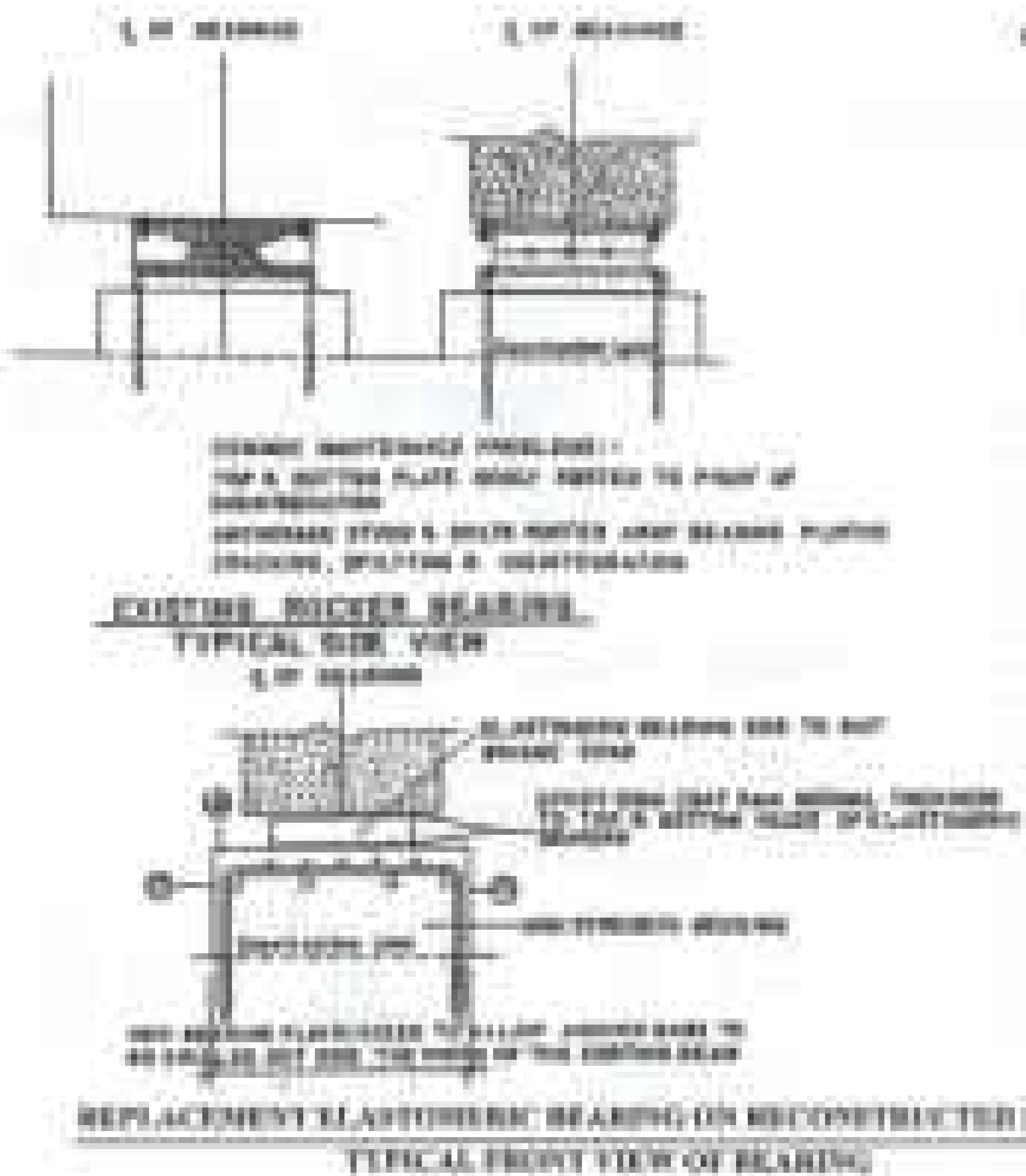


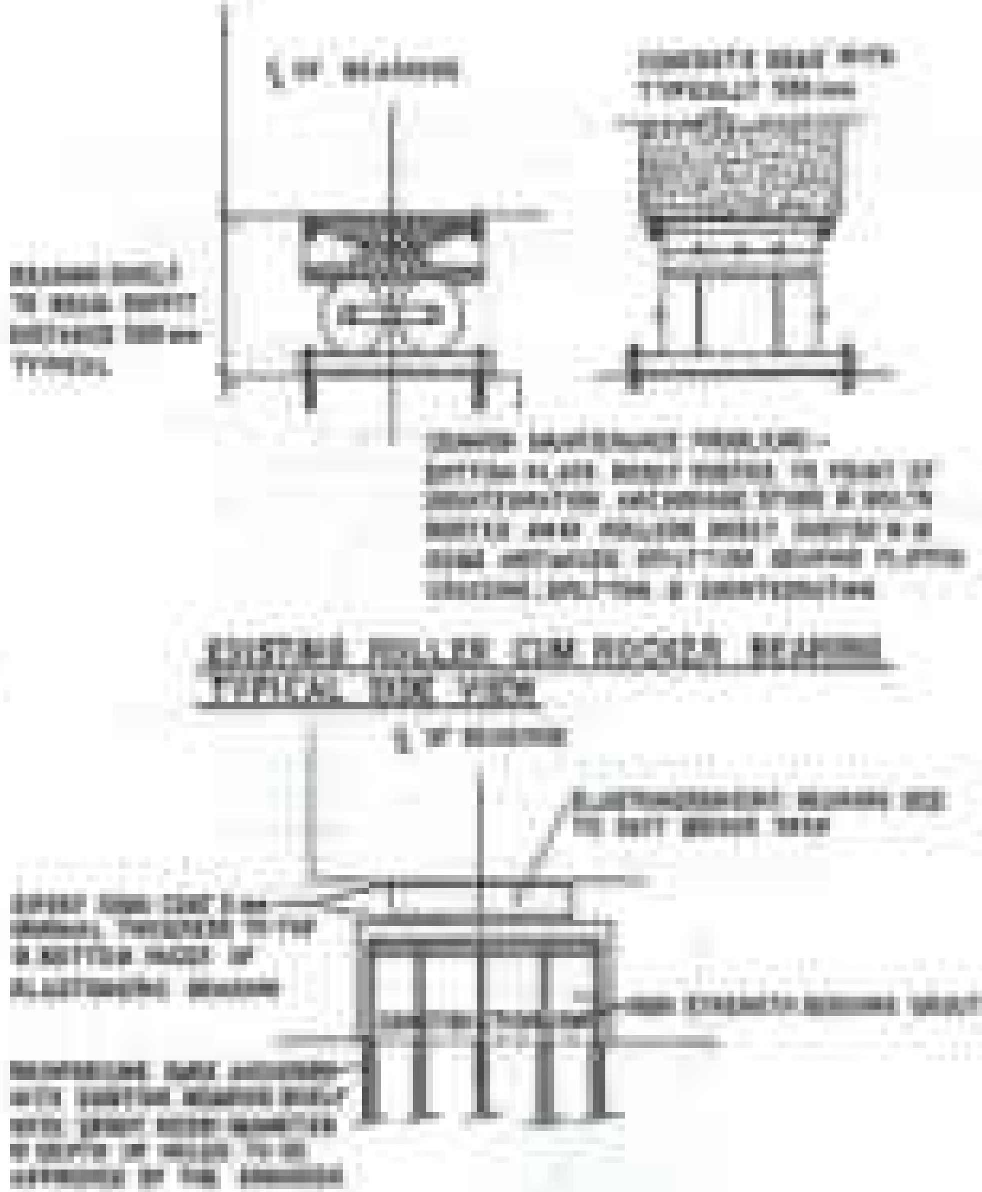
Fig.5 REPLACEMENT ROLLER CUM ROCKER BEARING (TYPICAL)



Notes on Bearing Replacement Sequence

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible]
8. [illegible]
9. [illegible]
10. [illegible]

Fig.4 REPLACEMENT OF ROCKER BEARING WITH ELASTOMERIC BEARING (TYPICAL)



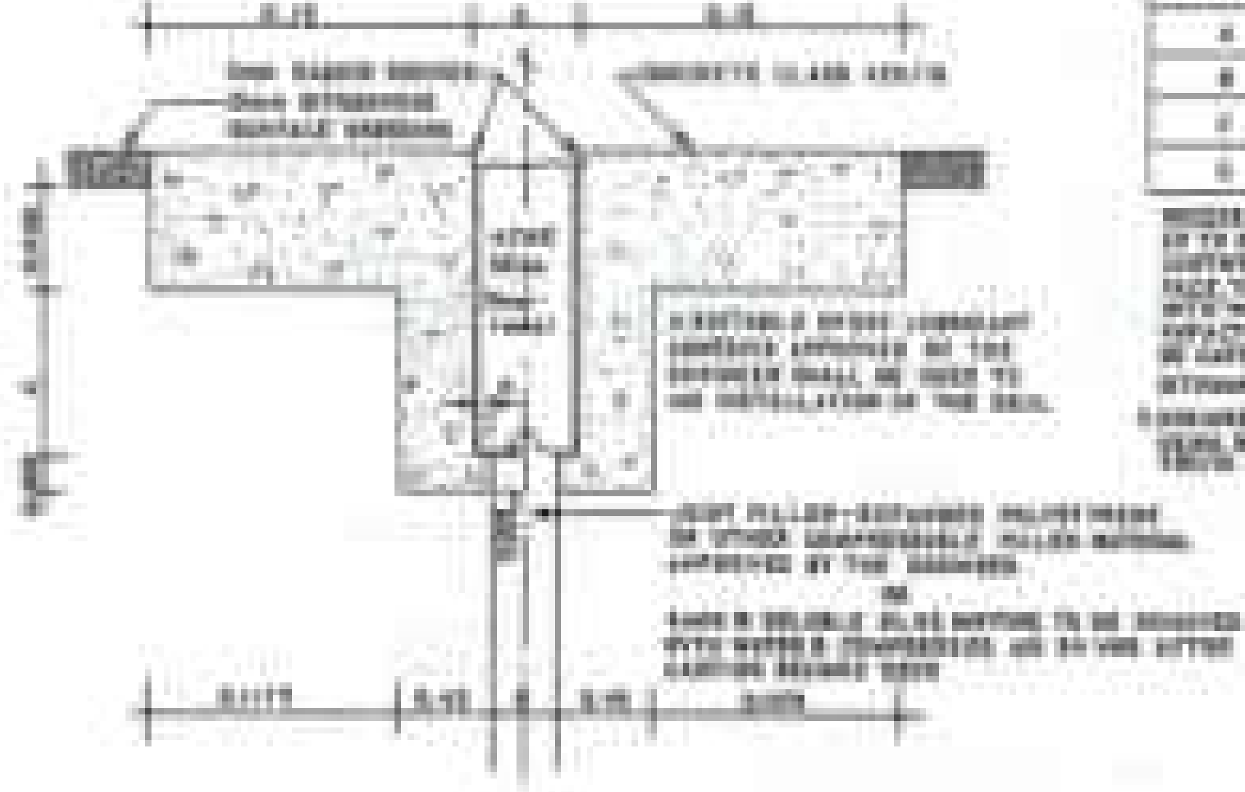
REPLACEMENT ELASTOMERIC BEARING ON RECONSTRUCTED PLINTH

TYPICAL SIDE VIEW OF BEARING

Notes on Bearing Replacement Sequence:

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible]
8. [illegible]
9. [illegible]
10. [illegible]

Fig.7 REPLACEMENT OF ROLLER CUM ROCKER BEARING WITH ELASTOMERIC BEARING (TYPICAL)



[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Fig. [illegible] EXPANSION JOINT DETAIL (SECTION THROUGH ROADWAY), [illegible]

([illegible])

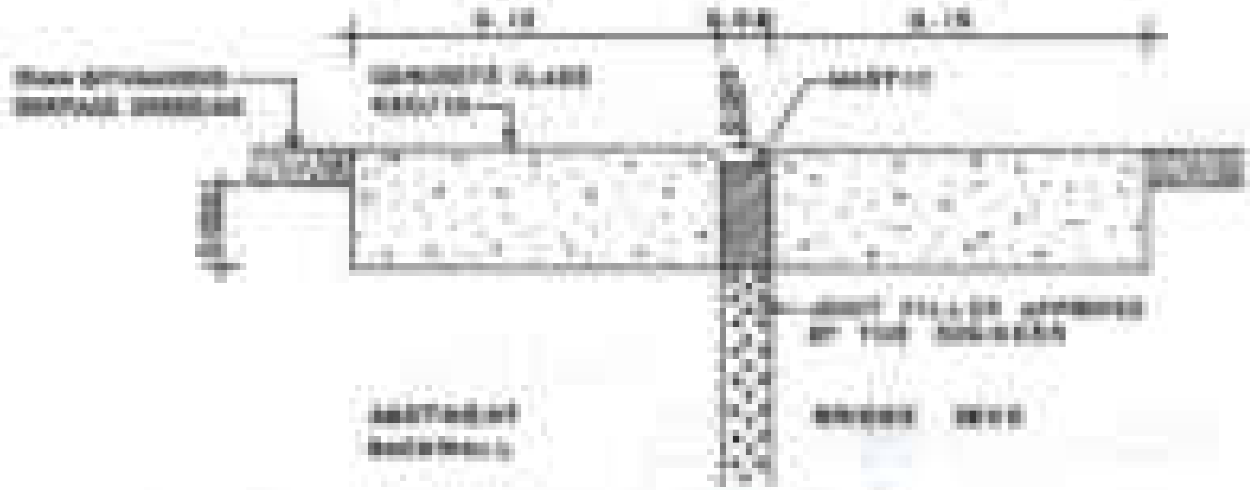


Fig.9a FIXED JOINT DETAIL (SECTION THROUGH ROADWAY), DOS STANDARD DESIGN
(SCALE: 1:10)

Fig.9b JOINT DETAILS (SECTION THROUGH SIDE WALK)
(SCALE: 1:10)

SOME EXPANSION JOINT TYPES BY BRIDGE JOINT ASSOCIATION

Buried
Use of elastic compressible strip may be used to form continuity of the waterproofing and surfacing. These can comprise of a proprietary flashings and strips with bridging plates or similar. Movement ranges generally +/- 10 mm [illegible].

Asphaltic Plug
Proprietary systems comprising of layers of specially modified binders and aggregate to provide a homogeneous expansion joint and smooth running surface. Movement ranges of standard grade material modules up to +/- 20 mm.

Nosing/Elastomeric elements in metal runners [illegible] modified resin nosing material bonded to the deck, incorporating steel rails or angles with cellular neoprene insert or similar which is mechanically retained or bonded to the metal rails. Movement ranges generally up to +/- [illegible] mm.

Fig. 19 a

SOME EXPANSION JOINT TYPES BY BRIDGE JOINT ASSOCIATION

Elastomeric

Elastomeric segmental joints comprising reinforced rubber with cantilevering fingers and plates bolted down in a recessed on top of a drainage membrane with epoxy bedding and transition strips. Movement ranges generally +- 25 mm to +- 185 mm.

Elastomeric elements in metal runners

Single or multiple elastomeric elements supported on metal supports which are tied into box cast within the bridge structure. Movement ranges generally +- 400 mm.

Cantilever comb or tooth joints

Cantilever comb or toothed metal plates bolted together and bolted to each side of the bridge joint with a drainage membrane. These can be proprietary systems or made specifically to suit the bridge movement and construction. Movement ranges generally up to +- 300mm.

Fig 14 b

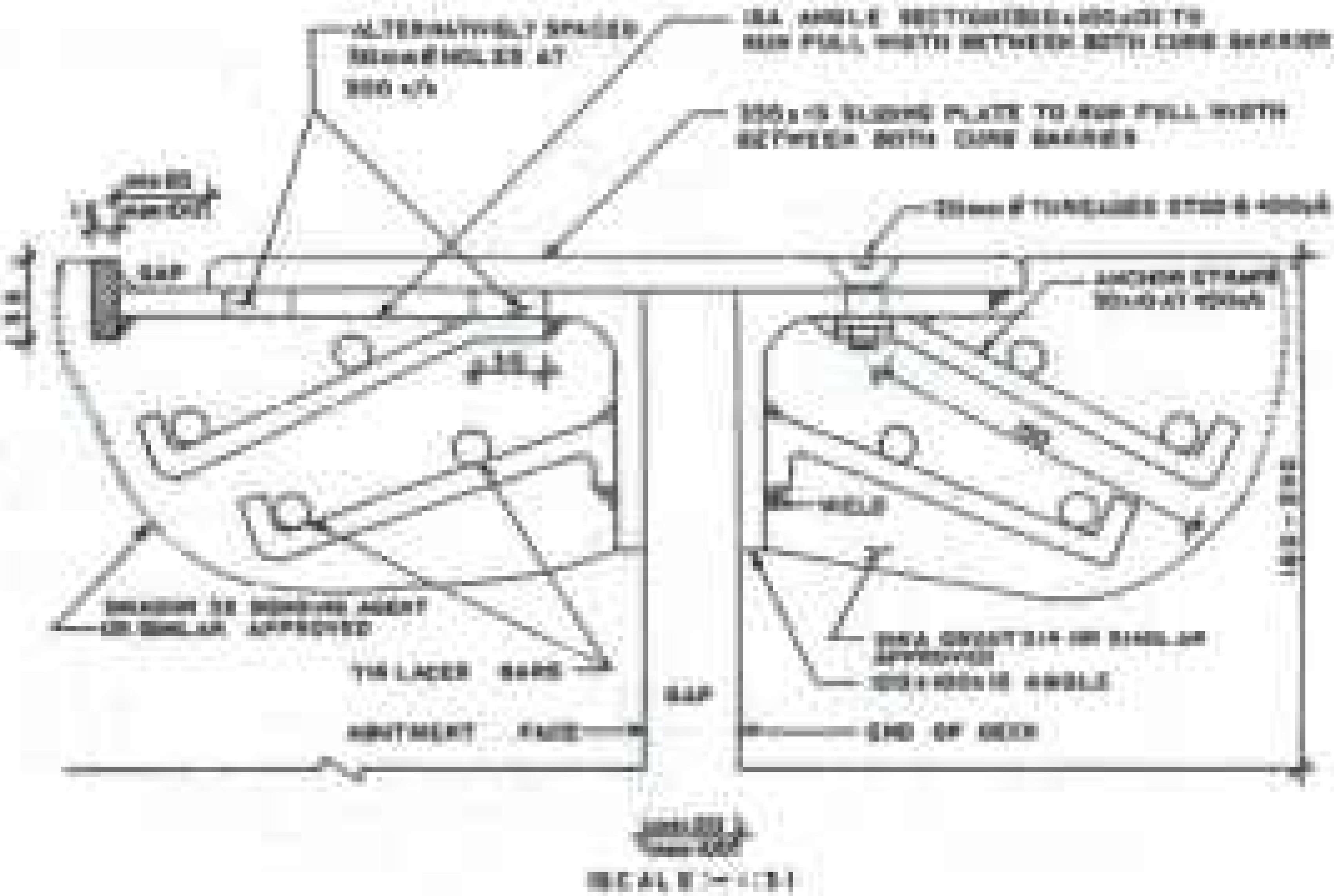


Fig. 31 GENERAL DRAWING SHOWING REPLACEMENT OF STEEL SLIDING PLATE TYPE EXPANSION JOINT (TYPICAL)

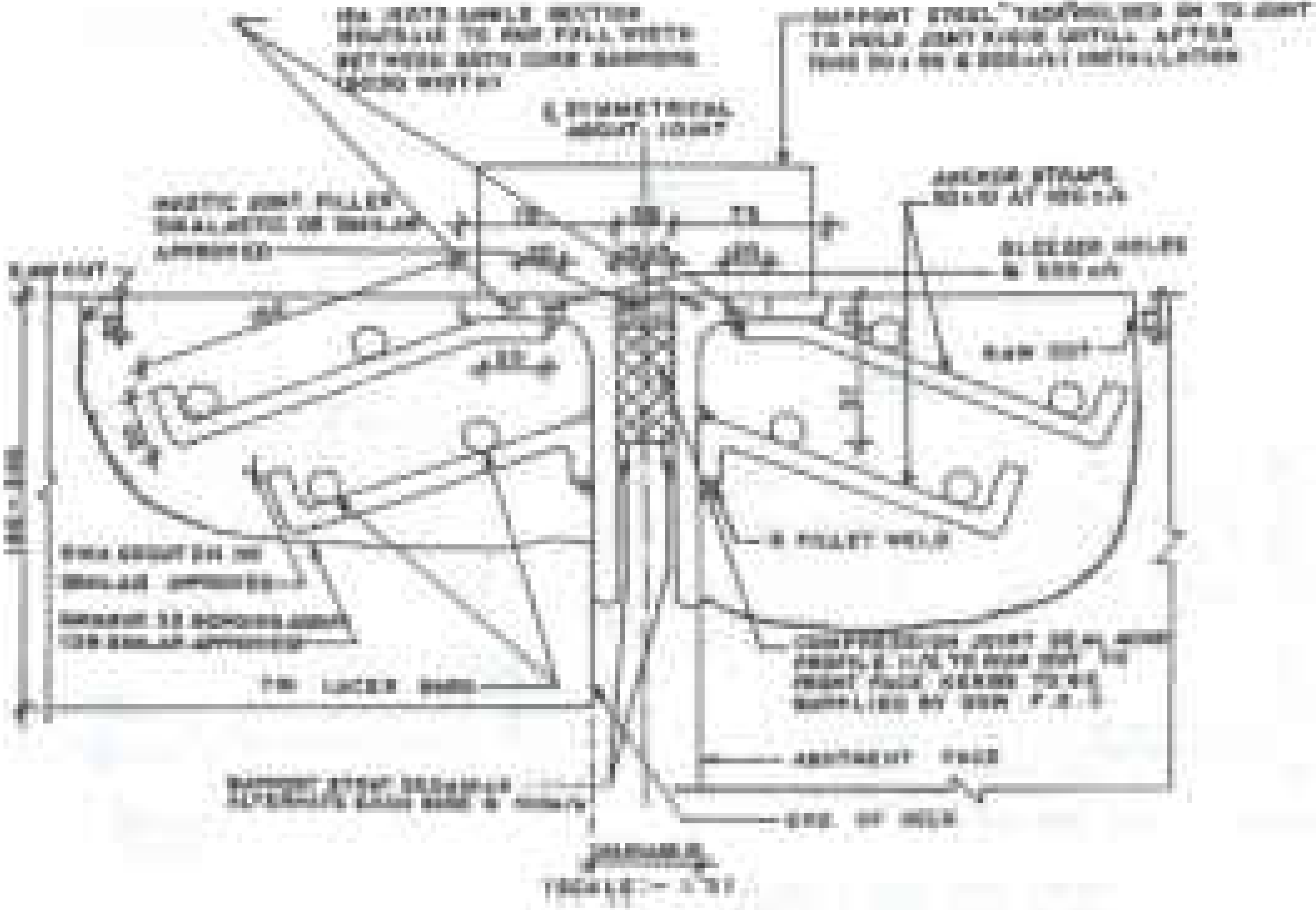


Fig. 12 GENERAL DRAWING SHOWING REPLACEMENT OF COMPRESSION SEAL TYPE EXPANSION JOINT (TYPICAL)

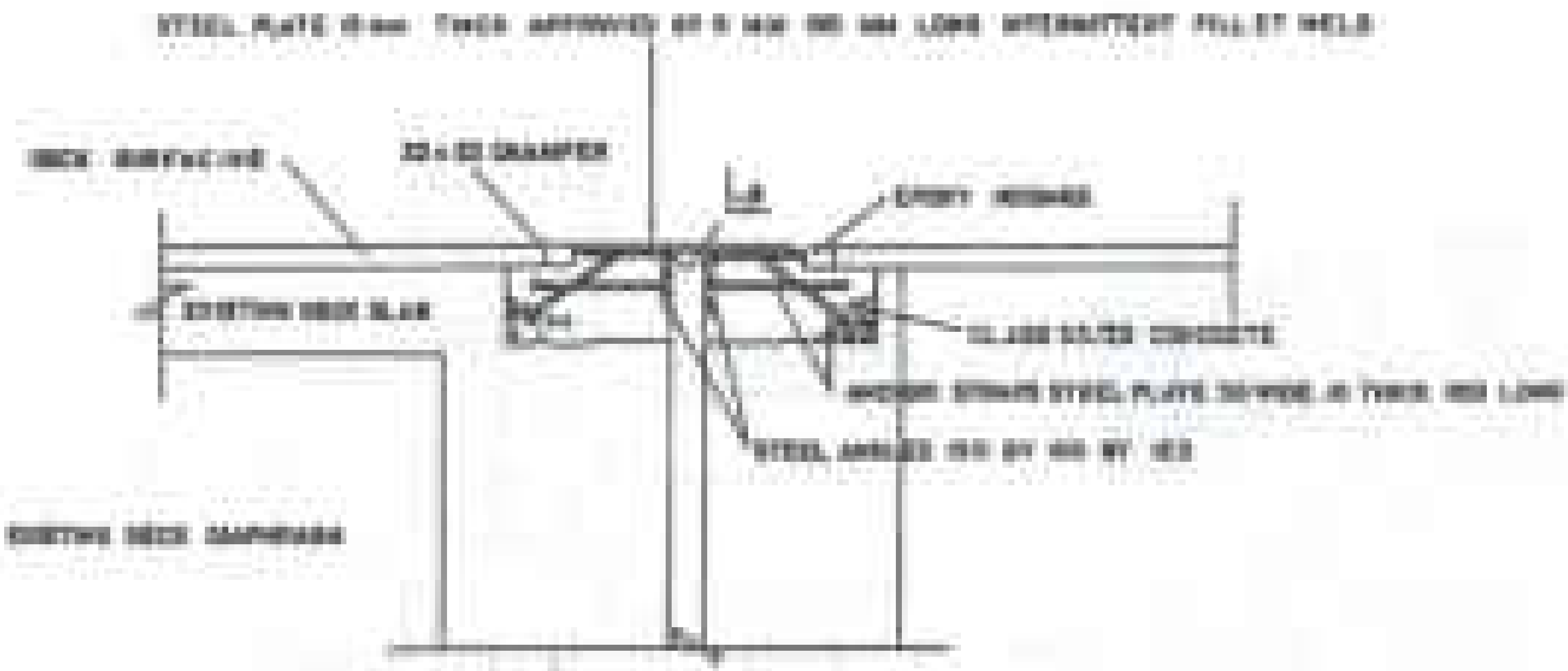
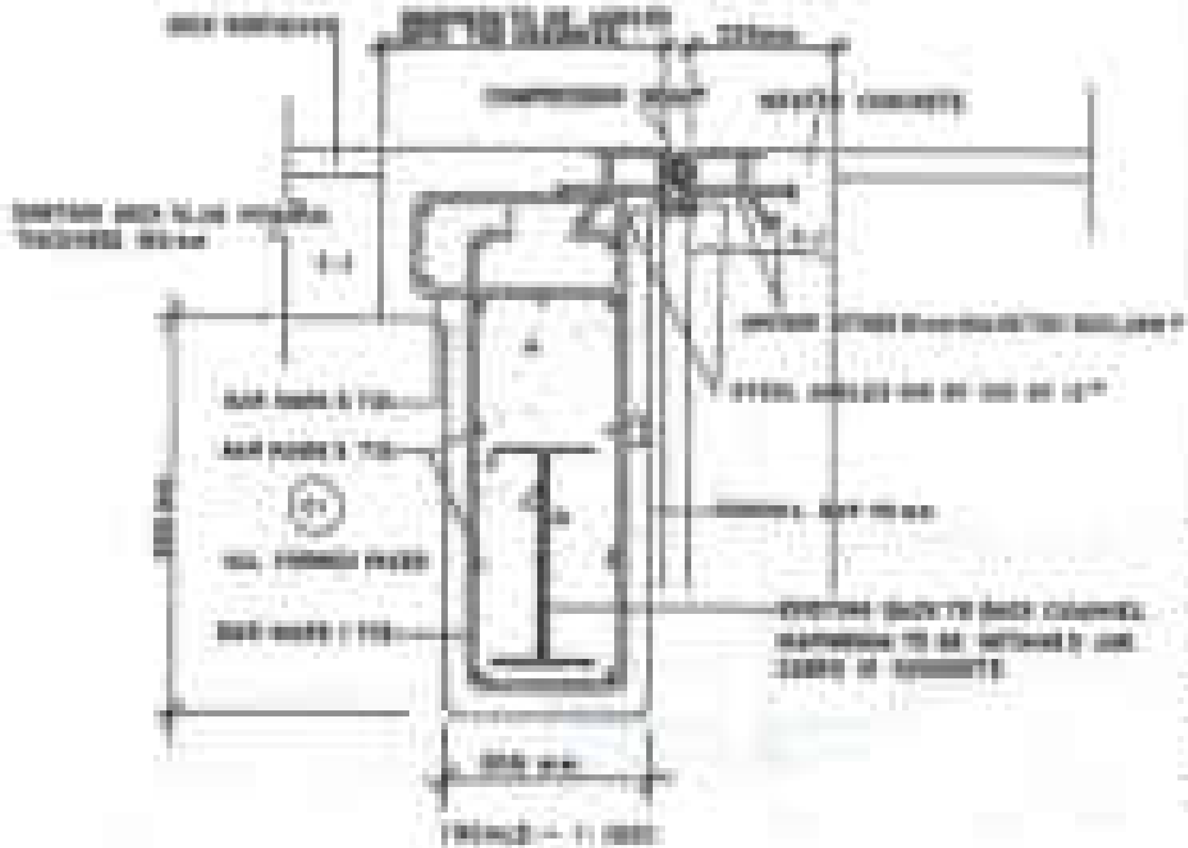


Fig. 15 TYPICAL EXPANSION JOINT DETAIL (USED IN ROAD MAINTENANCE PROJECT)



[illegible]

Fig. 14 TYPICAL ARMOURED COMPRESSION SEAL REPLACEMENT JOINT

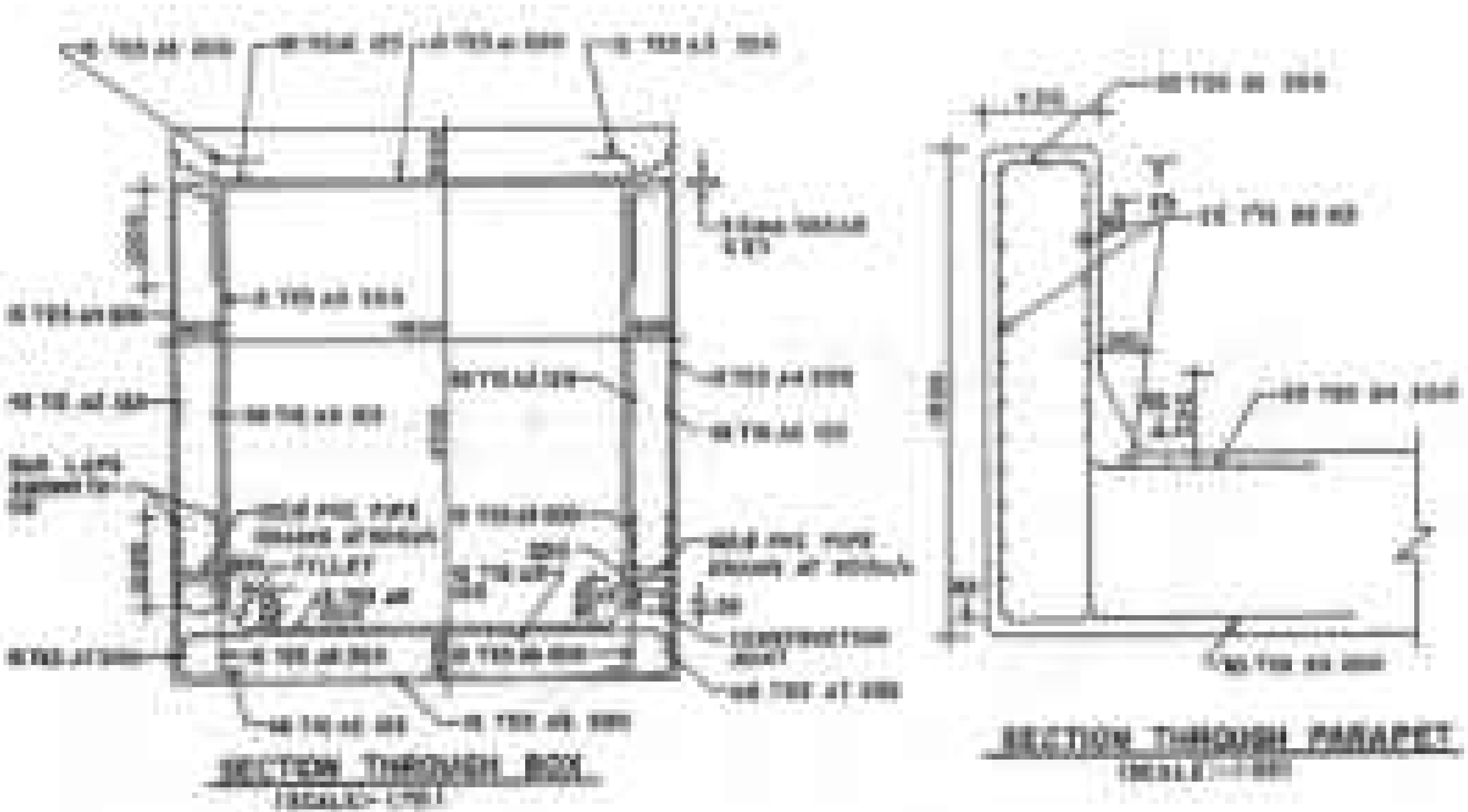


Fig. 16 REINFORCEMENT DETAILS OF WIDENING OF A TYPICAL CULVERT (AT BARAHISTHAN CULVERT ON PRITHVI HIGHWAY)

Notes on Widening of a Typical Culvert (Barahkhutan Culvert on Prithvi Highway)

Notes on General Arrangement Drawing

1. All dimensions are in mm.
2. The culvert extension has been designed for HB 40 units of HA loadings.
3. Class of formwork finish to be as follows: F1 buried or hidden surface, F3 surfaces permanently exposed.
4. Class of unformed finish to be as follows: U2 top deck slab and top base slabs U3 parapet tops.
5. Backfilling to be done only after top slab has been cured.
6. All exposed corners have 25 mm x 25 mm chamfers.
7. Class of concrete to be as follows:
   - All reinforcing concrete 25/20
   - Blinding concrete 7.5/40
8. Clear vertical joint is to be provided between the masonry wingwalls and the box extensions and to be filled with a suitable mastic filler.
9. The open drain channels to the south of the structure are to be extended to flow past the ends of the new masonry wingwalls.

Notes on Reinforcement Detail

1. Cover to the reinforcement to be 50 mm unless otherwise noted.
2. Reinforcement bars type "T" to be grade 415 type 2 deformed bars and type "R" to be grade 250 plain bars complying with BS 4449 or equivalent.
3. Reinforcement "95 T20 A3 200" are defined as "no of bars, type size, bar mark, spacing" respectively.
4. Unless otherwise noted reinforcement laps to be as follows:

Bar dia	laps
12	480
16	640
20	800
32	1280

5. Class of concrete to be as follows:
   - Box Extension and parapet 25/20
   - Blinding 7.5/40

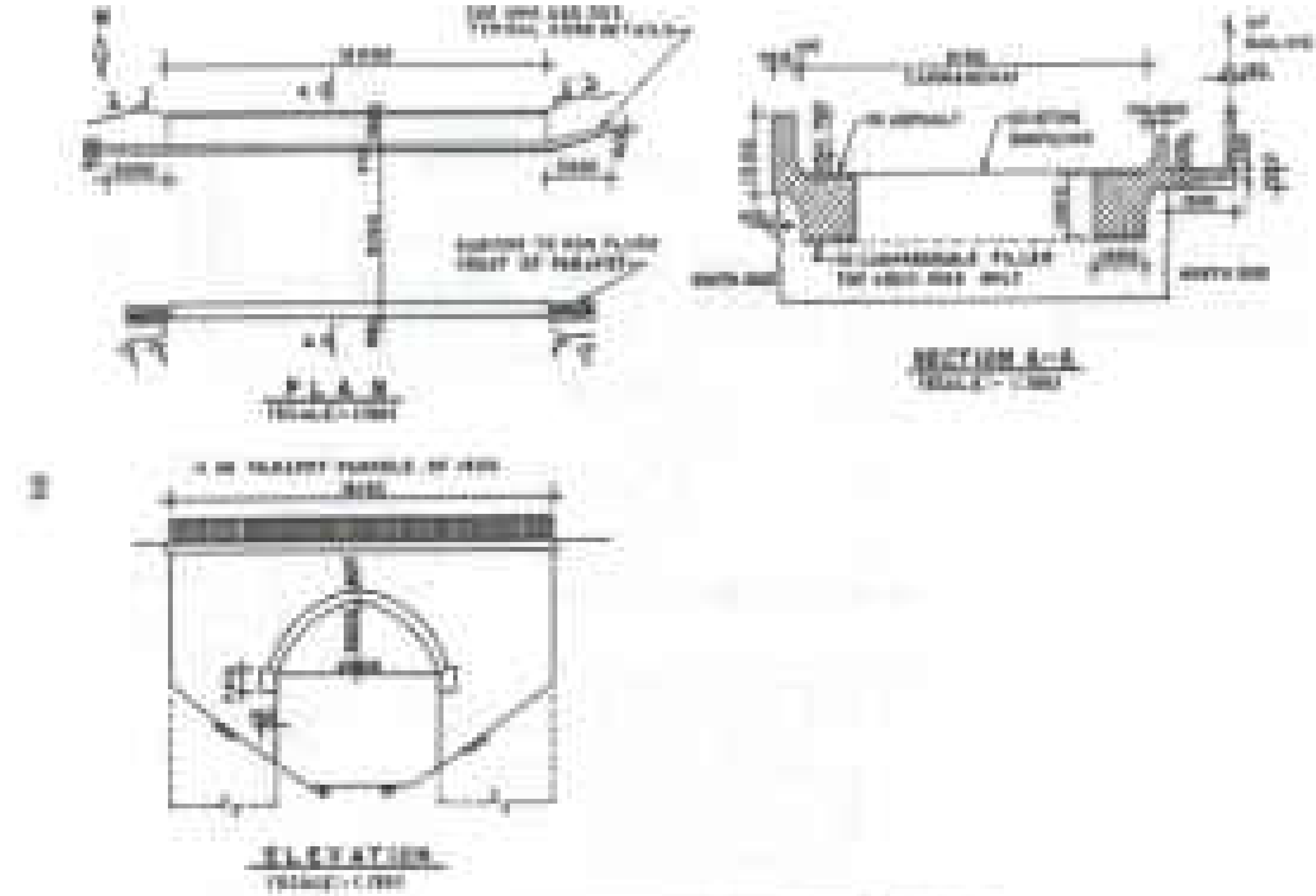


Fig. 17 GENERAL ARRANGEMENT OF REHABILITATION OF A TYPICAL BRIDGE (KHARARE BRIDGE ON PRITHVI HWY)

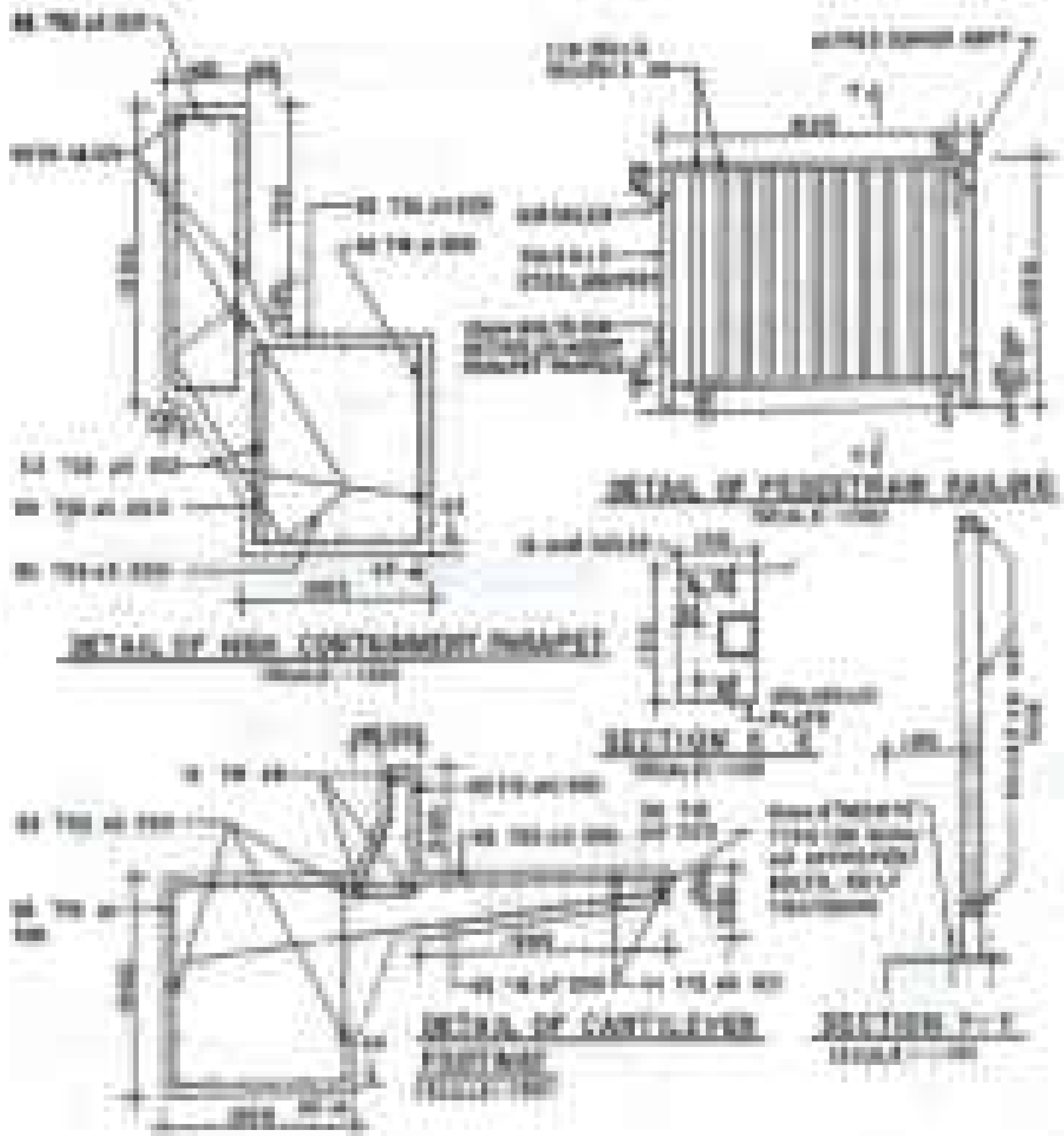


Fig. 19 REINFORCEMENT & PEDESTRIAN HANDRAIL DETAILS ON REHABILITATION OF A TYPICAL BRIDGE (KHAJANE BRIDGE ON PRITHVI HW)

General Details of Rehabilitation of a Typical Bridge (Khahare Bridge at Prithvi Highway)

Notes on General Arrangement Drawing.

1. All dimensions are in mm.
2. The high containment parapet has been designed for an impact load of 250 kN and the footway cantilever for 5 kN/m2 with a 100 kN point load.
3. Class of formwork finish to be as follows: F2 backed or hidden surfaces, F3 surfaces permanently exposed.
4. Class of unformed finish to be as follows: U2 top ground beams, U3 parapet tops and footway cantilever top.
5. End curb barriers to be aligned with edge of carriageway and to have minimum of 1.5 m width supplied for pedestrian access behind them.
6. The Gabions to the south of the structure are to be repositioned to give a smooth profile with the front face of the new high containment parapet.
7. All exposed corners have 25 mm x 25 mm chamfers.

Notes on Reinforcement and Pedestrian Handrail Detail.

1. Cover to the reinforcement to be 50 mm unless otherwise noted.
2. Reinforcement bars type "T" to be grade 413 type 2 deformed bars and type "R" to be grade 240 plain bars complying with BS 4449 or equivalent.
3. Reinforcement "01 T20 A/ 200" are defined as "no of bars, type size, bar mark, spacing" respectively.
4. Unless otherwise noted reinforcement laps to be as follows:

Bar dia	laps
12	600
16	800
20	900
25	1200

5. Class of concrete to be as follows:
   - Box Extensions and parapet: 25/20
   - Blinding: 7.5/40
6. All parapet railing welds to be a minimum 6 mm fillet welds.
7. The 10 mm dia chemical self tightening "Red Eye" type bolts (or similar approved) are to be accurately drilled into position after the footway cantilever concrete has cured. The footway rebar should be positioned to avoid the bolt hole positions.

1-2 Blocked Waterway Needs clearing off

3- Honey Combs and Exposed Rebars cover on Main beams

4- Cracked cross Beams and abutment Head

Photo 3-4: Some Minor Works needed at Bridge Waterway and Sup-structures

5- Expansion joint needs to be cleaned off to allow joint movement

6- Missing angle plated and compression seal on Expansion joint

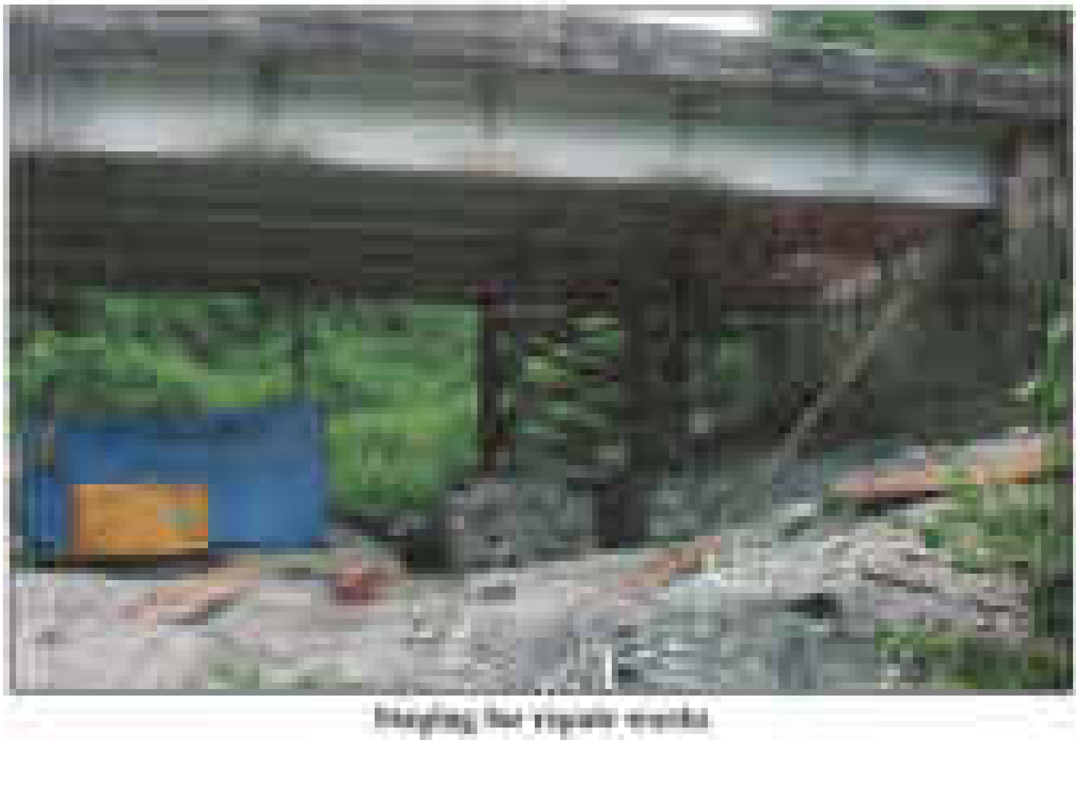
7- Replacement of Expansion joint (Working half width)

8- Elastomeric Bearing slipped off, needs repositioning

Photo 5.6: Some Minor Works needed at Expansion joint and bearings

Photo 8: Crack Sealing on the Pier of Lower Bridge : The scaffolding and sealing work

The damaged plate girders



Staging for repair works

Removal of damaged girder section

The removed damaged girder section

Photo 10: Rehabilitation works of Flood Damaged Ghoure Khola Bridge on Koshi Highways (Photo from I.S. Pradhan, SBD)

Lowering and Position of new girder section

Fixing the new girder section with old girder

Two out of three girders are repaired

Fixing of reinforcement and concreting

Photo 11: The Rehabilitation works of Blast damaged Chanda Khola Bridge on Koshi Highway (Source: Uttam Lal Pradhan, SDE, DoR), contd.