strain is proportional to the square of the frequency of vibration which can be determined by converting electronically to a voltage.

There are a variety of methods for measuring deflection. Selection is usually based upon site location, structure type and accessibility. Where there is a rigid base for fixing and access for visual reading then dial gauges may be used. Where remote recording is necessary then electrical transducers may be required.

Sometimes stretched invar wires are used to transmit the deflection from the bridge deck down to a position where gauges can be more easily installed. Where a high degree of accuracy is needed laser techniques may be used. Where lower accuracy is permissible precise levelling may be adequate. It may be necessary to supplement the measurement of deflections by measurements of rotation or change of slope, and this purpose a number of commercially produced inclinometers are available.

On many highway bridges it may be difficult to provide sufficient load to produce measurable strains and deflections. When the strains, in particular, are small it may be found that on subsequent loadings the original readings are not repeated. Changing temperatures during the measurements will produce thermal strains which can be out of the same order as those due to the loading. Careful consideration needs to be given to the method of loading and the likely strains and deflections before any tests are carried out. It may be necessary to select a time of day and weather when thermal strains are small.

7.2.13 Leakage through waterproof membranes

An electrical resistance technique may be used to locate leakage through waterproofing membranes. The resistance is measured between the reinforcement in the concrete deck and contact points on the bituminous surface formed by sponges saturated with water contain a wetting agent. A high resistance indicates that the waterproof membrane is intact but lower values indicate leakage. Measurements are made over a grid of points an contours of electrical resistance plotted. The results need careful interpretation and allowance must be made for apparent leakage due to conditions at the edges of joints.

7.3 Testing for the examination of steel bridges

7.3.1 Thickness testing

Testing for the thickness of members subject to corrosion can be carried out either by direct measurement where access is available, or alternatively by special ultrasonic testing equipment. Ultrasonic thickness testing instruments are available which enable the thickness to be measured from one surface to an accurate of approximately 0.1mm. This can be particularly useful for determining corrosion loss in preparation for assessments of residual strength. Dirt and corrosion products should be removed from the surface before the measurements are made.

7.3.2 Weld sizes

In any cases where there are doubts about the quality of welding or where evidence of cracking or defects have been found the sizes of fillet welds should be measured as leg lengths and in cases where the leg lengths are unequal both figures should be recorded. In addition a comment should be made on the profile to indicate whether the weld is convex or concave. If the weld is concave the throat should also be measured. Any evidence of surface defects such as pores or undercut should also be recorded.

7.3.3 Flatness testing

To check distortions and deviation from flatness the normal method is to apply a straight-edge to the surface and to measure the gaps between the straight-edge and the surface where deformations are present and record the maximum deformation and position. The easiest method of measuring gaps of this sort is by using a tapered wedge calibrated in 0.5mmsteps, the wedge being pushed into the gap as far as it will go and the magnitude of the gap read directly from the wedge. The length of the straight-edge used and the gauge length between crests of any waves of distortion should also be recorded, and a sketch provided showing the location of the distorted component in the structure.

Where distortion measurements have to be made over a longer gauge length than it convenient for straight-edges the normal practise is to use a taut wire stretched over the gauge length with offsets taken by tapered wedge to measure gaps between the taut wire and the surface of the distorted component

7.3.4 Black bolt and rivet testing

All such items should be inspected visually to check that they are still present and for any signs of looseness or movement.

They should also be inspected for evidence of corrosion or deterioration. In addition light tapping by a hammer in the hands of an experienced inspector will indicate whether the items are still tight. When they are tight a ringing sound is produced which penetrates into the full member, whereas when are loose there may be movement and the sound produced is a dull thud.

7.3.5 High strength friction-grip (HSFG) bolt testing

It may be required during certain special inspections, that connections using HSFG bolts are checked to determine whether the bolts are still correctly tightened. If there is evidence from the original installation of the use of either load indicating devices or the part-turn method it may be sufficient for occasional bolts to be checked. If there is no evidence of these methods being used more extensive checks may be advisable.

Bolts should only be examined one at a time, any loosened bolt removed and replaced with a new bolt, nut and washer. Where a bolt is removed the exposed surface should be examined for evidence of corrosion.

7.3.6 Dye penetrant testing

This form of testing is suitable for determining whether surface defects, and in particular cracks open to the surface, are present. It is necessary to remove paint and to clean the surface to be tested to obtain satisfactory results. After cleaning, the surface is sprayed with a red dye of low viscosity which seeps into any cracks or other defects open to the surface. The sample area is allowed to soak for period of some twenty minutes and the dye is then cleaned off from the surface using solvent. A dusting of chalk powder is then applied and if any cracks or surface defects are present the dye seeps back from the defect and appears as a stain on the white chalk surface.

The method of testing is relatively straightforward but requires care in cleaning and preparation.

7.3.7 Hardness testing

In cases where it is necessary to obtain an approximate indication of the strength of steel in a particular location it may be possible to carry out portable hardness testing. There must be adequate access to the surface area under consideration and the surface must be carefully prepared to a polished finish. This can be done by first grinding a spot of the order of 10mm to 20mm diameter and then buffing this surface using a fine emery band to produce the required fine surface.

Portable hardness testing instruments fall into two main types. In the first type the instrument has a ball or diamond which is pressed into the prepared area and gives a direct reading on the scale in hardness numbers. Several repeat readings should be taken at the same location and the average of these readings calculated as the hardness value.

7.4 Specialist Surveys

7.4.1 Scour Survey

The diver's observation may indicate obvious scour, but the main source of information will be from soundings. It is vital that soundings are related to a fixed datum which can be located easily and readily at subsequent examinations and which can be related to existing drawings of the bridge. Thus the changes in bed level and occurrence of scour over an extended period of time can be recognised.

The scour survey should initially be undertaken from the water surface and using measuring rods, weighted tapes or electronic sounding sounding devices, a bed picture should be built up. On solid beds this is sufficient, but where the bed is soft and may be overlaid with silt, then it will be necessary to take silt thickness measurements and a determined attempt should be made to establish a true bed level. This is best done by divers on the bed using sharp probes to try to reach a solid bed and measure the thickness of silt. Thus two soundings should be established at each location.

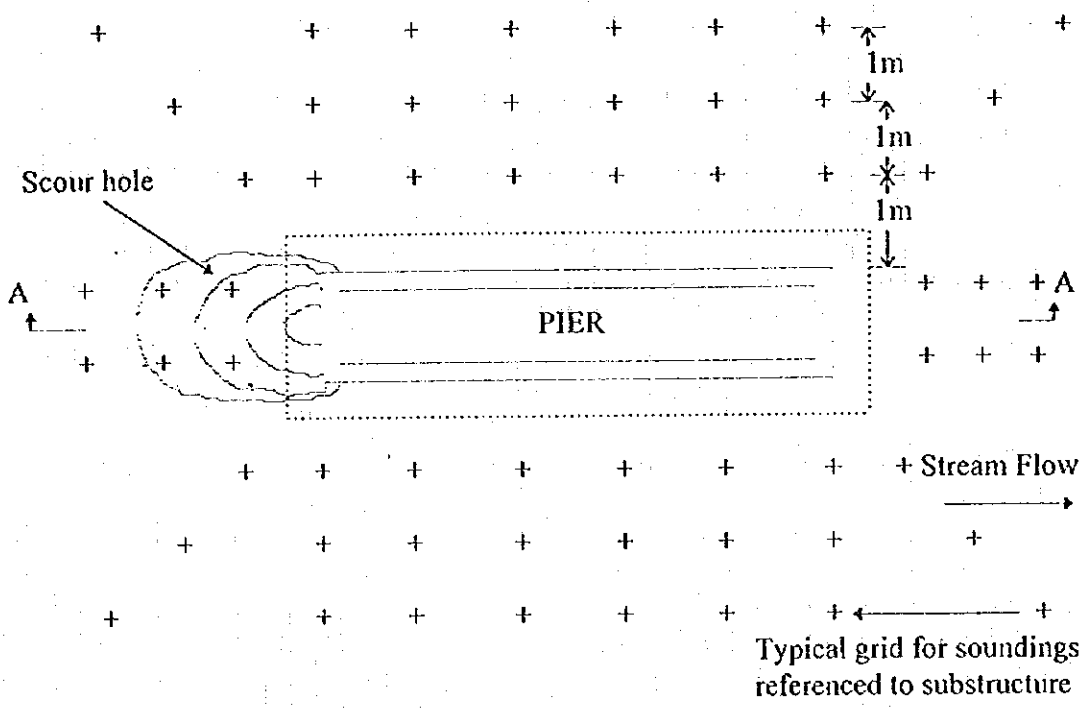
Measurement from datum to top of silt.

Measurement from datum to solid bed.

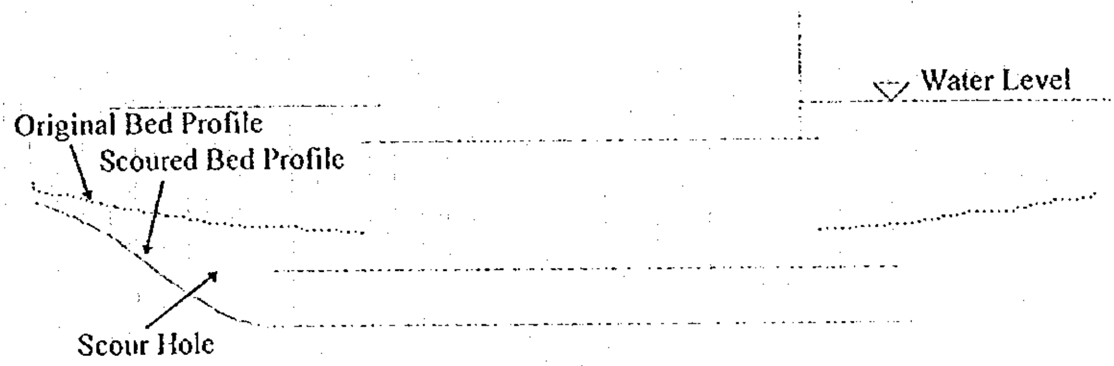
There must be two sets of scour measurements taken around the structure. The first is intended to establish localised scour around a pier or cylinder etc..due to localised disturbance of the river flow. This will often take the form of a deep depression on the upstream nose and a build-up of silt downstream.

Soundings should be taken along a series of radial lines extending from the structure at distances of 0m. 1m. 2m. and 3m. from the structure. On cylinders the radial lines should extend from the quarter points and on piers lines should extend as shown in Figure - 7.4.1

The second set of soundings is intended to measure general changes in the bed and regime of the river over a period of years. It consists of a series of cross-sections taken across the river parallel with the bridge. Soundings must be taken at 3m intervals. A minimum of 4 cross-section should be taken, one at each face of the bridge, one on the centre-line and one approximately 30m upstream. The desirability of additional cross-sections should also be considered. The cross-section must be related to a fixed datum - usually a bridge abutment - which can fix the cross-sections for subsequent years, even when substantial changes have occurred to the river.



Plan on Substructure



Sectoin A-A

Figure - 7.4.1 Scour Inspection

Japan International
Cooperation Agency(JICA)

The Republic of Turkey
Ministry of Public Works
and Settlement
General Directorate of Highways(KGM)

The Study on The Maintenance and Rehabilitation of Highway Bridges in The Republic of Turkey

FINAL REPORT

BRIDGE MANAGEMENT MANUAL

VOLUME 4-2

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in association with
JAPAN OVERSEAS CONSULTANTS CO.,LTD.

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Chapter 1

Introduction

Chapter 1 Introduction

1.1 General

This Evaluation Manual discusses the standardization and systematization of evaluation process on routine inspection data to identify the emergency ratings and importance ratings of bridges for maintenance and rehabilitation works on the bridges subjected to routine inspection.

Generally, the damage rating for deteriorated bridge and its components has been subjectively conducted only by skilled and experienced maintenance engineers. In order to make the rating process easily and accurately enough by unskilled engineers and technical staff, systematization and standardization are indispensable for the damage rating as well as prioritizing the deteriorated bridges for further countermeasures.

The first necessary matter to introduce is rationalization in collection of inspection information on the bridge, using a regulated inspection sheet and damage rating table as described in the Inspection Manual. The second necessary matter is to standardize and systematize the prioritizing procedures for the damaged bridges according to observation results.

This Evaluation Manual deals only as far as evaluation of routine inspection results and leave the rest of prioritization works description in the Maintenance Manual.

1.2 Manual Structure

This manual describes evaluation stage of bridge maintenance system and is written for all engineers involved in bridge inspection and maintenance operations on the State Highway Network in Turkey.

This manual consists of four chapters;
Chapter 1 is the introductory chapter and describes the concept of this Evaluation manual.
Chapter 2 describes contents and factors of evaluation.
Chapter 3 describes evaluation approach using the result of bridge inspection.
Chapter 4 describes the database system using computers to store the records of result on routine inspection, maintenance and rehabilitation for further inspection as well as the evaluation system using computer.

Chapter 2

Evaluation Items and Factors

Chapter 2 Evaluation Items and Factors

2.1 Evaluation Items

Evaluation shall be conducted on the items which are the same items for routine inspection. The details of those items are described carefully in the Inspection Manual. The items only are repeated in this section.

2.1.1 Foundation

The foundations of a bridge are basically the piles, pile cap and spread footing, etc.. The evaluation contents of foundation are as below;

- Deterioration of foundation,
- Scouring of riverbed and bank,
- Settlement of foundation, and
- Deferential settlement.

2.1.2 Substructure

The bridge substructure includes the abutments, wing walls, retaining walls, piers, columns and bank seat. Construction materials are usually concrete, stone or brick work, sometimes concrete with block or stone facings and occasionally steel or cast iron (in old structure). The evaluation contents of substructure are as below;

- Faults in concrete (including cracking, deterioration, corrosion of reinforcement),
- Faults in masonry and brickwork (including cracking, loss of mortar from pointing, loose or missing stones or bricks, weathering, spalling or splitting and growth of vegetation),
- Drainage and water leakage (de-icing salt through the deck slab and joints, ground water through construction joints in the abutment, corrosion or staining of reinforcements, weathering and leaching of concrete and masonry), and
- Movement of the substructure.

2.1.3 Superstructure

The superstructure is the main element of the bridge and many different forms are used, depending upon length of span, topography and other condition. The following items are the evaluation contents of reinforced concrete member;

- Cracking of concrete,
- Concrete peel off,
- Corrosion of reinforcement,
- Leakage of water,
- Porous concrete,
- Alkali-silica reaction,
- Accidental damage, and

- Chemical attack.

The evaluation contents of prestressed concrete member are deterioration of prestressing cables.

Furthermore, the following evaluation contents are included for the steel beams;

- Corrosion,
- Fracture,
- Cracking,
- Deformation and distortion,
- Paint damage,
- Missing or loosing of bolts or rivets, and
- Excessive wear (members of accommodating movement such as pins in joints or trusses).

2.1.4 Components and ancillaries

Components and ancillaries of bridge include pavement, kerb and railing, expansion joints, bearings and drainage.

The evaluation contents of pavement;

- Wheel indentation,
- Cracking, and
- Potholes.

The evaluation contents of kerb and railing;

- Cracking of kerb,
- Peel off of kerb,
- Rebar exposure of kerb,
- Deformation of railing,
- Corrosion of railing, and
- Missing of railing parts.

The evaluation contents of expansion joints;

- Loosing or movement,
- Freedom of movement clearance and alignment,
- Water leakage,
- Cracking of surfacing and buried joints,
- Deformation,
- Peel off, and
- Missing.

The evaluation contents of bearings;

- Body damage,
- Debris,

- Parts missing,
- Anchor damage,
- Bed damage, and
- Unusual movement.

The evaluation contents of drainage;

- Pipe damage,
- Blockage of pipe, and
- Inlet damage.

2.2 Evaluation Element

2.2.1 General

The evaluation shall focus on the elements listed below reflecting the characteristics of faults and damages analyzed through the results of the Visual Inspection;

- Emergency,
- Importance,
- Load capacity,
- Durability, and
- Aseismicity.

2.2.2 Emergency

Emergency element applies to the whole bridge and all the structural members. Emergency coefficient is uniformly applied to the whole bridge and its members.

2.2.3 Importance

Importance element considers the coefficients which are applied differently to each bridge parts and members. Some important bridge members, i.e., deck slab, steel girder, concrete girder, column and footing or abutment, for example shall have higher importance coefficient.

2.2.4 Load Carrying Capacity

Load carrying capacity element is mainly applied to damages of deck slab in relation with traffic volume.

2.2.5 Durability

Durability is applied to the deterioration of main bridge members in relation with traffic volume except deck slab.

2.2.6 Aseismicity

Aseismicity is applied to the deterioration of main bridge members in relation with horizontal seismic coefficient.

Chapter 3

Evaluation

Chapter 3 Evaluation

3.1 Evaluation Procedure

3.1.1 Objective

The evaluation of bridge deficiency rate should be based on the results of routine inspection. The concept of bridge deficiency rate is described as follows. The bridge deficiency rate is evaluated in relation with the weighted criteria or with extent of how much four components of bridge (foundation, substructure, superstructure, components and ancillaries) will affect to the total structural function of the bridge.

For determination of the priority of the maintenance and rehabilitation of highway bridges, the deficiency rate are converted to four-rank ratings, which are described in the latter section, by the statistical approach and are applied as the evaluation criteria to the structural deficiency of the bridge.

3.1.2 Work Flow

The bridge maintenance system presented in this manual is a support system to aid planning of maintenance and rehabilitation of highway bridges that is both systematically and practical. The system involves the use of a computer to store bridge-related data in a database system.

When supplied with data for a number of bridges, the system is able to determine the order of priority for various maintenance operations as well as diagnose the condition of existing bridges. The basic structure of the system is shown in Figure - 3.1.1.

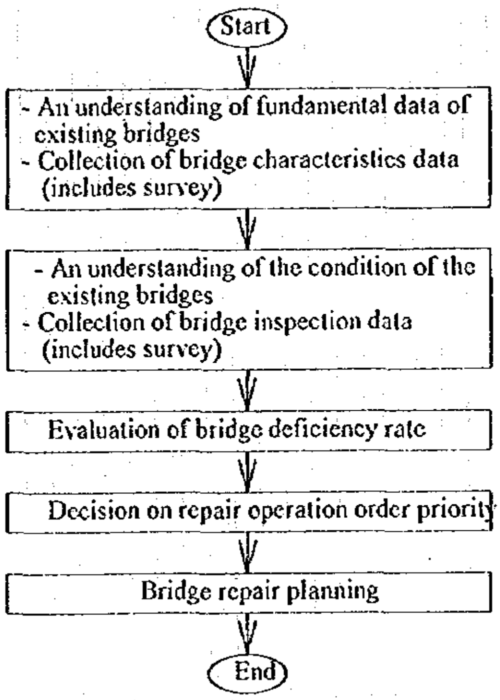


Figure - 3.1.1 System Concept

3.2 Evaluation Weight

3.2.1 General

Systematization and standardization are indispensable where many numbers of bridges are involved and same and repeated procedure for prioritization is required. Also, in order to handle a large number of data, the computer usage become very useful as well as can eliminate un-necessary mistakes.

There are two kinds of weighting applied in order to involve computer use and introduce standardization and systematization; one is to make inspection rating of 'A' to 'D' into numerical value; and the other is to set up weight on different evaluation element. The concept and actual value of weight are described.

3.2.2 Numerical Value for Rating

Rating by alphabet is recommended in the Inspection Manual, i.e. from 'A' for immediate repair work necessary to 'D' for no measure necessary. The use of numerical value tend to make the judgment of inspection staff into something of absolute judgment and makes adjustment at later stage difficult.

Adaptation of numerical value for each rating such as below is usually applied;

Table - 3.2.1 Numerical Value for Damage Rating

Rating	Numerical Value
A	5
B	3
C	1
D	0

Those numerical values shall not be an absolute judgment and shall be reviewed and adjusted often to reflect the actual situation of ratings.

3.2.3 Coefficient for Evaluation Element

There are no fundamental theory for setting up of coefficient for evaluation element, however, from the previous experiences, the figures such as the followings are generally used;

Table - 3.2.2 Coefficient for Evaluation Element

Bridge Component	Emergency Coefficient	Importance Coefficient
Pavement	1.00	0.75
Kerb & Rating	1.00	0.50
Expansion Joint	1.00	0.75
Deck Slab	1.00	1.00
Steel Girder	1.00	1.00
Concrete Girder	1.00	1.00
Bearing	1.00	0.75
Drain	1.00	0.50
Column & Footing	1.00	1.00
Abutment & Footing	1.00	1.00
Embankment	1.00	0.50
Riprap	1.00	0.50

3.3 Evaluation Analysis

The numerical valued rating of inspection shall be calculated systematically while applying the evaluation element's coefficient. In this regard, the emergency element shall have the coefficient of 1.00 to get focus more to the emergency state of the damages.

As to the importance element, more structurally important component of bridges shall get focused hence the higher coefficient applied to those members.

Other elements are added to those basic ones to take into consideration the traffic situation, and natural conditions (particularly of seismic condition) where the objective bridges are. As much attention as possible shall be paid to evaluate the damage state of bridges as a whole in view of load carrying capacity and durability to reach the final judgment on priority for maintenance works.

Summed total of points shall reflect the priority of maintenance work, however, in quite often cases, the judgment of the experienced maintenance engineer and the evaluation results do not have the satisfactory out come. The numerical value for the rating and the coefficient for the evaluation element shall be adjusted to have a good harmony in both party's out come.

Chapter 4

Database System

Chapter 4 Database System

4.1 Introduction

Routine inspection and repair plans supported by output information from the databases. The output information will provide a list of bridge to be inspected or repaired in terms of existing damage on bridges. This enables engineers to decide on inspection or repair plans more easily using information stored in the databases.

4.2 System Concept

4.2.1 System Concept

The concept of system is to store inspection data, to evaluate of deficiency rate, and determine the priority for repair work by evaluating existing damages on bridges. The basic structure of the system is shown in Figure - 4.2.1.

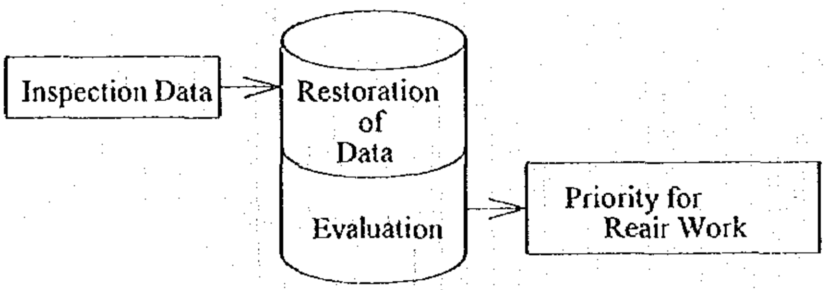


Figure - 4.2.1 System Concept

4.2.2 System Structure

The computer "IBM PSV model-2411" is used to load the database system. This computer has enough capacity to accommodate the road inventory, inspection and repair results for all the state highway bridges.

In order to manage information for maintenance work, the database management system (DBMS) is used for the following reasons;

- it is commercially available in Ankara with the possibility of after-care service,
- it has enough functions and can formulate a database system for maintenance work,
- it is easy for KGM staff to maintain and to make improvements in the system.

The hardware and software used in the system are shown in Figure - 4.2.2 and Figure - 4.2.3.

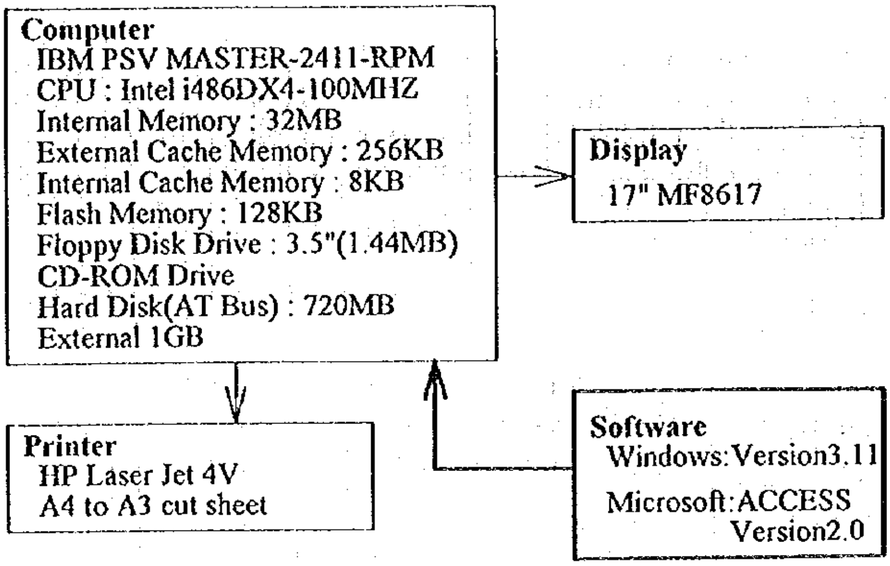


Figure - 4.2.2 Structure of Hardware

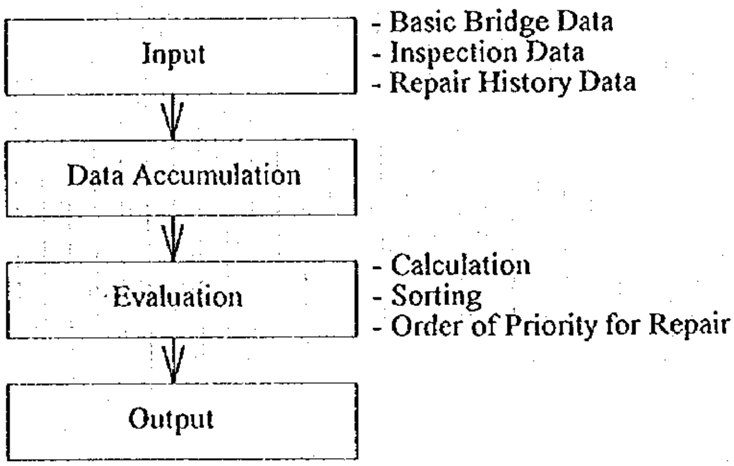


Figure - 4.2.3 Structure of Software

4.3 System Framework

4.3.1 System Components

The highway bridge's inspection and maintenance system plays an important role for road administrators in the road's maintenance, management and operation. In order to apply the system effectively for the practical maintenance work of the bridge, the system is subdivided into subsystems as shown in Figure - 4.3.1.

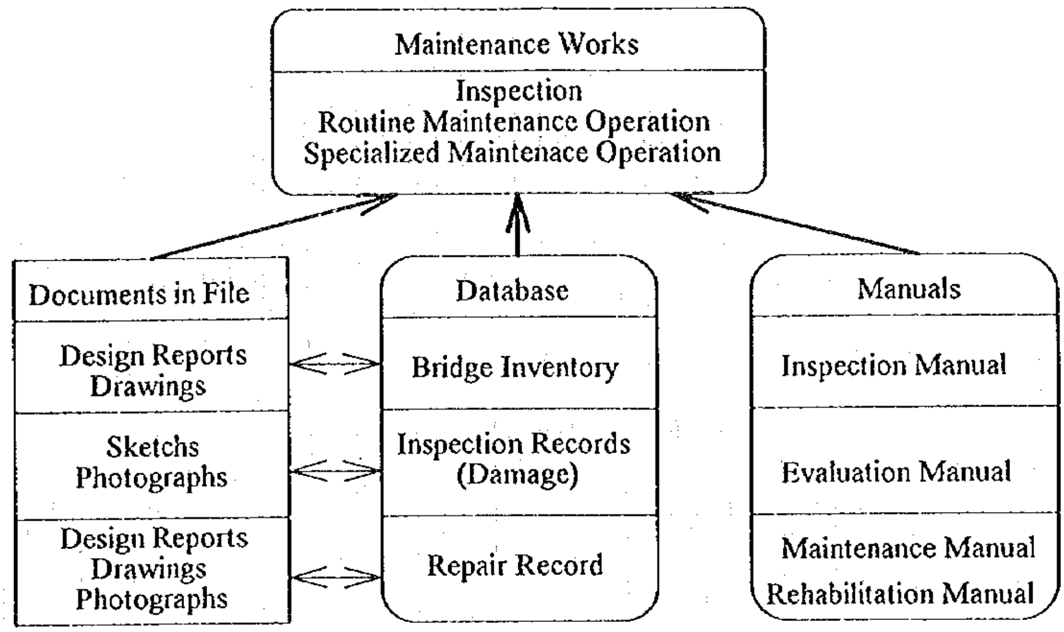


Figure - 4.3.1 System Framework

The inspection and maintenance system for the highway bridge consists of a database to manage maintenance information and manuals to assist KGM engineers with inspection and maintenance work as below;

- Inspection manual is handled out to assist inspection engineers and staff with routine, and special inspection work for the highway bridge,

- Evaluation manual provides methodology to prioritize damaged bridges for rehabilitation and strengthening the damaged components,

- Maintenance manual is drawn up so it can be applied to the bridge maintenance
  in routine works on cleaning and other protective operations, including minor repairs such as spot painting or protective coating, and

- Rehabilitation manual provides repair methodology on rehabilitation, components.

4.3.2 Database Framework

1) Structure of Database

The structure of database as shown in Figure - 4.3.2, which is composed of inventory, inspection, and repair information together with their operating applications.

The database compiles all the information necessary to manage highway bridges in a form of single database file, taking the easier access and information management by unskilled operators into consideration.

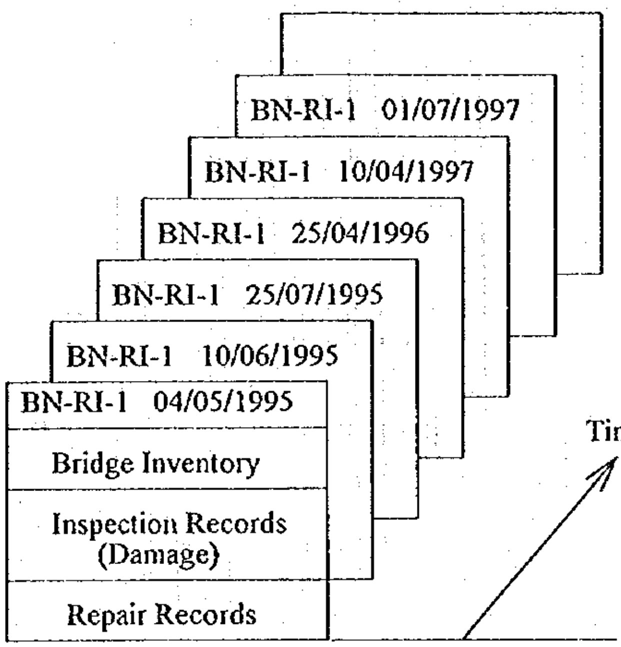


Figure - 4.3.2 Database Framework

Although the database is formulated not to compile the whole data necessary for bridge maintenance, such as photographs, figures and other detailed information obtained in maintenance work, the system is designed in such a way that the related information for maintenance work can be interfaced with key identifiers and record number by work.

2) Key Identifiers

Database files are similar to a table that consists of columns and rows. Columns are called a field, which corresponds to data items, and rows are called a record, which corresponds to a collection of data belonging to a common key identifier, such as one bridge in a database file. A record is distinguished by key identifiers that specify a given data record from other records in a database file. The whole database for maintenance work possesses several items with key identifiers at the head of each record. Consequently, every record has particular key identifiers to access and extract data from a database.

Key identifiers for the database, which is written into each data record in a form of sheet number, are defined as indispensable items with supplemental items to identify maintenance work conducted and bridge location on the highway. They are composed of 4 items and their combinations are as follows;

- Bridge Number,
  Bridge number, which is composed of 3 items; route number, Kilometer-post and subdivision on traffic direction.

- Work Category,
  Maintenance works in terms of inspection and repair, is to identify maintenance operations conducted for a designated bridge. They are categorized in the following character codes;

  RI: Routine Inspection,
  SI: Special Inspection, and
  RP: Repair.

- Ordinal Number, and
  This item is to identify page (number) in the same combination of the above bridge number and work category, using the ordinary number in a form of 1, 2, 3, and so on.

- Updated Date,
  This item is to identify the latest inventory data for a designated bridge in the database file.

According to the above key identifiers in each record in the database, the system can store, copy, and retrieve readily information necessary for information processing.

3) Data Items

The data items of the database for bridge maintenance on the state highway are determined in consideration of;

- Characteristics of the existing bridges on the highway,
- appropriate data volume to be managed by computer basis,
- effective usage of maintenance work, and
- appropriate data volume to be maintained by KGB staff itself, etc.

The details of the items for database is presented in Table - 4.3.1.

Key identifiers are set up to identify designated data records in the database. Attributive data are information essential to store into a database for maintenance work belonging to a collection of key identifiers.

In Table - 4.2.1, abbreviation and marks show the following;

- Type (type of data) : X : character data, N : numerical values.
- Digits: number of digits of the item.
- "code" in remarks is a code item which is provided in character or number

code together with detail characters of the window on the nionitor screen.

4) System Functions

The database system is formulated in such a way that it is possible to;

- Append,
  adds new data to the database, and is used when new facilities are installed or a new bridge on the highway is opened, or when inspection or repairs are carried out.
- Alter,
  alters information stored in the database based on changes in information, and is used in such cases as when a bridge component is renovated.
- Extract, and
  allows for the extraction of information stored in the database by any combination of retrieval conditions, for effective use of compiled data for a wide scope of maintenance work.
- Output.
  prints out information in a form of the latest inventory, inspection report, repair report, and historical records in the same manner, in response to the users request.

Table - 4.3.1 Data Items of Database (1/5)

Item	(Name)	Type	Digits	Remarks
(Key Identifier)				
Route		N	3	
Kilo-Post		N	6	
Sub-Division		N	2	by Traffic Direc.
Work Category		X	2	Code
Date of Work		N	6	MM/YY
(Bridge General)				
Bridge Name		X	20	
KGM-Division		N	3	Code
Division		N	3	Code
Name of River		X	20	
Design Spec. & Load		X	2	Code
Bridge Length		N	7.2	
Span Composition		X	25	
Carriageway Width		N	5.2	
Side Walk Width		N	5.2	
Skew Angle		N	4	
Contractor		X	20	
Constructed Year		N	4	YY
(Superstructure)				
Bridge Type		X	2	Code
Type of Support		X	2	Code
Type of Structure		X	2	Code
Number of Beams		N	2	
Type of Deck Slab		X	2	Code
Type of Surface		X	2	Code
Type of Railing		X	2	Code
(River Condition)				
Low Water Level		N	4.1	
Low Water Level Width		N	4.1	
High Water Level		N	4.1	
High Water Level Width		N	4.1	
Current Velocity		N	4.1	
Bridge Height from River Bed		N	4.1	
(Site Condition)				
Topography		X	2	Code
Geology		X	2	Code
Land Use		X	2	Code

Table - 4.3.1 Data Items of Database (2/5)

Item	(Name)	Type	Digits	Remarks
(Traffic Volume)				in AADT
Bus		N	5	
Lorry		N	5	
Pick-up		N	5	
Passenger Car		N	5	
Total		N	5	
(Inspection)				
Work Category		X	2	Code
Conducted Date		N	6	MM/YY
File Number		X	10	
(Damage Rank)				in A, B, C, D
Pavement :Wave		X	1	
Wheel Indent		X	1	
Crack		X	1	
Potholes		X	1	
Overall Rank		N	2	
Kerb & Railing :Crack		X	1	
Peel Off		X	1	
Rebar Exposure		X	1	
Deformed		X	1	
Corrosion		X	1	
Missing		X	1	
Overall Rank		N	2	
Expansion Joint :Noise		X	1	
Water Leakage		X	1	
Deformed		X	1	
Peel Off		X	1	
Missing		X	1	
Overall Rank		N	2	
Deck Slab :Crack		X	1	
Peel Off		X	1	
Rebar Exposure		X	1	
Honeycomb		X	1	
Void		X	1	
Water Leakage		X	1	
Overall Rank		N	2	

Table - 4.3.1 Data Items of Database (3/5)

Item (Name)		Type	Digits	Remarks
Steel Girder :Deformed		X	1	
Crack		X	1	
Corrosion		X	1	
Worn		X	1	
Bolt Missing		X	1	
Paint Damage		X	1	
Overall Rank		N	2	
Concrete Girder :Crack		X	1	
Peel Off		X	1	
Rebar Exposure		X	1	
Honeycomb		X	1	
Void		X	1	
Water Leakage		X	1	
Overall Rank		N	2	
Bearing :Main-Damage		X	1	
Parts Missing		X	1	
Anchor-Damage		X	1	
Bed-Damage		X	1	
Unusual Movement		X	1	
Overall Rank		N	2	
Drainage :Pipe-Damage		X	1	
Blocked		X	1	
Inlet-Damage		X	1	
Overall Rank		N	2	
Column & Footing:Crack		X	1	
Peel Off		X	1	
Rebar Exposure		X	1	
Honeycomb		X	1	
Void		X	1	
Water Damage		X	1	
Displacement		X	1	
Scour		X	1	
Overall Rank		N	2	
Abutment :Crack		X	1	
Peel Off		X	1	
Rebar Exposure		X	1	
Honeycomb		X	1	
Void		X	1	
Water Damage		X	1	
Displacement		X	1	
Scour		X	1	
Overall Rank		N	2	
Embankment :Depression		X	1	
Erosion		X	1	
Overall Rank		N	2	

Table - 4.3.1 Data Items of Database (4/5)

Item (Name)		Type	Digits	Remarks
Riprap :Missing		X	1	
Erosion		X	1	
Displacement		X	1	
Overall Rank		N	2	
(Damage Indices)				to be calculated
Emergency Index		N	3	
Importance Index		N	3	
(Repair Works)				
Pavement :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Kerb & Railing :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Expansion Joint :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Deck Slab :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Steel Girder :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Concrete Girder :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Bearing :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	

Table - 4.3.1 Data Items of Database (5/5)

Item (Name)		Type	Digits	Remarks
Drainage :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Column & Footing:Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Abutment :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Embankment :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
Riprap :Conducted Date		N	6	MM/YY
Work Category		X	2	Code
Repair Methods		X	90	Comments
Cost		N	6	x 1,000,000 TL
File Number		X	10	
(Comments)				
1		X	75	
2		X	75	
3		X	75	
4		X	75	
5		X	75	

4.4 Cording, Inputting and Reporting

4.4.1 Coding and Inputting

The data to be registered into the system falls into the following three types; inventory data for a bridge including the name, location, type and length of a bridge, etc., ; preliminary check data for a bridge based on bridge deficiency evaluation surveys performed periodically; and bridge repair history data containing the detailed and history of a repaired bridges as shown in Table - 4.4.1.

4.4.2 Outputting and Reporting

The data to be printed from the system can easily be output to the printer. After outputting the data, sketch and photograph should be put on the data sheet. The procedure from inputting to outputting are shown in Figure - 4.4.1.

Table - 4.4.1 Data Sheet

Key Identifier	Route	NNN	Chainage	9(6)	Sub-Division	NN	Work Category	X(20)	Date of Work	DD/MM/YYYY	Sketch of Site View

Inventory

Bridge General	Bridge Name	X(25)	Span Composition	X(25)			
	KGM-Division	9(3)	Carridgeway Width	9(6,2) (m)			
	Division	9(3)	Side Walk Width	9(6,2) (m)			
	Name of River	X(25)	Skew Angle	9(3) (degree)			
	Design Spec. & Load	X(25)	Contractor	X(25)			
	Bridge Length	9(8,2) (m)	Construction Year	DD/MM/YYYY			
Superstructure	Bridge Type	X(25)	Type of Deck Slab	X(25)			
	Type of Support	X(25)	Type of Surface	X(25)			
	Type of Structure	X(25)	Type of Railing	X(25)			
	Number of Beam	9(2)					
River Condition	Low Water Level	9(5,1) (m)	High Water Level	9(5,1) (m)	Current Velocity	9(5,1) (m/sec)	
	Low Water Level Width	9(5,1) (m)	High Water Level Width	9(5,1) (m)	Bridge Height from River Bed	9(5,1) (m)	
Site Condition	Topography	X(25)	Geology	X(25)	Land Use	X(25)	
Traffic Volume in AADT	Bus 9(5)	Lorry 9(5)	Pickup 9(5)	Passenger Car 9(5)	Total 9(5)		

Inspection

Work Category	X(20)	Conducted Date	DD/MM/YYYY	File Number	X(10)						
Evaluation	Pavement	Wave X	Wheel Indent X	Crack X	Potholes X						NN
	Kerb & Railing	Crack X	Peel Off X	Rebar Exposure X	Deformed X	Corrosion X	Missing X				NN
	Expansion Joint	Noise X	Water Leakage X	Deformed X	Peel Off X	Missing X					NN
	Deck Slab	Crack X	Peel Off X	Rebar Exposure X	Honeycomb X	Void X	Water Leakage X				NN
	Steel Girder	Deformed X	Crack X	Corrosion X	Worn X	Bolt Missing X	Paint Damage X				NN
	Concrete Girder	Crack X	Peel Off X	Rebar Exposure X	Honeycomb X	Void X	Water Leakage X			Overall Rank	NN
	Bearing	Main-damage X	Parts Missing X	Anchor Damage X	Bed-Damage X	Unusual Movement X					NN
	Drainage	Pipe-Damage X	Blocked X	Inlet-Damage X							NN
	Column & Footing	Crack X	Peel Off X	Rebar Exposure X	Honeycomb X	Void X	Water Damage X	Displacement X	Scour X		NN
	Abutment	Crack X	Peel Off X	Rebar Exposure X	Honeycomb X	Void X	Water Damage X	Displacement X	Scour X		NN
	Embankment	Depression X	Erosion X								NN
	Riprap	Missing X	Erosion X	Displacement							NN
Damage Indices	Emergency Index	NNN									
	Importance Index	NNN									

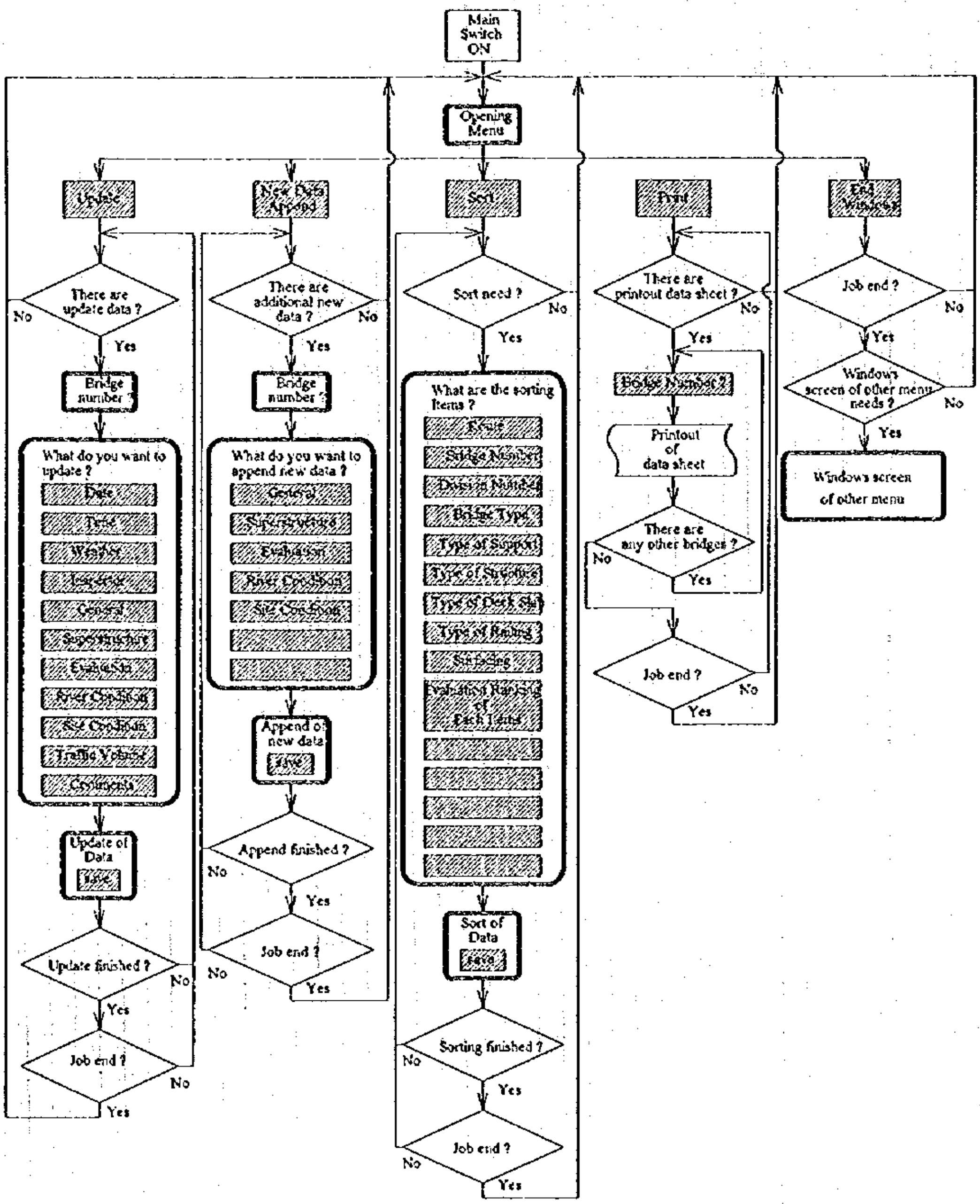
Photographs

Repair

Items	Conducted Date	Work Category	Repair Method	Cost x 1,000,000 TL	File Number
Pavement	DD/MM/YYYY	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	NNNNNN	XXXXXXXXXX
Kerb & Railing	10(6)	X(30)	X(50)	9(6)	X(10)
Expansion Joint	10(6)	X(30)	X(50)	9(6)	X(10)
Deck Slab	10(6)	X(30)	X(50)	9(6)	X(10)
Steel Girder	10(6)	X(30)	X(50)	9(6)	X(10)
Concrete Girder	10(6)	X(30)	X(50)	9(6)	X(10)
Bearing	10(6)	X(30)	X(50)	9(6)	X(10)
Drainage	10(6)	X(30)	X(50)	9(6)	X(10)
Column & Footing	10(6)	X(30)	X(50)	9(6)	X(10)
Abutment	10(6)	X(30)	X(50)	9(6)	X(10)
Embankment	10(6)	X(30)	X(50)	9(6)	X(10)
Riprap	10(6)	X(30)	X(50)	9(6)	X(10)

Comments

X(75)	X(75)
X(75)	X(75)
X(75)	X(75)
X(75)	X(75)
X(75)	X(75)



Remark ;

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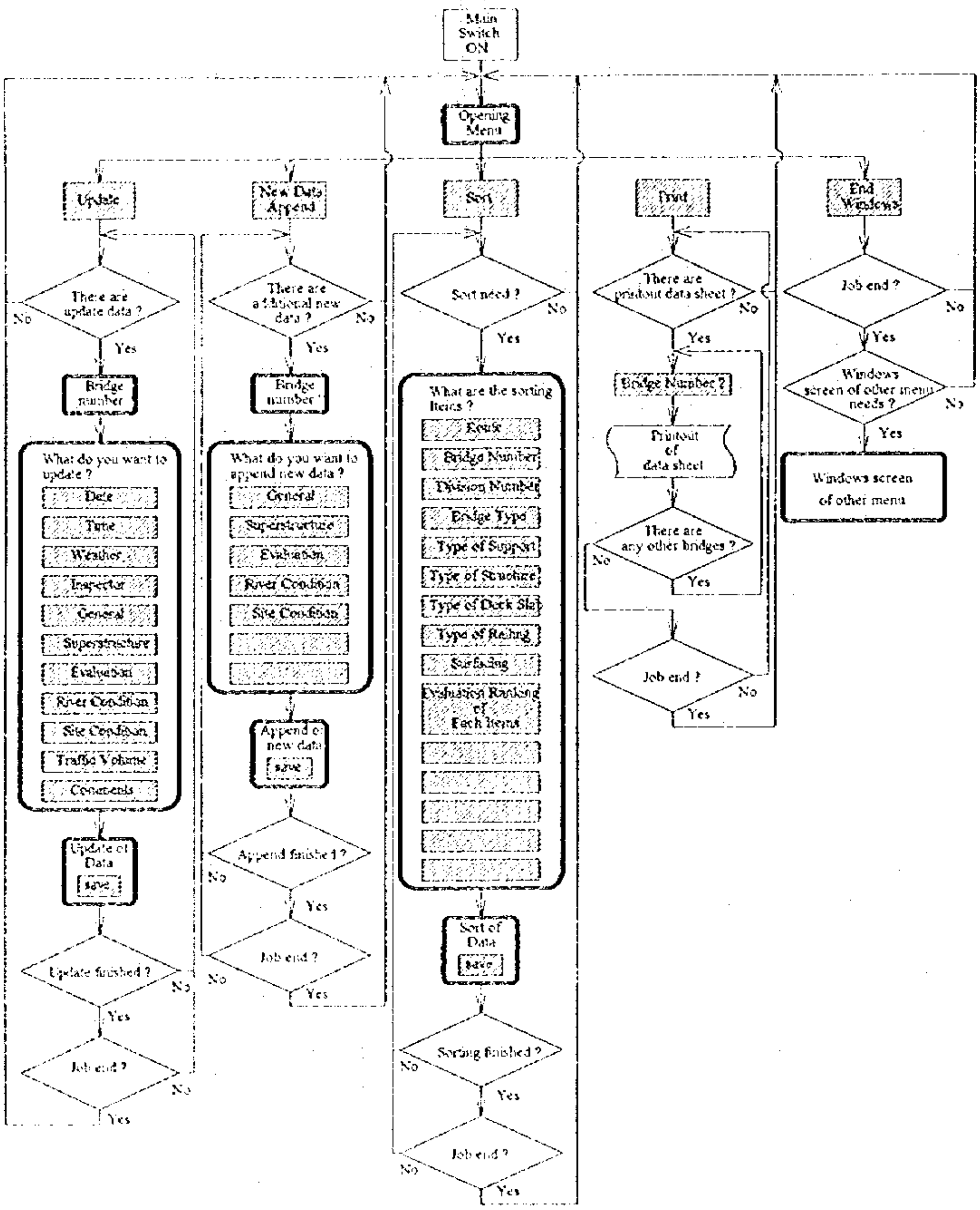
Figure - 4.4.1 Data Base System



Remark ; ; Screen ; Button in screen

Figure - 4.4.1 Data Base System

Japan International
Cooperation Agency(JICA)

The Republic of Turkey
Ministry of Public Works
and Settlement
General Directorate of Highways(KGM)

The Study on The Maintenance and Rehabilitation of Highway Bridges in The Republic of Turkey

FINAL REPORT

BRIDGE MANAGEMENT MANUAL

VOLUME 4-3

AUGUST 1996

ORIENTAL CONSULTANTS CO.,LTD.
in association with
JAPAN OVERSEAS CONSULTANTS CO.,LTD.

THE STUDY ON THE MAINTENANCE AND REHABILITATION OF HIGHWAY BRIDGES IN THE REPUBLIC OF TURKEY

MAINTENANCE AND REPAIR/REHABILITATION MANUAL

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Chapter 1

Introduction

Chapter 1 Introduction

1.1 Introduction

Highway bridges are important elements of the road network by virtue of their strategic location, and because of the consequences when they fail or when their loading capacity is reduced.

Maintenance is essential in prolonging the serviceability of highway bridges and in keeping bridges in use throughout their design life. Regular routine maintenance ensures that elements of the structure, notably the visible elements, are kept in a condition that meets these requirements. Some elements, such as bearings and expansion joints will need to be changed or modified at regular intervals, for the structure as a whole to achieve its design life. Other elements such as steel parapet railing will need to have the protective system renewed if these components are not to corrode.

Lack of maintenance leads to early deterioration of highway bridges. Highway bridges must be protected from the onslaught of environmental factors such as weather or the effects of scour which can seriously impair the structural integrity of the bridge. Expansion joints, if not regularly cleaned, can seize which in time will exert additional forces on other structural elements such as abutment curtain walls.

This Maintenance and Repair Manual provides advice on maintenance and reporting of KGM's highway bridges in addition to covering access arrangements and outlining safety considerations. Procedures and methods for comprehensive maintenance work including cleaning and repairs commonly carried out on highway bridges are discussed.

1.2 Manual Structure

This manual is written for all persons involved in bridge maintenance operations on the State Highway Network in Turkey. This manual should not be used in isolation but as part of a wider approach to bridge inspection and maintenance operations.

The manual consist of 7 chapters, Chapter 1 being the introduction. Chapter 2 describes bridge maintenance in general before showing the relationship between the database, bridge inspection, bridge maintenance and repair. The objectives of maintenance and repair, and general procedures applicable to maintenance and repair, are described in Chapter 3. Details of routine maintenance operations, repair operations and specialised maintenance and repair operations are provided in Chapters 4, 5 and 6 respectively. Finally Chapter 7 describes access and safety considerations relating to maintenance and repair works.

Chapter 2

Maintenance and Repair Outline

Chapter 2 Maintenance and Repair Outline

2.1 Aims of the Maintenance and Repair Manual

2.1.1 Systems Applicable to Maintenance Work

For effective management of KGM's bridge stock, a systematised maintenance method is of great value to the bridge administrators. The system records the existing condition of the bridges on the state highway network, and ensures that remedial measures are undertaken when they are needed. The relationship of this maintenance and repair manual to the system as a whole is explained below.

a) Standardisation of Information and it's Collection
By standardising the various types of information relating to bridge management and maintenance, this information can be used throughout the KGM organisation without the need for extensive training.

b) Standardisation of Work Procedures
As there are so many items of work associated with the maintenance and repair of the bridge stock, it is difficult to ensure that they are all undertaken on time, and to record the current situation. By standardising the approach to inspection and maintenance, set work procedures can be applied with the result that maintenance is much more effective.

c) Efficient Information Management
The use of a database to compile and manage maintenance information allows all engineers and administrators to easily extract current information vital to their work.

As part of this system for maintenance works, this manual will assist KGM engineers in carrying out repair works effectively and upgrade the quality of their maintenance and repair works.

2.1.2 Objectives of the Maintenance and Repair Manual

To achieve the improvements offered by the maintenance system described above for the state highway bridges, this manual provides advice for personnel engaged on maintenance work in the following ways:

a) Maintenance and Repair Methods

The manual provides technical advice on the planning of maintenance work , the causes of defects , the selection of repair methods and guidance on specific maintenance and repair operations.

b) Maintenance and Repair Work Procedures

The objectives , categorisation and procedures of bridge maintenance and repair described will result in smoother operation of the KGM maintenance organisation.

c) A Reference Book for Bridge Maintenance

Although this manual concentrates on maintenance associated with the KGM state highway bridge network , it provides technical guidance which can be applied to bridge inspection and maintenance generally. It should therefore assist in the training of engineers and workmen.

2.2 Framework of Inspection and Maintenance System

2.2.1 General

1) System Components

The bridge inspection and maintenance system is an important tool for bridge administrators in the bridge stock's maintenance, management and operation. In order to apply the system effectively to the practical maintenance of highway structures and facilities, the system is subdivided into subsystems as shown in Figure - 2.2.1.

The inspection and maintenance system for the KGM's highway bridges consists of a database to manage maintenance information and manuals to assist KGM engineers in inspection, maintenance work and operation of the database system.

The "Inspection Manual" is presented to assist inspection engineers in inspection works covering routine, emergency and the further detailed special inspection work for the bridge stock.

The "Evaluation Manual" provides the methodology to prioritise damaged bridges for rehabilitation and strengthening to the damaged bridge components.

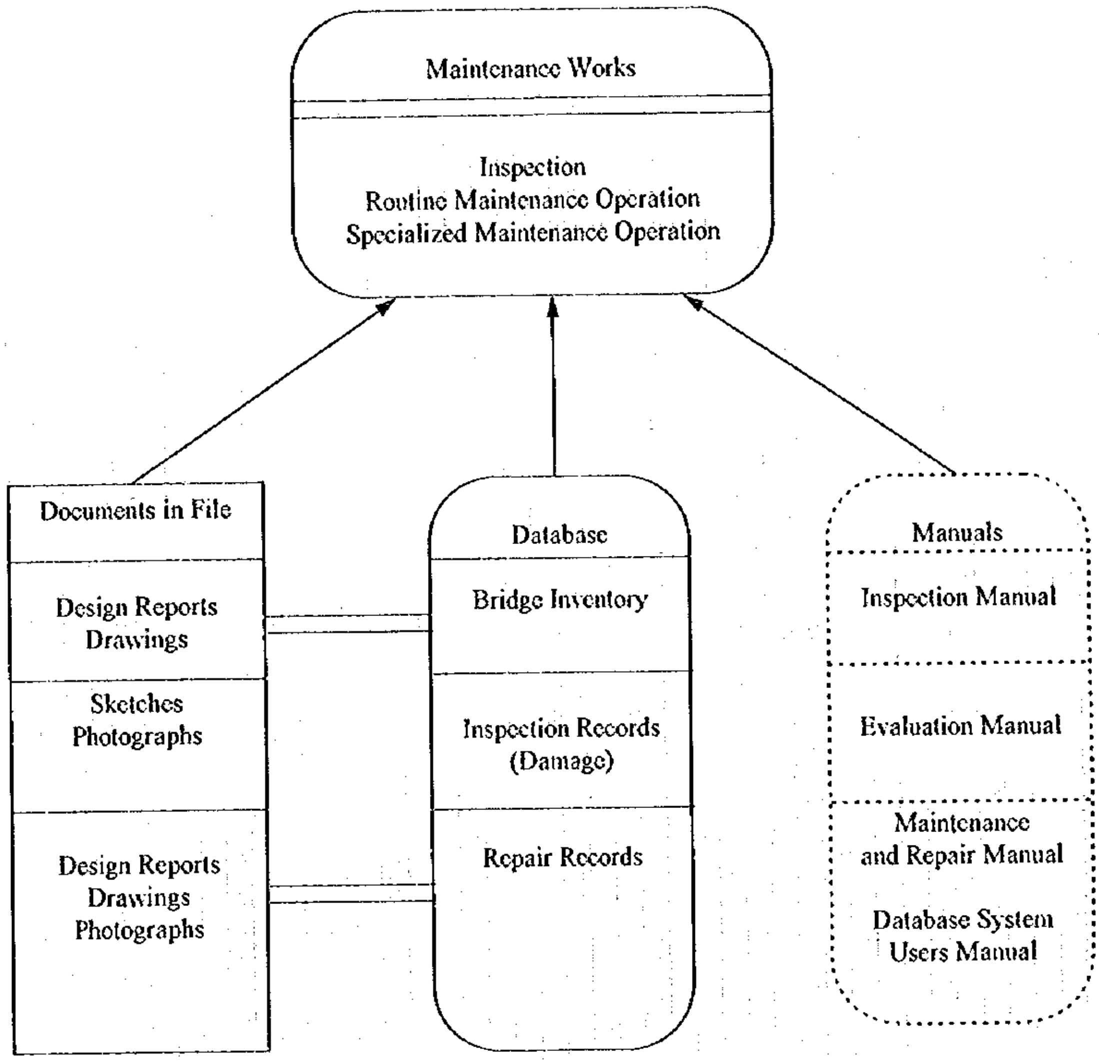
This "Maintenance and Repair Manual" is prepared to apply commonly to all the bridges on the state highway network. The manual is drawn up so that it can be applied to routine bridge maintenance operations such as cleaning and other protective operations including minor repairs such as spot painting or protective coating. The repair section provides repair methodology on rehabilitation, strengthening and improvement measures for a defective bridge or its components.

The manual on repairs is particularly useful in that it covers a range of repairs that can be carried out to maintain the bridge stock.

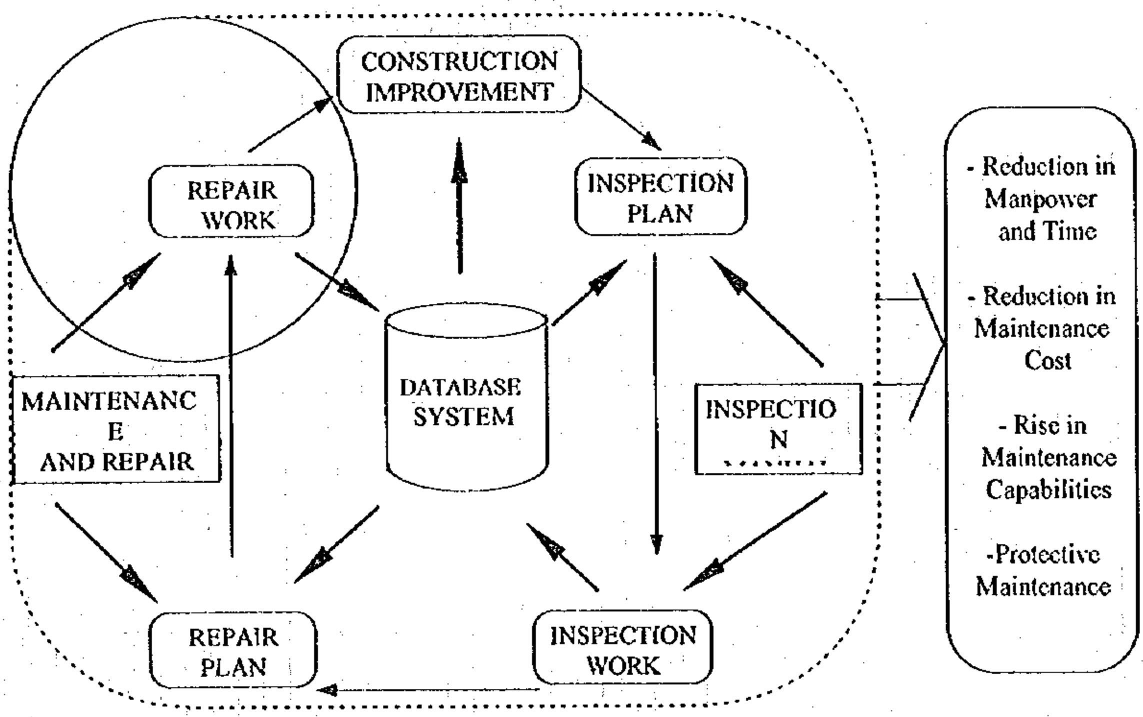
The Database System Users Manual is presented to operate the database system by KGM engineers. The inventory database applies to all bridges on the state highway network. Separate inspection and repair databases have been created which interconnect with the inventory database.

2) Systematisation of Maintenance Work

The systematised maintenance work flow is explained in general by Figure - 2.2.2.



THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED in association with JAPAN OVERSEAS CONSULTANTS COMPANY LINTED	Figure - 2.2.1 System Framework



THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED in association with JAPAN OVERSEAS CONSULTANTS COMPANY LIMTED	Figure - 2.2.2 Sytematised Maintenance Work Flow

Inspection and repair plans are supplied with output information from the database. The output information provides a list of bridges and facilities to be inspected or repaired in terms of the existing damage to highway bridges and facilities. This will enable engineers to decide on inspection and repair plans more easily using information stored in the database.

Inspection and repair manuals also support inspection and repair work and cover methodology, work methods, equipment for work, reporting, and inputting information for the database.

The inspection and maintenance system will provide a broad base of support for the maintenance and management of the bridge stock, and it will improve work procedures and methods resulting in greater efficiency and less incidental damage to these bridges.

2.2.2 Manuals for Inspection and Maintenance Work

The manuals cover all items essential to inspection and maintenance work from fundamental concepts to execution methods. In addition the manuals are user-friendly, to assist KGM staff in their daily maintenance work. All of the manuals have been prepared to improve the inspection and maintenance work by the application of the developed system, so that it is possible to:

- Provide information on the condition of all of the bridges covered by the database
- Ensure regular inspections are being undertaken
- Allocate priorities to the required maintenance operations
- ensure appropriate remedial measures are taken
- Permit the control of maintenance expenditure, and avoid unexpected maintenance costs

2.2.3 Database System

1) Database Framework

The database for inventory, inspection and repair comprises separate database files for the different areas of information. This results in effective computer usage, and avoids the duplication of information. Figure - 2.2.3 shows the relationship between the inventory database and the inspection and repair database.

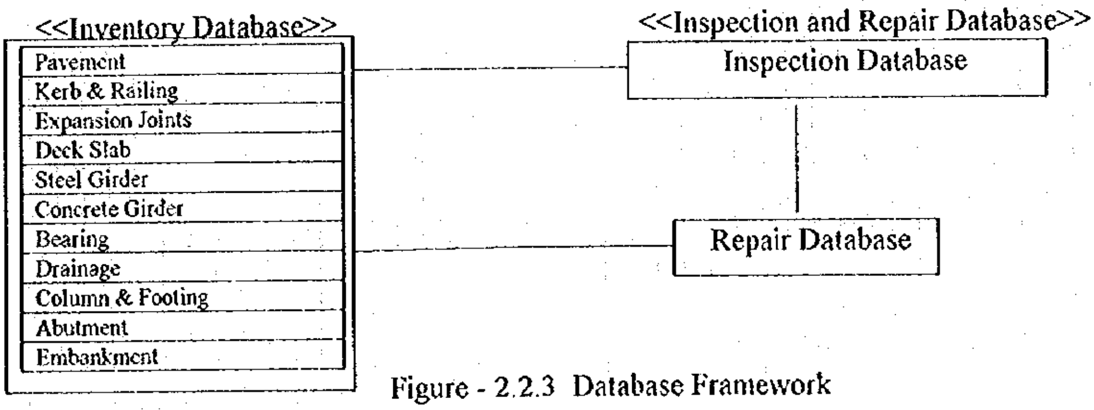
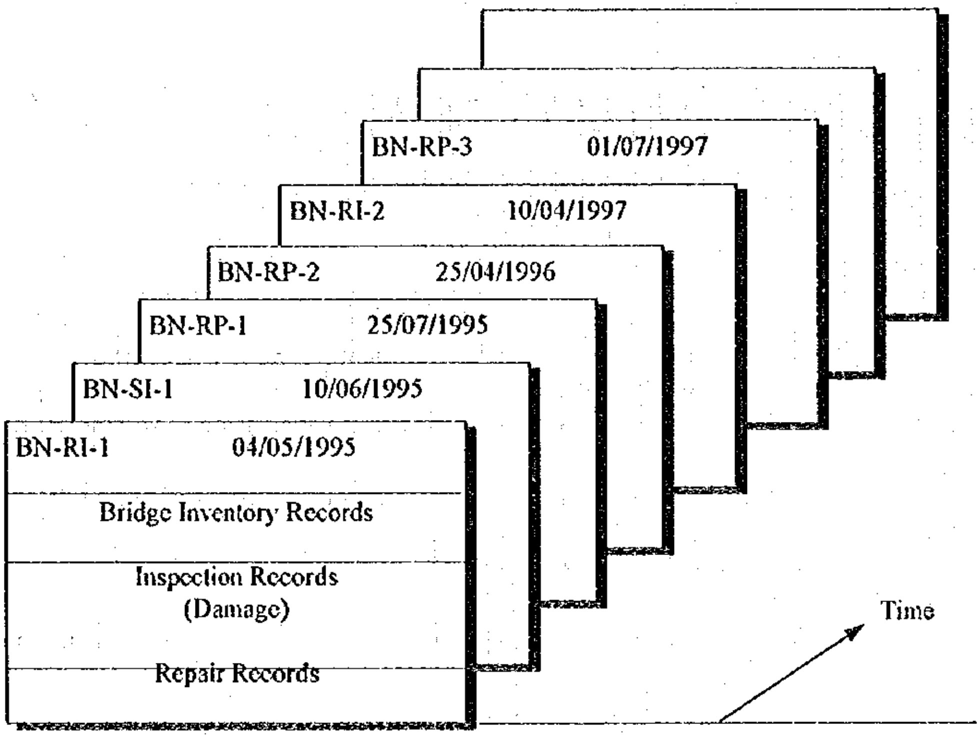


Figure - 2.2.3 Database Framework



THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED in association with JAPAN OVERSEAS CONSULTANTS COMPANY LINTED	Figure – 2.2.4 Database Records Storage

2) Database Record Storage

The record storage system for the database is shown in Figure - 2.2.3.2 and is composed of inventory, inspection and repair information together with their operating applications.

ecords are stored in chronological order and according to type of record for a designated bridge (denoted by BN in Figure - 2.2.4). The three main categories of work identified for maintenance works records are as follows:

RI - Routine Inspection
SI - Special Inspection
RP - Repair

A fuller explanation of the database record retrieval process and system functions can be found in the Evaluation Manual and Database System Users Manual. An empty and a completed database record sheet are shown in Appendix 1.

2.3 Inspection and Maintenance Procedures

2.3.1 General Work Flow

The purpose of maintenance work on highway structures and facilities is to ensure they are in good condition, to avoid interruption of the flow of traffic and to extend the life of the infrastructure. Figure - 2.3.1 illustrates the process of the maintenance system, comprising inspection and repair work, in the form of a flow chart . The condition of highway structures and facilities is first established by inspection, and then repairs are undertaken as necessary to correct any defects that are found.

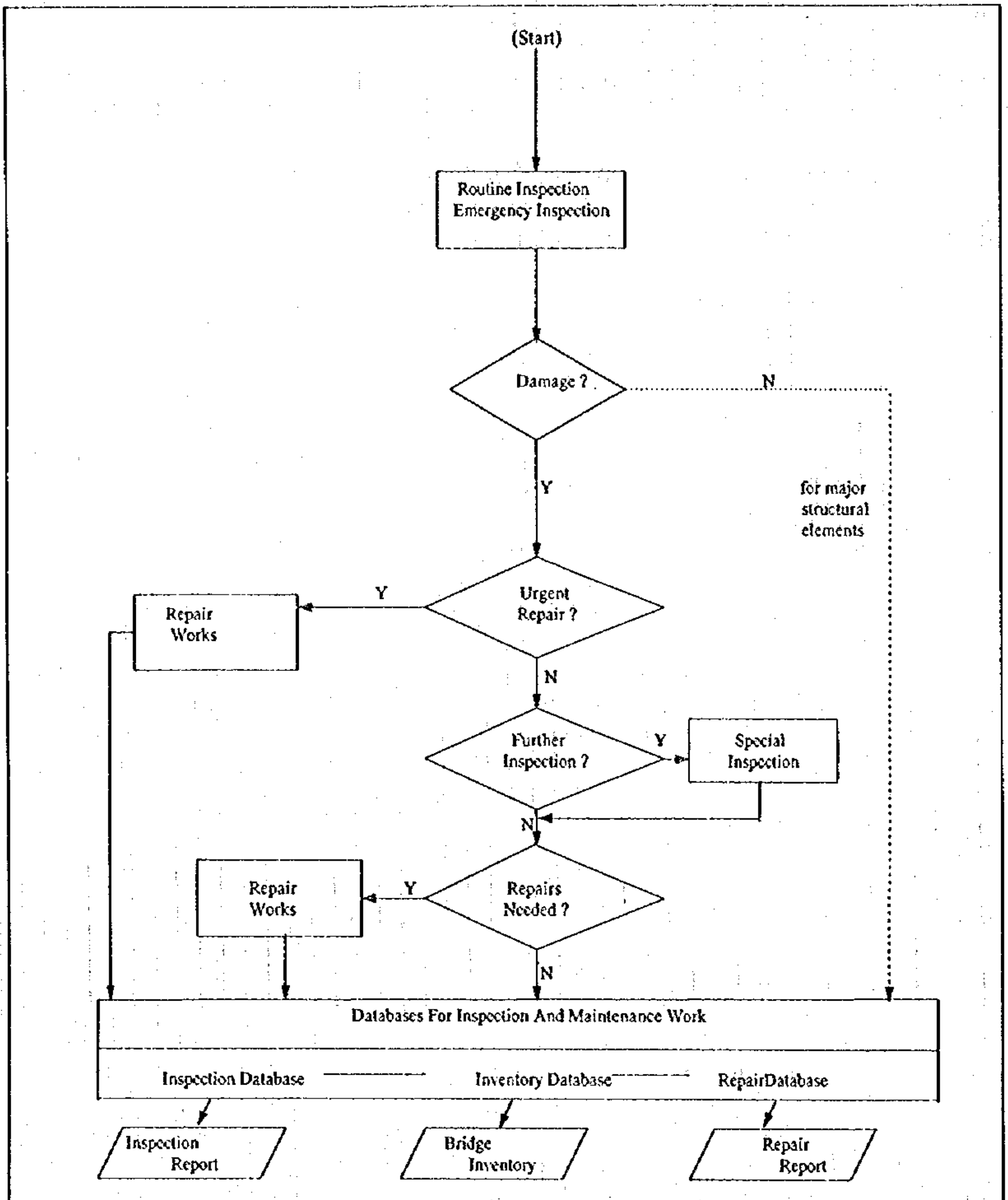
The routine daily inspections of a highway will discover and record some of the defects in highway structures and facilities, and this information will supplement the bridges database. However it is the organized routine inspection programme for structures that will provide detailed information for the database.

The inspection of the major elements of a structure, such as the superstructure, pavement, expansion joints and supports, is recorded in the database whether or not defects are found. In this way the process of inspection is recorded.

However the results of inspection of secondary elements are only entered into the database if their damage rating is worse than level "C".

Where the damage rating for an element is level "A", urgent repair may be required. If so, the repair shall be undertaken before the observations are entered into the database.

Following the discovery of defects in a major structural element of level "B" or worse, a special inspection would normally be undertaken to establish the cause and possible consequences.



THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED in association with JAPAN OVERSEAS CONSULTANTS COMPANY LIMTED	Figure - 2.3.1 Routine Inspection Procedures

The decision to carry out repairs following the discovery of serious defects should take account of the following considerations:

- influences on the flow of vehicular traffic
- the safety of third parties
- any effects on the load carrying capacity of the structure
- durability of the structure
- the annual repair plan and budgets

The inspection, maintenance and repair , and system user manuals provide guidance on the information to be entered into the database, and the method of data entry. System users can retrieve the stored information as it is needed in relation to specific maintenance work. The output can be obtained on a daily, monthly or annual basis.

2.3.2 System Components

The inspection and maintenance system provides support for its users in the following ways.

1) Judgment of the need for repairs

The scope of structures and facilities is defined by the system, together with a standardized system of categorizing defects. Four ranks (A,B,C and D) are used to define the severity of defects. Level "A" is the most serious. The decision to repair a structure is based upon these ranks in addition to the annual repair plan and budget.

2) Selection of methods of repair

This manual provides guidance on appropriate repair methods for the various problems encountered. In some cases further inspection or investigation, following discovery of a defect, will be necessary to ensure an appropriate repair method is chosen. For example, the reasons for cracking in concrete members are often not immediately apparent, and further investigation may be appropriate. However expected defects, such as pavement wear, can be repaired without the need for further investigation work.

3) Repair Records

Coding sheets are provided for recording repair works. A single sheet is applicable to all bridges.

4) Operation of database

The system permits the users to "append" , "alter" or "delete" repair data. Output is in the form of a "repair report", "member list to be repaired" or "cost evaluation list" to assist engineers in planning repairs.

The system user manual describes the operation of the database in detail.

5) Reporting of repair results

Repair report forms can be output from the database system . As these provide formal records of repair and maintenance work in KGM, it is important to check the output to ensure that all data was correctly entered.

Chapter 3

General Approach to Maintenance and Repair Work

Chapter 3 General Approach to Maintenance and Repair Work

3.1 *General*

3.1.1 Application of the Maintenance and Repair Manual

This Maintenance and Repair Manual for the State Highway Network provides a comprehensive reference document on maintenance and repair works. It covers the aims of maintenance work, the procedures to be followed, planning, specific maintenance operations and reporting. The manual has been written to apply to the types of bridges, likely defects and appropriate remedial measures which apply to the state highway network. However the guidance provided will equally apply to similar structures elsewhere.

3.1.2 Objectives of Maintenance and Repair

The existing State Highway Network has an important strategic role as the primary highway route network for vehicular traffic connecting major cities in Turkey.

With a high annual increase in vehicle registration and vehicle usage, this role will increase in the future together with economic growth and activity in the country.

Within the context of the State Highway Network the bridge stock plays a key role. It is essential that the bridge stock is adequately maintained so that premature deterioration is not encountered.

Maintenance and repairs to the bridges shall be undertaken to ensure their servicability and to limit road accidents:

- to provide the best possible and safest service for bridge users.
  To avoid a reduction in the service provided and to limit the number of road accidents and consequential disruption, it is important to maintain the carriageways and associated facilities in good condition, and to avoid any reduction in the load carrying capacities of the structures.

- to protect third parties from harm.
  Where the state highways pass through urban areas road accidents are likely to result in injury to third parties.It is therefore important to repair defects which could cause road accidents.

- to ensure durability of the structures.
  Failure to repair a damaged structure will often result in an increased rate of deterioration. Adequate maintenance will therefore prolong the life of structures.

- to prevent environmental deterioration.
  Deterioration of the highways would cause damage to the local environment, in terms of noise, exhaust gases and vibration due to traffic. In addition a lack of bridge maintenance can result in aesthetic deterioration of an area.

Good maintenance minimises the costs of sustaining a highway network, in addition to meeting the objectives described above.

Maintenance and repair works may be sub-divided into the following three categories according to their objectives:

- Rehabilitation
  To restore the function of a damaged or deteriorated structure or facility to its initial condition, in order to achieve the original load carrying capacity, durability and aesthetics etc.

- Reinforcing
  To strengthen the function or capacity of a damaged or deteriorated structure or facility, in order to correct an originally inferior function or capacity.

- Improvement
  To provide a damaged or deteriorated structure or facility with better functions or a higher capacity then it originally possessed, in order to cope with increased needs.

3.1.3 Maintenance and Repair Work Framework

Maintenance and repair work is categorized into routine maintenance operations and specialized maintenance operations as shown in Figure - 3.1.1.

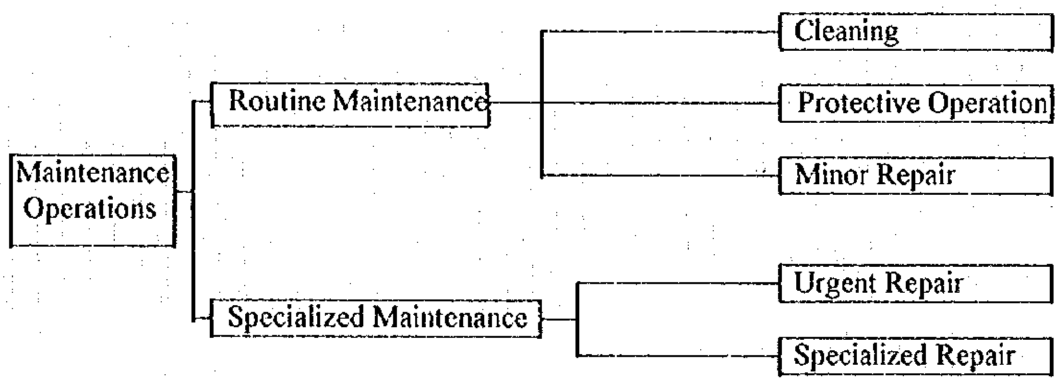


Figure - 3.1.1 Maintenance and Repair Framework

Routine maintenance work is composed of cleaning and minor repairs, as follows:

- Cleaning
  To maintain structures and associated facilities in good condition, it is necesary to clean and to remove debris and vegetation from abutment and pier bearing shelves, around bridge bearings, expansion joints, drainage inlets, etc.

- Protective Operations
  To ensure the continued function, durability and aesthetics of bridges and associated

facilities, protective operations must be undertaken at appropriate times.These would include periodic repair of protective systems to steelwork structures.

- Minor Repairs
  These include small-scale repair work arising from washouts and embankment erosion, the replacement of missing or loose nuts and bolts, etc.

- Urgent Repair
  Immediate remedial work is needed to restore a damaged component to a condition for which only routine maintenance is necessary. Work should be scheduled for completion at an early date to prevent further damage to the component or the need for complete reconstruction at a later date.

- Special Repair
  As a result of unexpected damage or deterioration, special remedial work is necessary.It requires special skills, equipment or materials to restore the function of a damaged component.

In addition to the above, emergency measures will sometimes require immediate attention to ensure the safety of vehicles and third parties. These may include the removal of damage members, or the provision of traffic management and lighting equipment.

3.1.4 Specific Bridges

The inspection and maintenance system defines the specific bridges it covers, along with their components and the records of their condition. This information is stored in a standardised manner. The bridges and their components are classified according to function, material, defect and maintenance characteristics. Particular maintenance records must be similarly classified to ensure correlation with the inventory.

The system covers all elements of the specific bridges, including superstructures, substructures, pavement, traffic safety facilities and embankment protection, divided into twelve categories:

- Pavement	: pavement of bridge,
- Kerb&Railing	: concrete kerbs and steel railings,
- Expansion joints	: buried and rubber joints,
- Deck slab	: concrete deck slab,
- Steel girder	: steel girders or truss members,
- Concrete girder	: reinforced or prestressed concrete girders including cross irders,
- Bearing	: rubber pads or steel bearings,
- Drain	: composed of inlets and water outlet pipes,
- Column&Footing	: columns,column crossheads and footings,
- Abutment	: walls, columns and footings,
- Embankment	: embankment and shoulders within 5 metres of the bridge ends,
- Riprap	: riprap at bridge ends.

3.2 Maintenance and Repair Works

3.2.1 Maintenance and Repair Work Procedures

There are three categories of maintenance and repair work :

- cyclic maintenance works, such as cleaning
- unexpected remedial measures which require immediate attention
- repairs which can be undertaken within a programmed schedule

The work procedure for repairs is illustrated by Figure - 3.2.1. The details of this approach are described below:

a) Extract members to be repaired

Members for which defects have been found, but not repaired, are recorded within the database. It is possible to extract a list of such members.

b) Cost Evaluation

Having selected the members to be repaired, a detailed assessment of the works required and the locations shall be carried out to ascertain the costs involved.

c) Budgets Plan

The results of the cost evaluation shall be included in a budgets plan, taking account of all maintenance and repair requirements including cleaning and urgent repairs.

d) Annual Plan

The purpose of the annual plan is to control maintenance activities whilst spreading the work load throughout the current year. In preparing this plan account should be taken of :

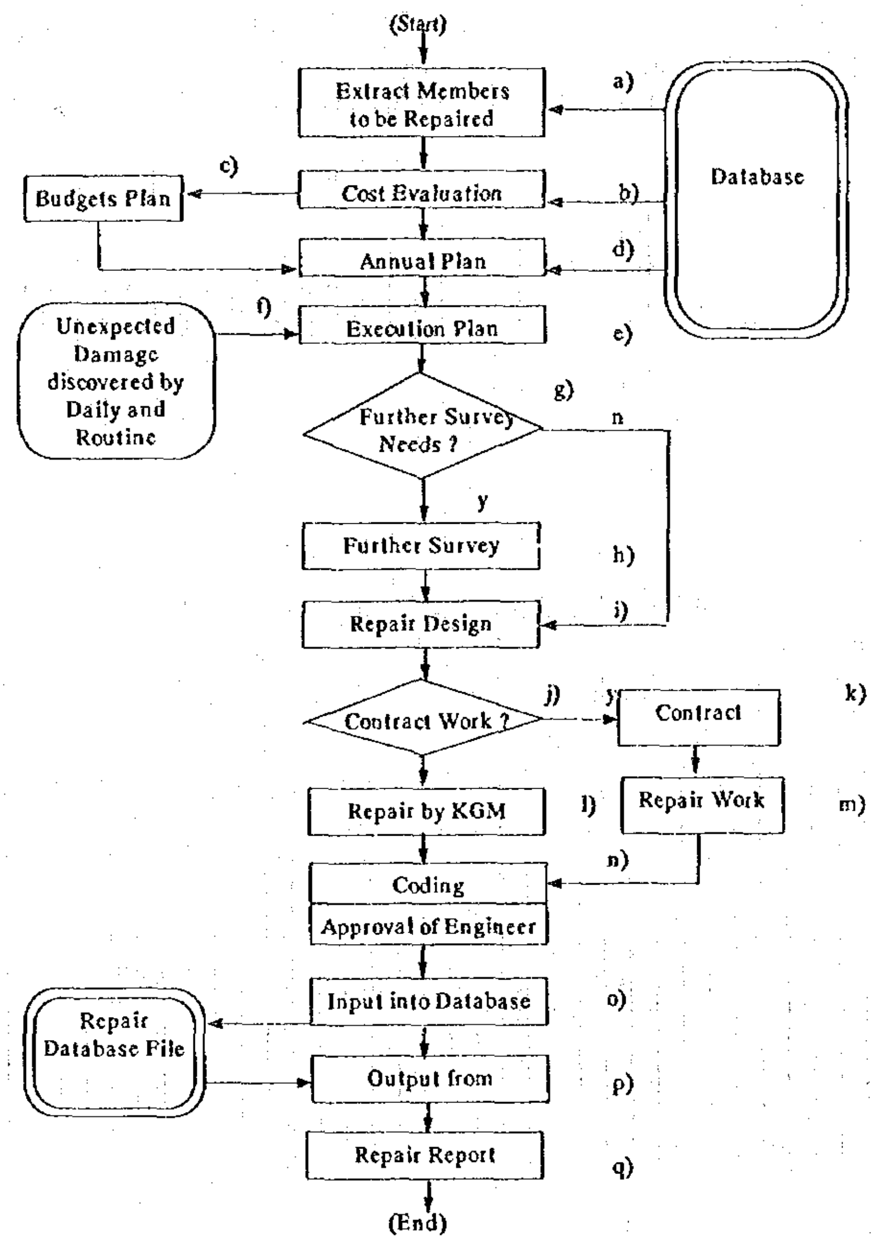
- the preferred timing of certain activities, such as the dry season for river embankment protection works

- the availability of specialist components such as expansion joint parts.

- budgetary constraints

e) Execution Plan

Short-term (monthly or weekly) plans of work shall be prepared, allocating labour, equipment and materials to the various work locations within each time period.



THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED *in association with* JAPAN OVERSEAS CONSULTANTS COMPANY LINTED	Figure - 3.2.1 *Repair Work Procedures*

f) Unexpected damage discovered by routine inspection

The need for urgent repairs will arise as damage is discovered by routine inspection. It will be necessary to respond immediately to some of these situations, even though they do not appear in the current execution plan. Such repairs must be given the highest priority to avoid further damage.

g) Further Survey Needs

The engineers must decide whether further detailed inspection work or monitoring is necessary prior to tackling a repair, and establish how additional information will be gained.

h) Further Survey

A survey plan shall be prepared, and investigation carried out accordingly.

i) Repair Design

Once all of the necessary background information is available, detailed repair design shall be undertaken. Detailed drawings and material specifications will have to be prepared.

j) Contract Work

It is necessary to decide whether repair work is to be carried out by KGM's direct labour force or by a contracting company from the private sector.

k) Contract

When repairs are to be carried out by a private sector company, it will be necessary to tender the work and to let the contract to the successful tenderer.

l) Repair Work by KGM

Repairs are carried out by KGM.

m) Repair Work By Private Contracting Company

A private contracting company conducts the repairs under the supervision of KGM, or consulting engineers on behalf of KGM.

n) Coding/Approval of Engineer

Repair results shall be coded on standard sheets by bridge engineers responsible for maintenance, the results being verified by the chief bridge maintenance engineer before input into the database.

o) Input into Database

Coded repair results for repairs shall be input into the relevant repair database file by an operator.

p) Output from Database

A repair report, which is one of the available output forms from the repair database, is to be used as the official report form for KGM's repair database. At the same time, output reports can be used for confirmation of correct input of repair data.

q) Repair Report

An original printout of the above repair reports should be kept on file in the bridge maintenance department. Photocopying of the originals should only be undertaken by authorized personnel to ensure that only current information is passed onto interested parties.

3.2.2 Maintenance and Repair Planning

1) Cleaning Planning

a) Work Items

Cleaning works must be planned, prior to the execution of works, on a monthly and yearly basis, before the commencement of the fiscal year. Essential cleaning works for bridges are as follows:

- Road surface cleaning
- Deck drainage facility and culvert cleaning
- Bridge joints
- Bridge bearings
- Concrete barriers
- Lighting
- Piers, abutments, wing walls and retaining walls
- Concrete beams; steel beams, girders, trusses; and fascia panels
- Removal of vegetation

b) Annual Planning

An annual cleaning plan, in the form of a table for the year, shall be established. It shall take account of:

- Seasonal characteristics such as rainy and dry seasons, to ensure that each area of cleaning work is carried out in the most appropriate season,
- Consistency of manpower for execution of work throughout the year,
- Appropriate arrangements for equipping the works,
- Work conditions and safety of workers,

- Traffic conditions and roadside conditions.

c) Monthly Planning

Monthly cleaning plans in the form of tables, shall be established. They shall include:

- Details of manpower requirements on a daily basis,
- Details of equipment requirements on a daily basis.

Based on the established yearly and monthly plans, the progress of cleaning achieved shall be regularly reviewed and managed. It may be necessary to modify the original plans to perform cleaning work effectively.

2) Repair Planning

a) Work Items

Repair work is more difficult to plan than cleaning operations. Some repairs may need specialist attention and others will arise unexpectedly.

For this reason repair work is divided into two categories. The first is unexpected emergency repair work, which should be undertaken immediately on discovery of the problem. The second is repair work which can be carried out as part of a routine repairs schedule.

Routine repair comprises protection and carrying out minor repairs as follows:

- Repainting of steel structures and facilities,
- Small scale repairs due to washouts and embankment erosion,
- Replacement of loose or missing anchor nuts and bolts,
- Minor repairs to pavement, drainage, kerbing, parapet railing and expansion joints, etc.

Repairs other than those described above, either fall into the category of specialized repairs or have resulted from an emergency inspection. Repairs categorized as urgent require KGM to restore the damaged components immediately to prevent further damage to the component or the likelihood of a further accident. Specialized repairs may require further inspection to determine the repair method, evaluate costs and plan a budget according to the work content and special skills or equipment required, etc.

The inspection and maintenance system can assist bridge repair engineers in formulating a repair plan as follows.

b) Annual Planning

Having extracted from the database a list of members to be repaired, an annual plan can be prepared taking account of any budgetary constraints. It should take the form of a table, and must take account of:

- Preferred times of year for particular types of repair,
- Consistency of manpower for execution of work throughout the year,
- Appropriate arrangements for equipping the works,
- Working conditions and the safety of workers,
- Traffic and roadside conditions.

c) Execution Planning

Monthly or weekly execution plans, in the form of charts, shall be prepared. They should include the following:

- Detailed manpower requirements on a daily basis.
- Detailed equipment availability and equipment requirements on a daily basis.

Chapter 4

Routine Maintenance Operations

Chapter 4 Routine Maintenance Operations

4.1 General

4.1.1 Objectives of Routine Maintenance Works

The structures and their facilities on the state highway network are constantly affected adversely by road traffic and natural conditions. Even if all of the bridges had been constructed exactly as designed, the loadings were always below those assumed in design, and no direct damage was caused by vehicles, their performance would still deteriorate. Accumulated dirt and debris would affect the road surface, the performance of the drains, and the functioning of the bearings and expansion joints.

Routine maintenance relates to servicing rather than repair. Its objectives are:

- to ensure that the bridges continue to function as intended,
- to protect against deterioration, and to thereby ensure durability,
- to provide the best possible service to users of the state highways.

Routine maintenance does not cover the repair or renewal of structural elements or components which have become unserviceable because of general wear and tear or deteriorated for other reasons. Such work should be identified during the regular inspection process, and should be included in a planned structural maintenance programme.

4.1.2 Routine Maintenance Framework

Routine maintenance work generally involves repetitive operations which are technically simple. Although many items of routine maintenance are fairly minor in themselves, failure to carry them out may lead to deterioration of structures, and the need for more serious repair operations in the future. Typical activities are :

- simple cleaning by mechanical means or by hand (of carriageways, verges, joints, drains, gutters etc.), removal of rubbish and vegetation.
- replacement of damaged or deteriorated safety barriers.
- lubrication operations.

4.1.3 Frequency of Routine Maintenance Works

The rate of accumulation of dirt and debris on the carriageways and in the drains will depend on the traffic density, proportion of heavy vehicles, topographic conditions, meteorological conditions and the immediate environment. Consequently frequencies for the various routine maintenanceoperations must be derived based upon local experience. Table - 4.1.1 gives maximum routine maintenance intervals for typical activities.

Table - 4.1.1 Routine Maintenance Intervals

Activity	Routine Maintenance Interval
Road Surface Cleaning	6 months
Clean out road gullies	6 months (*)
Clean out drainage man-holes	12 months
Cleaning bearing shelf	12 months
Cleaning signs and lighting	12 months
Clear vegetation	12 months
Clearance of flood debris from rivers	12 months

(* before and after the wet season)

4.1.4 Routine Maintenance Schedules

Routine maintenance schedules set out the operations to be undertaken, and their frequency. KGM Bridge Maintenance Engineers should identify those items of routine maintenance which are appropriate for each particular structure, and prepare a schedule of operations. Reference should be made to the Structure Maintenance Manual (if any) to ensure that any specific requirements are included, particularly for large and complex structures and components. The schedule should be appended to the Structure Maintenance Manual, and will remain valid until an element or component is replaced or modified. A typical schedule is provided in Appendix 2.

4.2 Cleaning Works

4.2.1 General

Road cleaning is essential to reduce danger to road users. The removal of dust, rubbish, and objects which have fallen from vehicles, provides an important contribution to road safety and the flow of traffic. Similarly the maintenance of drains, fences, signs and lights improve driving conditions.

There are three categories of cleaning works :

- Road surface cleaning : machine cleaning using a sweeper and/or a sprinkler, or the manual removal of larger objects
- Drainage cleaning : machine cleaning using a jet cleaner and/or manual cleaning
- Bridge facilities cleaning : machine cleaning by jet cleaner and/or sprinkler or manual cleaning

4.2.2 Road Surface Cleaning

1) Planning

Cleaning of the road surface over bridges is generally undertaken within the overall highway cleaning strategy. The appropriate method of road surface cleaning and the efficiency achieved will depend upon the nature and condition of the highway and its environment. It will therefore be necessary to plan according to local conditions to ensure appropriate cleaning distances and frequencies are chosen. Other considerations are the location of the depot, machine capacity and locations of tips.

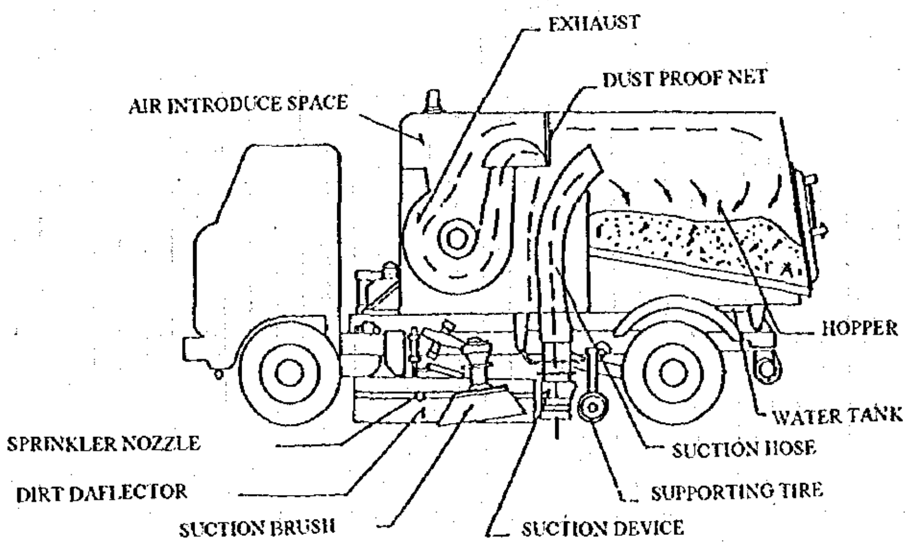
The quantity of dirt and debris on a highway will depend on the traffic volume, proportion of heavy vehicles, topographic and meteorological conditions and the nature of the local environment. In urban areas measures must be taken to prevent dust formation as a result of sweeping. High winds may necessitate more regular cleaning to limit the adverse effect of dust on driving conditions.

2) Cleaning Methods

For the purpose of removing dirt and debris from the highway, cleaning is undertaken by mechanical or manual methods, or by a combination of both.

a) Mechanical Cleaning

Road sweeper machines are used to clean along each side of the carriageway, or along each side of both carriageways where appropriate. Figure - 4.2.1 shows a typical machine.



THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED in association with JAPAN OVERSEAS CONSULTANTS COMPANY LIMTED	Figure - 4.2.1 Road Sweeper Machine

Since the operation of a road sweeper in itself raises dust, which can present a hazard to drivers, measures to reduce dust will be necessary in certain situations. This is achieved using sprinkler equipment incorporated in the road sweeper machine, or a separate road sprinkler may be used prior to cleaning if dust formation is particularly severe.

Brush type road sweeper vehicles should be of the high speed type. The entire surface of the brush must be kept in light contact with the road surface during sweeping.

b) Manual Cleaning

Manual cleaning may be used for the removal of dust, debris and objects which have fallen from vehicles. Material removed is loaded onto a truck which runs along the edge of the carriageway, for transportation to a suitable tip.

It is important that the truck is parked so as not to obstruct traffic. In some situations it will be necessary to position cones and a sign behind the vehicle.

4.2.3 Cleaning of highway drainage

Most of the drainage components will not be at bridge locations, and their cleaning will be carried out as part of the overall highway routine maintenance.

A jet cleaner is generally used to remove accumulated dust and sand from buried pipes, including pipes cast into bridge piers. Blocked pipes will result in the build up of water on the carriageway, with consequent effects on traffic flow and road safety.

The high pressure water expels dust and sand from the pipes, and into the gullies. Flushing with water after the gullies have been emptied will complete the cleaning process. Where water pressure is ineffective, obstructions can be removed by passing a screw auger through the blocked pipe and then flushing with water. Alternatively for large pipes it may be possible to remove obstructions by manual scraping.

Drainage ditches must be cleaned out, either manually or using the suction device on a road sweeper machine, to prevent overflow and flooding of the carriageway.

4.2.4 Bridge Facilities Cleaning

1) Cleaning of Bridge Joints

Some bridge joints, particularly on large bridges, incorporate drainage components. They must be cleaned to remove accumulated sand and grit, to prevent water collecting on the bridge deck. Either manual or jet cleaning is normally employed for this purpose.

Care must be taken when jet cleaning joints to ensure that water and sand do not spill onto adjacent roads or properties.

2) Cleaning of Concrete Barriers

Concrete parapets and barriers should be cleaned, either manually or using a jet cleaner.

3) Cleaning of lights and road signs

Over a period of time dust accumulates on the surfaces of lights and road signs. It must be removed to prevent the gradual deterioration of road lighting and signing. An elevated platform or hoist will be needed for this cleaning operation, so due consideration must be given to safety measures.

4) Cleaning of bridge bearings

Mechanical and sliding bearings must be cleaned to ensure that they continue to function as intended. Accumulated dirt and debris on any moving parts should be removed using a jet cleaner, or by hand. It may be necessary to use an elevated platform or hoist, so due consideration must be given to the method of working and safety measures.

4.3 Clearance of Flood Debris from Rivers

Flooding of rivers crossed by the State Highways sometimes results in the accumulation of debris around bridge supports. This can affect the flow of a river locally, in turn causing scour around the foundations. Routine inspections will identify such problems.

The clearance of flood debris is a technically simple operation, which can be undertaken in conjunction with the cleaning of bridge bearings, generally on an annual basis. However additional clearance works will be necessary following periods of flooding.

4.4 Labour and Equipment

4.4.1 General

Routine maintenance operations by their nature are small, repetitive and technically simple. They can generally be undertaken by a small gang of workmen with limited equipment. Guidance on the levels of labour and equipment is provided below.

1) Cleaning and Debris Removal

Regular cleaning of bridges, including hand sweeping, cleaning of drain pipes and bridge bearing shelves, removing debris from expansion joints and drainage openings, and removing graffiti from the structure.

Table - 4.4.1 Labour and Equipment for Cleaning and Debris Removal

Labour	: Equipment
1-Foreman	: Pick-up Truck
1-Driver	: Water Jet Truck
1-Machinery Operator	: Compressor
3-Labourers	: Drain rods
Flagmen (as required)	: and sundry hand tools

2) Cleaning and Painting of Steelwork, Signs and Guard Rails

To touch up paint work on bridges,signs and guard rails. Cleaning of roadside steelwork affected by spray and spash in wet weather or salt spray in the winter months.

Table - 4.4.2 Labour and Equipment for Cleaning and Painting of Steelwork

Labour	: Equipment
1-Foreman	: 1-Truck - extending platform preferred
1-Driver	: 2-Extending ladders
2-Labourers	:
Flagmen (as necessary) :	

3) Repair, Cleaning and Lubrication of Bridge Bearings

The repair, cleaning and lubrication of bearings is necessary periodic servicing for all types of fixed and expansion type bearings. The extent and frequency of servicing is determined by the bridge inspection programme. This task does not include jacking or propping of bridge decks as this is deemed a specialist operation.

Table - 4.4.3 Labour and Equipment for Repair, Cleaning and Lubrication of Bridge Bearings.

Labour	: Equipment
1-Foreman	: 1-Truck
1-Welder	: 1-Arc welding unit
2-Labourers	: 1-Compressor
Flagmen (as required)	: 1-Acetylene cutting & welding unit
	: 1-Sand blaster
	Power hand tools, various types
	1-Generator
	Various small hand tools

Chapter 5

Repair Operations

Chapter 5 Repair Operations

5.1 General

5.1.1 Principles of Repair

Repair operations are those maintenance activities which address specific defects identified by the inspection process. They can be categorised into rehabilitation, reinforcing and improvement.

The urgency of a repair will depend upon the consequences of not carrying it out. Some repairs will require urgent attention to ensure the safety of road users or other members of the general public. Others will have an urgency governed by the rate of deterioration of the unrepaired structure or element, or by the need to restore a structure's load carrying capacity.

It is not possible to define repair operations applicable to all structures. The defects encountered and appropriate methods of repair will vary according to structure types, and the elements concerned. However before tackling any repair it is important to establish the cause of the problem. Failure to do so is likely to result in an ineffective repair.

5.1.2 Consideration of Repair Methods

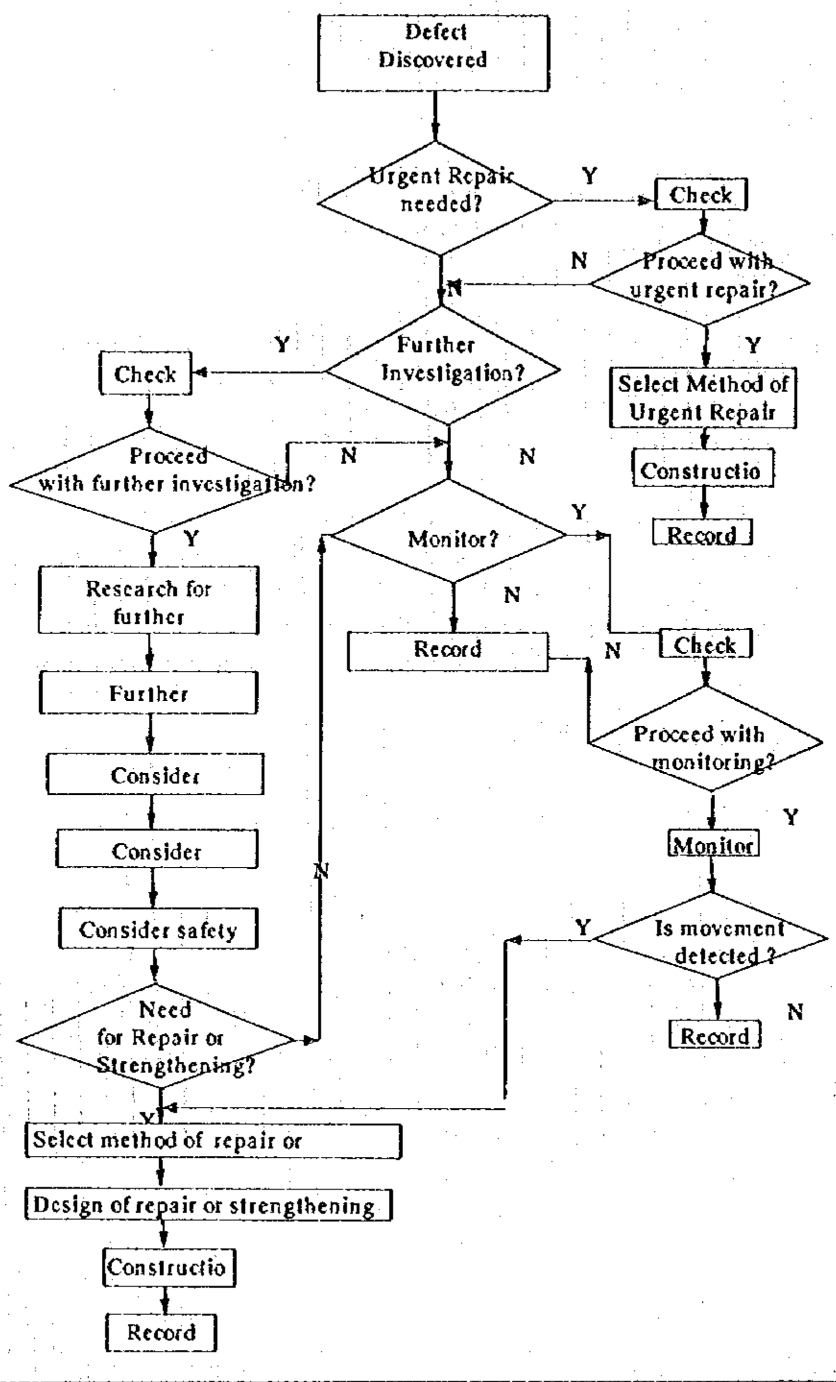
The process of choosing a suitable method of repair is shown by Figure - 5.1.1. The following items refer to specific parts of the process.

- Further investigation is likely to entail a more detailed inspection of the defective area, perhaps using special access equipment or specialist inspection equipment. Analysis of data acquired from this investigation should assist the decision making process.
- Monitoring will help to establish whether the defect is getting worse, and if so the rate of deterioration.
- The process ensures that all key decisions are checked, to avoid the waste of resources.
- When the serviceability of a structure falls below a certain level, repair becomes essential to safeguard its users and/or the general public.
- Sometimes a repair will be necessary to maintain the durability of a structure.
- Repair may be necessary for safety reasons.

5.2 Remedial Measures for Concrete Structures

5.2.1 *General*

Many concrete structures have a high level of structural redundancy. In addition the weight of a concrete structure accounts for a significant proportion of the total loading. It is therefore rare that a concrete structure fails suddenly, without first showing signs of distress. Nevertheless such bridges deteriorate with time, and the need for some maintenance during the life of a concrete bridge is almost inevitable.



THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED in association with JAPAN OVERSEAS CONSULTANTS COMPANY LINTED	Figure - 5.1.1 Process of Choosing a Repair Method

There are various causes of deterioration. Which of them applies should be determined prior to the design of a repair.

5.2.2 Classification of Bridge Types

The various types of structure encountered on the State Highway Network are shown in Figure - 5.2.1. There are several types of concrete bridge, as follows :

- Reinforced concrete simple girder, and simple slab,
- Reinforced concrete continuous girder, and continuous slab,
- Reinforced concrete gerber simple/continuous girder,
- Prestressed concrete simple girder,
- Reinforced concrete frame,
- Reinforced concrete arch,
- Reinforced concrete bowstring arch,
- Composite steel/concrete

5.2.3 Defects in Concrete Structures

1) Types of Defects

The defects encountered in concrete structures are :

a) Cracks

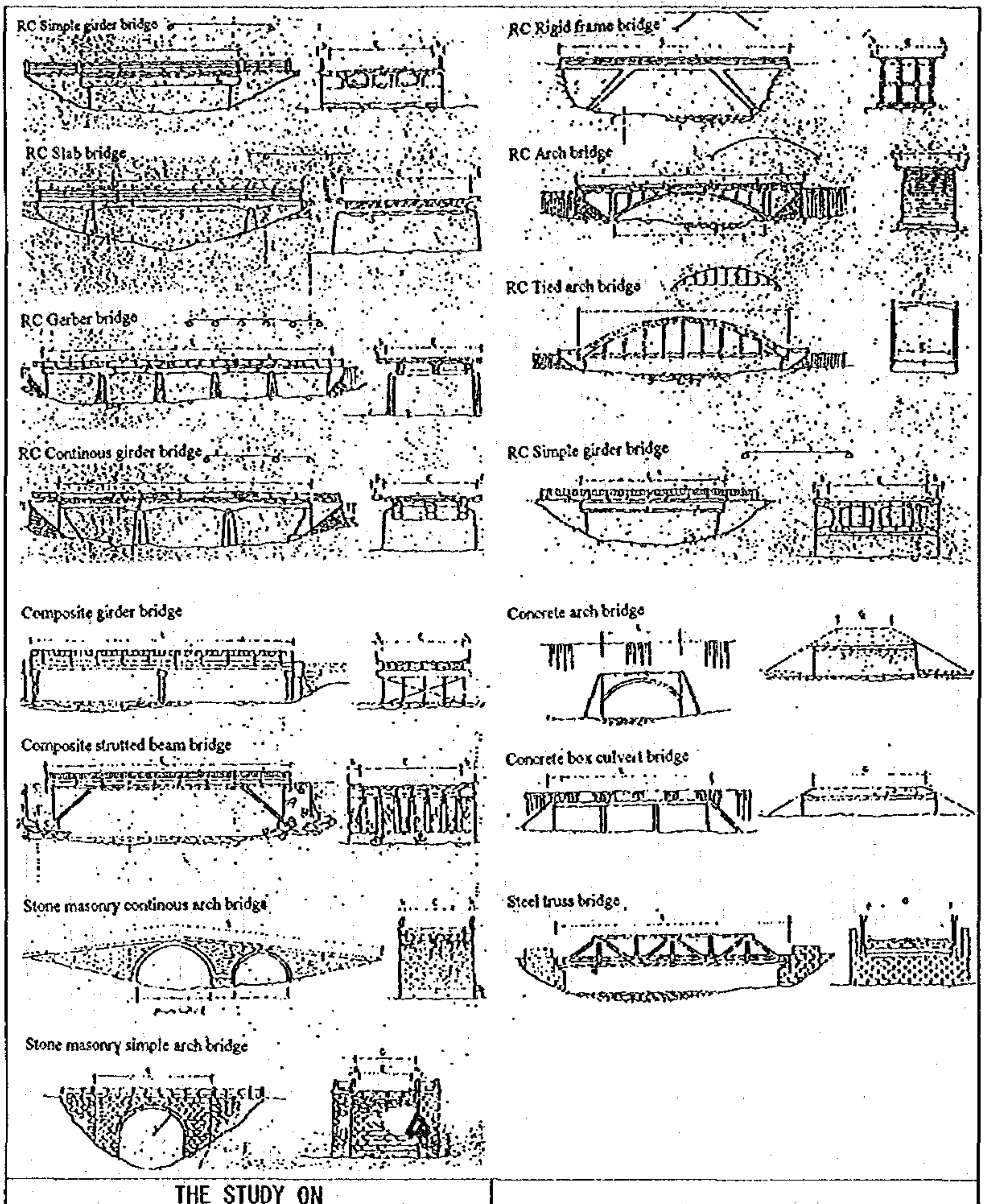
Cracks are associated with most forms of distress in concrete structures. They may be the result of plastic movement, shrinkage, overstress, restraint to bridge movement caused by siezed bearings, differential settlement of the structure, the results of scour, or chemical attack. When a crack is discovered its location, width and length should be recorded to enable its development to be monitored and its cause to be established.

b) Scaling

Surface pitting of exposed concrete surfaces resulting from freeze/ thaw cycles is known as scaling. Large areas can be affected. The entertainment of air in a concrete mix has been shown to be effective in preventing this form of deterioration.

c) Spalling

Expansion beneath the surface of concrete, for example as a result of reinforcement corrosion, produces tensile stresses which exceed the concrete strength and areas of the concrete surface break away. This effect is known as spalling. Typical causes are concrete carbonation and chloride attack.



THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED in association with JAPAN OVERSEAS CONSULTANTS COMPANY LIMTED	Figure – 5.2.1 Bridge Type Classification by KGM

d) Popouts

Popouts are cavities in concrete caused by the expansion of porous aggregates or reactions between constituents of the concrete mix. They usually appear soon after construction, but may not occur until later depending on the depth of embedment, the level of instability and the concrete permeability.

e) Honeycombing

Honeycombing occurs where the spaces between coarse aggregate particles are inadequately filled, with the result that the hardened concrete has an open structure. It is caused by the loss of cement grout where formwork is inadequately sealed, or by segregation of the wet concrete.

2) Causes of Defects

a) General

Defects in concrete structures result from many factors such as poor design detailing, construction deficiencies, structural failure due to overstress or loss of section resulting from other defects, freeze/thaw effects, chemical attack, settlement of the foundations, changes to the support or loading conditions caused by scour or silting, failure of bearings or expansion joints, and traffic collision damage. Table - 5.2.1 details the various causes.

Table - 5.2.1 Causes of Defects in Concrete Structures

design errors	incorrect concept	• inappropriate structural arrangement • inappropriate structural form
	calculation errors	• design specification error • inadequate factor of safety • stress analysis error • omission of design consideration
	drawing/detailing errors	• poor reinforcement or prestressing detail • failure to provide all of the required reinforcement/tendons • outline drawing errors • inadequate checking of drawings
construction errors	poor materials	• poor quality concrete • poor quality reinforcement or prestressing tendons • use of incorrect grade of material
	poor workmanship	• unsuitable construction method or order of construction • inexperienced or careless workmen • temporary works failures (formwork and falsework) • inadequate supervision • deterioration of material caused by inadequate storage conditions
external effects	• increased traffic levels or overloading • accidental damage (collision, falls, fire) • natural phenomena (food, subsidence, heave, earthquake) • influences of the bridge approaches • chemical action (sea water, polluted water, de-icing salts, airborne pollution) • failure of adjacent structure resulting in different ground conditions	

It is often difficult to establish the cause of a defect when the visible evidence gained from inspection is limited. Design and construction records may be of assistance if they are available. Various causes may have contributed to the formation of a particular defect. However every effort should be made to determine the cause to ensure that the correct repair strategy is adopted.

Sometimes the cause is clear, for example fire or collision damage.

b) Design Errors

Common design errors which result in defects are :

- the specification of insufficient concrete cover to reinforcement, which results in cracking and spalling.
- failure to allow for the effects of creep
- incorrect movement joint spacings and locations
- poor detailing of expansion joints
- poor drainage details which result in leakage or clogging

c) Construction Errors

Adequate supervision at the construction stage is essential to ensure that the works comply with the design. Many inherent defects can be covered up, but severe problems may arise some time later. Typical construction defects are :

- incorrect concrete mix proportions
- failure to adequately support reinforcement, resulting in movement during concreting
- inadequate cleaning out during preparation for concreting
- failure to provide the specified concrete cover to reinforcement
- insufficient compaction of concrete
- inadequate formwork support
- lack of curing of concrete elements

d) Corrosion of Reinforcement

The corrosion of reinforcement is caused by carbonation and chloride attack. Carbonation involves the loss of the protective alkaline environment provided by good quality concrete. The presence of excessive amounts of chloride ions, originating from salt in marine locations and de-icing applications, or from the use of the admixture calcium chloride, will also destroy the passive layer which prevents corrosion. When reinforcement corrodes it expands causing tensile stresses in the surrounding concrete which result in cracking and spalling.

e) Expansion Joint Failure

The failure of expansion joints may result in undesirable stresses in concrete elements and/or leakage of contaminated water onto the elements below. The accumulation of debris in a mechanical joint can cause it to sieze, so that thermal movements can only be accommodated by deformation of structural elements. Excessive stresses may result in compressive or tensile failure of concrete.

f) Settlement

Settlement of a structure, which was not anticipated and allowed for in design, can result in very severe damage to concrete structures. Wide cracks and crushing where members come into unintentional contact may indicate that settlement has occurred. When settlement is suspected a structure should be carefully monitored to assess whether movement has ceased or is continuing. Excessive settlement can cause complete collapse of a bridge.

g) Alkali-Aggregate Reaction

Some aggregates used in concrete react chemically with high alkali cements, causing disruption of the concrete. This form of deterioration is called alkali-aggregate reaction, and results in extensive cracking.

h) Overstress

Structures may be overstressed by conditions outside the control of the designer and constructor, such as overloading, changes to the flow of a river, failure of adjacent structures and various natural causes.

j) Vehicular Collisions

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

k) Fire Damage

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

m) Scour

The effects of scour can change throughout the life of a structure. Accumulations of silt and debris may reduce the channel of a river or cause it to follow a different course. Similarly the uncontrolled extraction of gravel or sand from river beds can affect the flow, causing scour at bridges further along the river. As scour can completely undermine the foundations of a bridge and thereby cause it to collapse, it is essential that its occurrence is detected at an early stage or preferably prevented.

3) Causes of Specific of Defects in Particular Elements

The locations and types of defects in particular elements can be predicted to some extent, by consideration of the element behavior and construction techniques.

a) Deck slabs

The locations of structural and shrinkage cracks will vary between solid slab decks and beam and slab decks. The orientations of cracks will depend on the skew of the bridge and the reinforcement configuration. Generally shrinkage cracks will be evenly spaced between points of restraint such as girders. Solid slab decks will tend to crack near free edges when subjected to excessive loading, and near the obtuse corner if they are heavily skewed.

Chloride attack will tend to affect the upper surfaces of deck slabs, particularly where de-icing salts are frequently used. Edges of slabs subject to water runoff may also be affected.

Carbonation may also be most severe on upper surfaces; lower surfaces will generally be sheltered. However low concrete cover is a common defect on slab soffits, so reinforcement corrosion, spalling and surface delamination will be encountered.

Honeycombing should be rare in slabs because they are relatively easy to cast, provided the formwork is well sealed. However pieces of timber, reinforcement off-cuts and tie-wire will often be found cast into the soffit.

b) Girders

Prestressed concrete beams should not contain significant cracks transverse to the direction of prestress. The presence of such cracks may indicate serious deterioration or overloading. Cracks which follow the lines of post-tensioning tendons may have been caused by plastic settlement of concrete in a confined area, or they may indicate that some wires have fractured and re-anchored.

Shrinkage cracks in reinforced concrete beams are likely to be transverse to the axis of a beam, and evenly spaced. Flexural cracks may be found in the soffit near mid-span, and diagonal shear cracks in the side faces near the supports. Vertical cracks may be encountered in the side faces of deep beams.

Honeycombing can occur in areas of heavy reinforcement in girders. Congested cross sections also make the removal of construction debris difficult, so pieces of timber, reinforcement and wire will often be found cast into beam soffits. Beam soffits with limited headroom are vulnerable to collisions from high vehicles.

Problems with bridge bearings may results in cracking and spalling in the support regions of beams.

c) Piers and Abutments

Shrinkage cracks are frequently observed in the faces of bridge abutments and slab-type piers, as a consequence of the large mass of these elements. Pier columns are more likely to crack as a result of structural effects.

Inadequate bearing details can cause localised cracking and spalling. Walls and columns can be difficult to cast, particularly if they are heavily reinforced. Consequently honeycombing can result from inadequate compaction.

Failure of expansion joints or drainage systems can result in large flows of contaminated water over bearing shelves and abutment faces, resulting in chloride attack and reinforcement corrosion. Reinforcement with inadequate concrete cover is particularly vulnerable. It is therefore common to find exposed, corroding reinforcement, cracking, spalling and surface delamination. Bridge piers can be vulnerable to collisions, and bridge supports in or adjacent to rivers can suffer from scour.

5.2.4 Repair Techniques

The techniques used to repair concrete structures require specialist skills, equipment and materials. The following methods are described in Chapter 6 :

- Crack Injection
- Small patch repairs using a proprietary polymer-modified cementitious mortar
- Concrete repairs using a proprietary polymer-modified concrete
- Sprayed concrete repairs using a proprietary polymer-modified cementitious mortar.

5.3 Minor repairs to metal structures

5.3.1 Repairs to Structural Members

1) General

Defects in structural steelwork members can seriously affect the strength and life of a structure. Loss of section or deformation of the thin components of a steelwork section can change its properties to a large extent. For this reason the decision to repair a steelwork member must always be made by an experienced structural engineer.

The strength of a member may be governed by local or global buckling considerations rather than by a yield criterion, and the geometry of a cross section and the presence of any local imperfections will affect the buckling resistance. In addition the introduction of holes or other discontinuities may have implications on the fatigue resistance of a member, and consequently its life.

However some local defects can be repaired, without the need for replacement of the affected member. Consideration must be given though to whether temporary additional support is needed while repair work is being undertaken.

2) Types of defects

Typical defects encountered are :

a) Deformation of a flange and/or web as a result of vehicle collision.

b) Corrosion caused by water penetrating the bridge deck or bridge expansion joints.

c) Corrosion caused by the build-up of water and debris in areas of poor detailing.

d) Deterioration of the steelwork protective system as a result of atmospheric conditions, salt spray from vehicles, or physical damage.

e) Damaged or missing fasteners

f) Damage resulting from structural distress such as cracking, particularly in the region of welds, local or global buckling and yielding of elements.

3) Repair of minor defects

Correction of very minor deformations by heat treatment will be possible in some cases, but it is important to understand what has caused deformation before attempting to rectify it.

Where fasteners are damaged or missing, new ones equivalent to the original or intended fasteners should be tightened unless they are high strength friction grip bolts, in which case they should be replaced. Tightening of these bolts requires extension beyond the elastic limit, so that retightening would result in a weaker connection than assumed in the design.

4) Localised remedial painting

Corrosion of steelwork will require some degree of remedial painting. Where extensive breakdown of the protective system has resulted from water penetration or normal deterioration with time, full re-painting should be undertaken. Guidance on this specialised maintenance operation is given in section 6.2.5.

Local patch repairs to a protective system should use the same types of paint as in the existing system, to ensure compatibility. Surface preparation will normally be carried out using a wire brush. Although this method will not remove rust from pits in the steel surface, the use of grit blasting would cause too much damage to the surrounding coating. The existing paint coats should be feathered back to ensure overlaps of at least 75mm for each repair coat. Drying times recommended by the paint manufacturer must be adhered to so that each coat is properly cured prior to overcoating.

5) Damage resulting from structural distress

It is unlikely that minor repairs will suffice where defects have resulted from structural distress. Such defects may indicate inadequate design or overloading of a structure, in which cases strengthening of the affected members may be required.

Weld defects can result from poor welding practice during construction. Whilst repairs may be possible, special expertise is needed to investigate, repair and test structural welds.

5.3.2 Repairs to other metal elements

Vehicle and pedestrian parapets, lighting columns and traffic signs are often damaged by vehicle collisions, in addition to corrosion. With the exception of repainting, repairs would generally be limited to either complete or partial replacement of elements affected.

Collision damage to a parapet may necessitate repairs to the parapet anchorages in addition to the fence itself. Guidance on concrete repair techniques is provided in section 6.2.3.

5.4 Repairs to Carriageway Surfacing

5.4.1 General

The condition of the carriageway surfacing is crucial to the performance of a highway. It affects the riding comfort for vehicles, but more importantly it determines the level of safety of the highway. The loss of skid resistance and the occurrence of surface deformations adjacent to bridge expansion joints and potholes present severe hazards.

Deterioration of the carriageway surfacing commences as soon as a highway is opened to traffic. Traffic loading, the effects of weather and the aging of the surfacing materials all take their toll.

Major maintenance intervals and strategy for the highway as a whole will be determined on the basis of a detailed assessment of the defects present. However localised defects will occur both on and off structures during the periods between major maintenance works, and appropriate local repairs will be necessary. This section describes those defects which are likely to be encountered in the surfacing over structures, and the repair methods which may be adopted.

The defects found in the surfacing on bridges and viaducts vary from those which occur in general pavement construction because:

- the base course is rigid,
- the base course is impermeable,
- the presence of expansion joints creates discontinuities in the wearing course.

In particular the entrapment of water within the surfacing on a structure can cause severe damage by exfoliation (stripping) of the asphalt mixture.

Deterioration of the surfacing results in loss of riding comfort, increased vibrational effects applied to the structural elements and the expansion joints, and increased water penetration through the surfacing to the upper surface of the bridge deck. Defective surfacing will deteriorate rapidly, so repairs must be undertaken quickly when the need arises.

The criteria to be adopted in the repair of carriageway surfacing are that the carriageway must be:

- even
- strong
- resistant to sliding

5.4.2 Types of Defects

The defects encountered in carriageway surfacing on bridges and viaducts, and their likely causes, are given by Table - 5.4.1. Some forms of defects are peculiar to the surfacing on structures.

a) Cracks

In addition to general cracking in the surfacing, cracks often occur between bridge expansion joints and the adjacent pavement.

b) Faulting (level differences)

Level differences can occur adjacent to bridge expansion joints, both over the structure and beyond it. They are caused by the difficulty of compacting the asphalt mixture around a joint, and of compacting the underlying backfill adjacent to a structure.

c) Flaws

Flaws on the pavement surface are caused by traffic accidents and objects falling from vehicles. As the surfacing on structures can be relatively thin, such damage can extend down into the structure. Any damage to the expansion joints, bridge deck waterproofing (where it exists) or deck must be carefully examined before the surfacing is repaired. Whenever damage affects more than half the depth of the surfacing, an area of surfacing extending 0.5m in each direction (measured from the edges of the visible damage) shall be removed to facilitate a thorough examination of the structure or waterproofing below.

Table - 5.4.1 Defects in Carriageway Surfacing on Structures, and their Causes

Classification			Likely Cause
Damage relating mainly to the pavement surface	Cracking	- Hair line crack - Wider crack	- Inferior quality of mixture - Unsuitable compaction temperature
	Deformation	- Rutting - Longitudinal roughness - Corrugation - Bump - Depression - Flush (bleeding of asphalt)	- Excessively heavy vehicle traffic (static load) - Insufficient stability of mixture - Vehicles running on a particular line - Inferior quality of mixture - Braking of vehicles on a slope - Severe traffic conditions - Insufficient stability of mixture - Unevenness of slab surface - Excessive or uneven application of tack coat - Excess of asphalt in mixture - Use of soft asphalt - Excessive or uneven application of tack coat
	Faulting	- Irregularity near bridge expansion joint	- Variation in stiffness between bridge expansion joint and pavement - Unevenness at the joints of structures - Deformation caused by the lack of stability of the mixture - Abrasion
	Disruption	- Pot hole - Exfoliation of asphalt - Weathering - Blistering	- Inferior quality of mixture - Insufficient compaction - Penetration of rainwater etc. - Connecting bolts of steel-deck slab - Very dense mixture - Swelling of air which is trapped under surface course - Evaporation of solvent from tack-coat - Evaporation of moisture from the concrete slab
	Abrasion	- Polishing	- Insufficient compaction - Poor asphalt quantity - Excessive heating of mixture - Weathering of asphalt - Use of aggregates which are soft and liable to be worn
	Others	- Flaw	- Falling objects from vehicles, and accidental damage
Damage relating mainly to the pavement structure	- Cracking	- Line crack - Alligator cracks	- A bridge which has a relatively large deflection - Concentration of local stress due to specific character of vibration of a bridge - Specific character of slab deflection - Vibration of bridge - Deflection of bridge - Inferior quality of mixture - Weathering of asphalt

5.4.3 Selection of Repair Methods

The selection of an appropriate repair method should be made on the basis of Table - 5.4.2, which provides guidance on the measures suitable for each specific type of defect. Where several types of defect are present a suitable overall repair strategy must be chosen.

Some defects found in surfacing over structures can be attributed to the nature of the structure beneath. Conversely certain defects in the surfacing will result in damage to the bridge. It is therefore important to fully examine the causes of any defects encountered. Sometimes repair of a relatively small area of surfacing will be necessary to prevent damage to a structural element.

Table - 5.4.2 Methods of Repair According to Defect Types

Classification of Defects			Repair Method
Damage relating mainly to pavement surface	Local Crack	- Hairline crack - Wider crack	- Seal coat - Filling
	Faulting	- Unevenness around expansion joint	- Patching - Reconstruction
	Deformation	- Rutting - Longitudinal roughness - Corrugation - Blump, depression - Flush(bleeding of asphalt)	- Milling, reconstruction - Milling, reconstruction - Milling, reconstruction - Milling - Carpet coat, sprinkling of fine aggregate and / or sand
	Abrasion	- Polishing - Scaling	- Carpet coat,resinous surface treatment, reconstruction - Carpet coat, patching
	Disruption	- Pot hole - Exfoliation - Weathering	- Patching, reconstruction
	Others	- Flaw - Blistering	- Patching - Patching
Damage relating mainly to the pavement structure	Full-depth cracks	- Line crack - Alligator cracks	- Filling, reconstruction - Carpet coat, reconstruction

5.4.4 Repair Methods

1) Temporary Repairs

a) Patching

This method of temporary repair can be applied to pot holes, local areas of faulting, bumps, local cracks and depressions. Where an emergency repair is needed, an area of defective surfacing may be filled without removing the defective material. However such a repair is likely to become damaged again, and therefore appropriate preparation is recommended.

The material used for patching should be similar to that of the existing surfacing. Hot and cold asphalt mixtures are available. Although cold asphalt mixture is more convenient for transport, storage, and placing, its initial stability and durability are inferior to those of the hot mixture, and it requires a curing period after compaction. Hot asphalt mixture is therefore preferable for the repair of surfacing subjected to heavy traffic loading.

Typical mix proportions for dense graded asphalt concrete (hot mix) are given in Table - 5.4.3.

Table - 5.4.3 Typical Mix Proportions of Dense Graded Asphalt Concrete

	Sieve Size mm	Dense graded asphalt concrete
Percentage of aggregate weight passing sieves (%)	13	100
	10	80-100
	5	55-75
	2.5	35-50
	0.6	18-29
	0.3	13-23
	0.15	8-16
	0.074	4-10
	Asphalt quantity (% in weight of whole mixture)	6± 0.5%
	Asphalt	Penetration 60-80

Having removed the defective area of surfacing by cutting a rectangle around it using a concrete cutter, the area must be cleaned. A burner should be used to dry out any wet areas, prior to applying the tack coat (asphalt emulsion) to the base and sides of the repair. Care must be taken to avoid local build-up of the tack coat. The asphalt concrete is placed, and compacted using a road roller or a heated tamper, such that the completed repair stands higher than the surrounding surfacing, by up to about 1cm. to allow for settlement under traffic loading Although the use of a road roller is preferable for compaction generally, it will not achieve effective compaction in a corner or along an edge, and a heated tamper will achieve adequate results for a small repair. When the depth of a pot hole exceeds 7cm, the material should be compacted in two layers. Roller or tamper marks should be erased using a smoothing iron.

When a hot mix asphalt concrete is used, a repair can be trafficked once the surface is cool enough to touch by hand.

b) Filling

Filling is a temporary repair method applied to large line cracks. The cracks are cleared of dirt and debris using compressed air, loose material is removed from adjacent to them, and wet areas are dried using a burner. They are then filled with asphalt mortar, slurry mixture, blown asphalt, joint sealer or mastic asphalt.

c) Surface Treatment

Surface treatment is used to repair cracks, deformation, abrasion and disruption, once the surface of a pavement has been made even. The most effective form of surface treatment is a carpet coat, involving the spreading and compaction of a hot mixture over the existing pavement in a thin layer (1.5 to 2.5cm). However care must be taken not to significantly increase the superimposed dead loading on a bridge by repeatedly laying coats of additional material.

The hot mixture comprises crushed aggregates, screenings, sand, filler and bituminous material. The maximum desirable aggregate size is one half of the layer thickness; generally 5 or 13mm. Straight asphalt of penetration over 80 is generally used as bituminous material. Standard mix proportions are given in Table - 5.4.4.

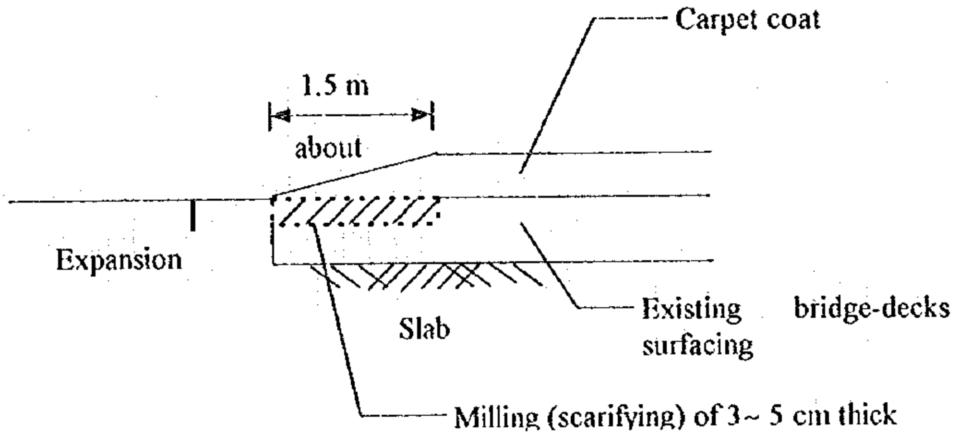
Table - 5.4.4 Standard Mix Proportions for Carpet Coat

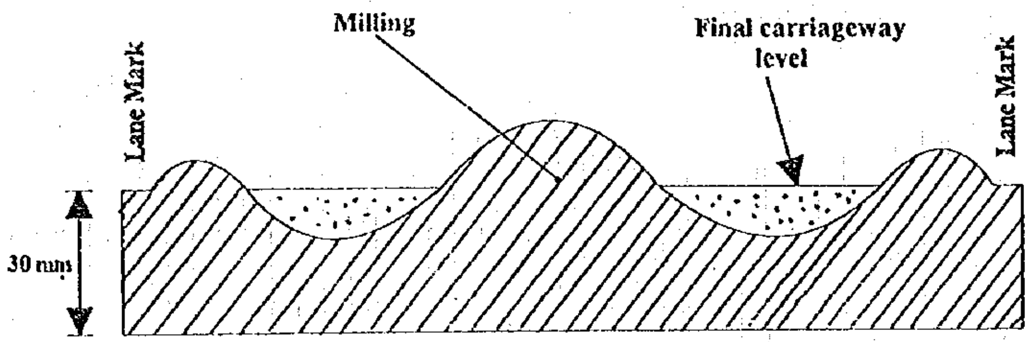
Sieve opening mm	Percentage of weight passing sieves %
13	100
5	90-100
2.5	50-80
0.3	15-35
0.074	3-12
Asphalt quantity %	6.0-9.5

A tack coat of asphalt emulsion is applied before placing the hot mixture. It is preferable to use a tack coat with strong adhesion, such as a rubber-mixed emulsion.

The mixing temperature for the hot mixture should not exceed 180°C. Compaction should commence immediately after placing, and should be undertaken at as high a temperature as possible.

Figure - 5.4.1 shows how differences in height can be avoided adjacent to an expansion joint when a carpet coat is applied.





THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED in association with JAPAN OVERSEAS CONSULTANTS COMPANY LIMITED	Figure - 5.4.1 Example of Transition after Milling at Edge of Bridge Expansion Joint Figure - 5.4.2 Reconstruction to rectify rutting

d) Milling

Where surface irregularity is particularly severe, the uneven areas can be milled (scarified) to restore the alignment of the surfacing and to improve skid-resistance. This method is often used to remove rutting, bumps or deformation caused by the fluidity of asphalt concrete on long, steep slopes and on the approaches to junctions.

Hot or cold milling may be used. Hot milling involves heating the surface of the pavement to between 60 and 180°C prior to cutting away the surface.

Care must be taken when milling over a concrete slab, as the surface of the slab will probably be irregular. Similarly when milling above a steel deck, all bolt and rivet heads must be located and marked before work commences. Removal of asphalt concrete from around the fasteners must be carried out by hand, as must the removal of material adjacent to expansion joints.

e) Grooving

The improve the frictional coefficient of a wet carriageway, grooves can be formed either transversely or longitudinally to the direction of the highway. Generally 3mm grooves at 25mm intervals are used. However the fluidity of asphalt concrete is such that the grooves last for only a short period of time.

f) Treatment of Flush

Dry crushed aggregates are sprinkled onto the pavement surface and rolled in to restore skid-resistance or to reduce fluidity of the asphalt concrete. The use of crushed aggregates pre-coated with cut-back asphalt or asphalt emulsion is effective.

Care must be taken in urban areas to avoid scatter of crushed aggregates which do not adequately penetrate the asphalt.

2) Long-term Repairs

Where longer-term repairs are required to the surfacing over a structure, milling and reconstruction will be necessary.

The minimum depth of milling should be 30mm., and the minimum depth of paving is generally 2.5 times the maximum aggregate size for the asphalt mixture. Figure - 5.4.2 shows the extent of milling and reconstruction required to rectify rutting within one traffic lane.

The timing of costly long-term repairs must be chosen carefully to avoid premature failure. Whilst paving should be undertaken during the dry season, high temperatures are likely to result in early rutting of the new pavement.

In addition the replacement wearing course must be allowed to cool fully before being opened to traffic. High internal temperatures, despite a cool surface, will result in rutting and deformation under heavy vehicle loading.

The area of reconstruction should be rectangular with one side parallel to the highway centre-line. Its width should be at least 2.5m to permit the use of normal paving machinery.

After cutting the asphalt layer(s) vertically using a concrete cutter around the perimeter of the repair, the existing material can be removed using a back-hoe. The excavation must be trimmed neatly and clean prior to the application of a tack coat. Asphalt emulsion tack coat should be spray-applied generally, but should be brushed onto the cut faces of asphalt layer. The hot mixture asphalt concrete should be laid and compacted, using a steel roller or a tyre roller, such that the final level is slightly higher (5 to 10mm) than the adjacent existing pavement to allow for settlement under traffic loading. Adjacent to an expansion joint the new pavement should be 2 to 3mm higher than the joint.

Exfoliation (stripping) of the asphalt mixture is a common problem where surfacing is laid directly onto a waterproofed steel bridge deck. The following measures can be adopted to avoid this phenomenon :

- use of an adhesion agent (0.3 to 2.0 % of straight asphalt weight)
- use of lime or cement (1.0 to 3.0 % of asphalt mixture by weight) as part of the filler
- use of asphalt with low penetration (40 to 60)
- use of an improved asphalt, containing rubber or resin.

The use of an improved asphalt is also beneficial to withstand the effects of flexure of a steel deck.

5.5 Repairs to Expansion Joints

5.5.1 General

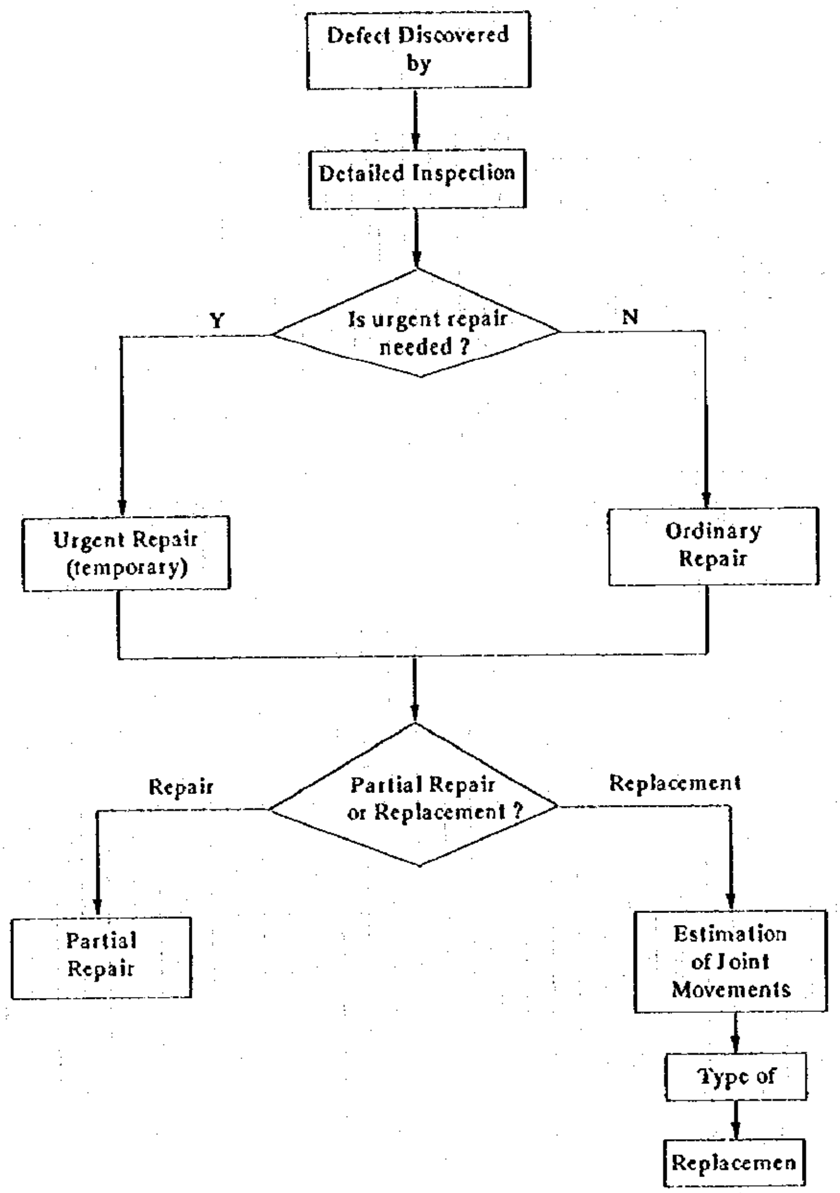
Damaged or inadequate expansion joints can adversely affect the flow of traffic and they present dangers to road users and their vehicles. Even relatively minor defects can result in discomfort for drivers and their passengers. In addition the failure of an expansion joint will allow water to leak onto the structure below, causing deterioration of the bridge deck, bearings and substructures. Noise and vibration produced by a defective joint subjected to traffic loading can be a problem in urban areas.

Expansion joints are particularly susceptible to damage, being subjected to direct loading. Once damaged they can be diffucult to repair successfully.

5.5.2 Causes of Damage to Expansion Joints

Damage to expansion joints usually results from inadequate design, poor construction or excessive loading.

5.5.3 Flow Chart for Repair of Expansion Joints



THE STUDY ON THE MAINTENANCE AND REHABILITATION of HIGHWAY BRIDGES in THE REPUBLIC of TURKEY AUGUST, 1996 ORIENTAL CONSULTANTS COMPANY LIMITED in association with JAPAN OVERSEAS CONSULTANTS COMPANY LIMTED	Figure - 5.5.1 Repair of Expansion Joints

Many of the joints encountered on the state highways are very simple, comprising a joint gap with or without a covering plate, covered by surfacing. This arrangement can accommodate only very small movements without cracking the surfacing.

More complex expansion joint arrangements rely on fixings to the bridge deck and the abutment curtain wall for structural integrity, and on rubber seals for watertightness. The fixings must be adequately designed and installed, or the joint will be disturbed by the impact from vehicles. Overloaded vehicles or excessive traffic levels can cause properly designed and installed fixings to fail prematurely. The accumulation of debris on a rubber seal can result in splitting with the passage of vehicles.

Compaction of surfacing material is difficult to achieve adjacent to expansion joints, causing weaknesses in the pavement. Deterioration of the surfacing at these locations increases the impact loading applied to the joint itself.

An expansion joint must be able to accommodate the translational and rotational movements which occur in the bridge deck at a particular location. Inadequate provision for there effects during either design or installation will result in damage.

The use of poor quality joint materials, and the deterioration of constituent materials, also result in joint defects.

5.5.4 Methods of Repair

Many of the existing expansion joints on the state highways are ineffective. Although they permit bridge deck movements, water can pass through them onto the structures below. It may be possible to carry out temporary repairs, particularly where decks are 'fixed' to the substructures, but in the longer term replacement with more suitable joint arrangements is the only realistic option.

1) Temporary Repairs

Expansion joints which comprise carriageway surfacing over the joint gap at 'fixed ends' may be repaired by cutting a groove 20mm wide and 25 to 30mm deep across the carriageway, directly above the expansion gap, and filling it with rubberised bitumen. It may be necessary to remove any bulged surfacing above the joint first, using a milling machine, or local patching of the carriageway may be required. Before undertaking such a repair the bridge articulation should be verified to confirm the locations of 'fixed ends'.

This type of repair is unlikely to be effective at 'free ends', where significant movements are anticipated.

2) Partial Repairs

Joints comprising a rubber seal located in metal rails may be repaired by replacing the seal. However more extensive damage is likely to require at least partial replacement of the joint arrangement as a whole.

Rubber slab joints and steel comb joints are generally bolted down to the bridge deck and curtain wall. The replacement of missing fixings and tightening of loose fixings are the only likely repairs. More serious defects will probably necessitate partial or complete replacement.

3) Replacement of Joints

The installation of replacement expansion joints requires special skills, equipment and materials. The installation of the following joint types is described in Chapter 6 :

- Rubber Slab Joint
- Rubber Seal in Metal Rails Joint

4) Treatment of Concrete Surfaces Beneath an Expansion Joint

When a replacement expansion joint is installed, the concrete surfaces within the expansion gap should be sprayed with bitumen emulsion prior to fixing the joint. This will provide some protection if the joint fails in the future. The failure of a joint to provide a watertight seal may go unnoticed for some time if inspections coincide with dry periods.

Chapter 6

Specialised Maintenance and Repair Operations

Chapter 6 Specialised Maintenance and Repair Operations

6.1 General

The maintenance operations described in this chapter require specialist experience of particular techniques, equipment and materials. The use of personnel who are lacking relevant experience is likely to result in a poor quality operation which may be completely ineffective. Therefore although some of the maintenance and repair operations are expensive, it is unlikely to be cost-effective to attempt them without the appropriate expertise.

All of the operations described will require close supervision by a competent engineer, to ensure compliance with the correct procedures. This manual will assist the engineer in understanding the principles of the operations, and by setting out what constitutes good practice.

Some of the operations, such as plate bonding, expansion joint replacement and maintenance painting, will require an element of engineering design. Input from an experienced structural engineer will also be necessary when concrete repairs are to be undertaken, to assess the need for propping.

6.2 Detailed Guidance on Particular Operations

6.2.1 Strengthening of Concrete Bridges Using Externally Bonded Plates

1) General

The technique of bonding steel plates to concrete bridges using epoxy adhesives can be used to increase the load carrying capacity of girders and slabs in certain situations. However it is very sensitive to standards of workmanship, and regular in-service inspection is essential following its application. The viability of this technique for a particular structure must therefore be carefully considered.

Bonding a steel plate to the tension face of a reinforced concrete section increases the depth from the compression face to the neutral axis and the area of effective reinforcement, thereby increasing the moment of resistance of the section.

This method of strengthening can also be applied to prestressed concrete members, but the designer must ensure that stress transfer due to creep in the concrete will not result in excessive compressive forces being induced into the plates.

2) Application of Plate Bonding

Plates should not be bonded to the soffits of bridges for which clearance from carriageways below is critical, or where frequent damage from vehicle collisions has occurred. When headroom is considered, allowance must be made for the location of bolts required at the ends of a plate to resist peeling stresses, and bolts along the length of a plate which would provide temporary support should debonding occur.

Investigations should be undertaken to assess the integrity and durability of an existing member prior to the application of plate bonding. Surfaces that are damp or subject to leakage, particularly if contaminated with chlorides, will not be suitable; other remedial measures may be required before plate bonding is attempted. Corrosion of reinforcement within a member is likely to result in cracking and spalling, which may cause debonding of the plates.

Plate bonding should only be considered for members where chloride values are generally less than 0.3 % by weight of cement, and half-cell potential measurements are generally less negative than - 350mV with respect to a copper/copper sulphate electrode.

3) Methods of Plate Bonding

There are three methods of bonding steel plates to a concrete soffit, as described below.

Method A : Single plates of the required thickness.

A paste consistency resin is applied to the plate which is pressed into position against the soffit by wedging off a temporary stiff girder. The adhesive thickness will vary because the stiffness of these plates will not allow them to follow the concrete profile closely. Plastic spacers should be used to ensure a minimum adhesive thickness is maintained.

This method permits bonding to proceed quickly, but is relatively uneconomical in terms of the quantity of resin.

Method B :Multiple plates bonded in layers to give the required total thickness.

This method is slower than method A, but less resin is needed. Resin is applied to each plate which is offered to the soffit as described above, but the thinner, more flexible plates will follow the profile of the concrete surface.

Method C :Single plates of the required thickness, bonded by resin injection.

The plate is held in position by anchor bolts, and its edges are sealed using a paste consistency resin. Liquid resin is then pumped into the space between the plate and the concrete soffit, ensuring that no voids remain.

Although this method is quick and minimises the quantity of resin, it can be difficult to ensure complete bonding and the greater time lapse between steel preparation and final resin injection can make it difficult to maintain the necessary standard of surface preparation.

Whichever method is adopted, the edges of the plate (s) should be sealed with a resin putty or mortar after the adhesive has cured, to prevent moisture ingress. The plates and all associated steel components must be adequately prepared and protected. An appropriate system must be chosen for the particular environment that is compatible with the adhesive.

4) Design Considerations

Testing of the existing concrete and reinforcement may be necessary to determine strengths for the design of the strengthened member.

Design of the strengthened section should follow the usual principles of reinforced concrete design. In particular a check should be undertaken to ensure that the section is not over-reinforced; a brittle concrete failure must be avoided.

For single plates, the width to thickness ratio should not be less than 50. Plates at least 4mm thick should be used to avoid distortions during surface preparation and handling. The *transverse clear distance between plates should not be greater than twice the overall depth of the* member less 100mm.

Under working loads the stress range in the plates should not exceed 150N/mm^2 for all load combinations, to avoid fatigue failure.

An anchorage length at the end of the plate will be required. Bolts should be provided within this length to resist longitudinal shear stresses. They must be adequately anchored into the concrete.

Consideration should be given to stresses arising due to imperfections in the concrete profile. If steel plates are made to follow these imperfections additional stresses will be induced in the plate, adhesive and concrete.

Plates should not extend into areas of compression, unless special provision is made to resist plate buckling.

5) Construction Requirements for Plate Bonding

The concrete surface to which a plate is to be bonded should be prepared by grit blasting to remove weak material, laitence and surface contamination. Wide cracks and porous areas should be sealed with a compatible resin. The prepared surface should be free of dust and surface dry.

The contact surfaces of the steel plates should be degreased and blast cleaned to grade Sa 2.5 of ISO 8501-1 before the application of an epoxy based primer which is compatible with the adhesive. The primer should be applied within 4 hours of blast cleaning. Where the resin is to be injected, blast cleaning may be carried out on site within 4 hours of injection.

Epoxy resin adhesives must be used in accordance with the manufacturer's instructions. It is recommended that the resin and hardener have different colours to ensure adequate mixing. *The resin should be spread immediately after mixing to dissipate the heat generated by the* chemical reaction; this will extend its workability time. By spreading the resin slightly more thickly along the centre of the plate than at the sides, the risk of void formation within the resin can be reduced.

Where resin is injected, mixing takes place during injection. Resin is introduced through a pipe which is withdrawn as filling takes place.

Appropriate testing should be undertaken to confirm the flexural modulus of elasticity and bond strength to steel of the adhesive.

6.2.2 Crack Injection

1) General

Where cracks are evident in concrete elements, it is important to establish their cause before deciding upon any method of treatment. If the cause can be removed prior to repair for example by strengthening an undersize member, the likelihood of a successful repair will be much increased. In particular, whether a crack is dormant or live will affect the method of treatment.

If the movement of a crack cannot be eliminated, it may be possible to use a plasto-elastic resin filler capable of accommodating future movements. However if large or rapid cyclic movement is anticipated, the crack should be treated as a movement joint; a recess cut along the line of the crack should be sealed with an appropriate mastic, thermoplastic or elastomer. The sealant should be bonded to the sides of the recess only, and debonded from the bottom.

The injection of cracks should be undertaken by suitably experienced personnel. Consideration should be given to consulting specialist companies in this field.

2) Materials

A number of materials can be used for crack injection, including epoxy resins, polyester resins and synthetic latexes. Epoxy resins, although relatively expensive, offer several advantages over the alternatives for the injection of dormant cracks. Formulations are available which will harden in wet conditions and adhere to moisture. Epoxy resins will achieve excellent adhesion, and their curing shrinkage is low. They have good mechanical strength, and are resistant to a wide range of chemicals.

Polyester resins cost less than epoxy resins, and can have lower viscosity which allows better penetration. However the bond strength can be reduced in wet conditions.

Synthetic latexes, such as styrene butadiene, acrylic and polyvinyl acetate, are even cheaper than polyester resins but have considerably less strength. The presence of water can preclude their use though.

3) Methods of crack injection

The injection of resin into cracks is achieved by either pumping the material or by creating a vacuum which will draw the resin into the cracks.

Injection points are fixed at intervals along the crack to be injected, generally between 200 and 500mm apart. The crack is sealed at the surface between injection points to prevent the resin from running out. Where low viscosity resin is to be used, and the crack extends to the back face of the member, it will also be necessary to seal the crack on this face. Thixotropic resins have been developed for situations, such as retaining walls and bridge abutments, where access to the rear face is not available. These resins will cease to flow when the injection pressure is released.

A wide variety of devices is used to pump resin into cracks, ranging from modified sealant guns to special-purpose twin metering guns. The latter mix the resin and hardener near to the point of delivery and thereby reduce wastage.

Resin is injected at each injection point until it flows out of the next one, when an external pressure is applied.

The vacuum method of injection has a number of advantages over pumping. More 'dead end' cracks are filled, and the possibility of the resin following the easiest route is reduced. The build-up of transverse forces within the crack is eliminated. In addition the vacuum method can be applied to areas of multiple cracking.

6.2.3 Concrete Repairs

1) Preparation for concrete repairs

The Engineer shall determine the extent of each concrete repair. It may however be necessary to extend repair areas as the work proceeds. All loose, disintegrated and unsound concrete shall be removed from the areas identified. The programme of concrete removal shall be specified by the Engineer, to ensure that structural integrity is maintained. Propping may be required in some instances.

Wherever practicable, high pressure water jetting shall be used for the removal of concrete. This operation shall be supervised by experienced personnel familiar with the techniques and constraints of high pressure water jetting. Enclosures shall be provided around the areas of work to give complete protection to other workers and the general public from debris, spray and any other effects. Careful consideration must be given to the methods of dealing with contaminated water and debris. Clean and fresh water shall be used, with the jetting unit operating at a pressure not exceeding 207 N/mm^2. A lightweight electric demolition hammer may be used for final trimming of the areas broken out.

The perimeter of each area of concrete to be removed shall be saw cut perpendicular to the face of the concrete, to a depth of at least 15mm, to ensure adequate containment of the repair. Where the concrete cover to reinforcement is less than 15mm, the Engineer shall be consulted. The use of an electronic cover meter to establish the depth of reinforcement along the proposed line of the cut, prior to saw cutting, will avoid unnecessary damage to reinforcement.

In situations where high pressure water jetting cannot be used for the removal of unsound concrete, jack-hammers or mechanical chipping hammers and hand tools may be used. To avoid fracturing of sound concrete, power tools shall not be operated at an angle greater than 45 degrees measured from the original concrete surface.

The surface of the concrete remaining must be dense with no large irregularities, no loose particles of aggregate, and no surface cracking. Similarly the concrete surface immediately outside the repair area must be sound with no loose particles of aggregate or surface cracking. The perimeter of the repair area, beyond the depth of the saw cut, shall slope at an angle of not less than 45 degrees to the plane of the concrete surface being prepared.

Each area to be repaired shall extend a minimum distance of 100mm beyond any region of corroded reinforcement. Where the Engineer considers that reinforcement corrosion is excessive or that reinforcement has been damaged during the breaking out operation , additional bars of the same strength shall be provided to restore the original cross-sectional area of steel. Unless otherwise agreed with the Engineer, appropriate lap lengths shall be provided to achieve effective continuity between original and additional bars. The area of concrete removal shall be extended accordingly.

Concrete shall be removed to a depth of 30mm behind any reinforcement which is exposed either before or during the breaking out process.

All exposed reinforcement shall be thoroughly cleaned either by dry blast cleaning followed by high pressure water jetting, or by wet blast cleaning. Particular attention should be given to pits and crevices. Dry methods of cleaning will not be effective in removing corrosion products. The appropriate standard for the preparation of reinforcement is Swedish Standard SIS 055900 SA D 2.5. The Engineer shall determine whether all exposed concrete and metal surfaces require steam cleaning to remove traces of oil, grease and other contaminants.

Some repair systems require that exposed steel reinforcement is primed before placing of the repair mortar or concrete. The chosen repair system manufacturer's recommendations shall be adhered to.

When an area has been prepared for concrete repair, it shall be protected from salt spray from passing traffic.

2) Small patch repairs using a proprietary polymer-modified cementitious mortar

Polymer-modified cementitious mortar can be used for relatively small patch repairs extending to a depth of about 50mm from the concrete surface. The use of cementitious material, rather than resin-based material, is preferable for concrete repairs because a repair will perform better if its properties are similar to those of the surrounding concrete.

Prebatched acrylic polymer modified cementitious mortar shall be used. It shall have the following material properties :

Minimum compressive strength = 30 N/mm^2 at 28 days

Minimum slant shear bond strength = 23 N/mm^2 at 28 days

Coefficient of linear thermal expansion = 7 to 13 $\times 10^{-6}$ / °C.

Maximum initial surface absorption = 0.005 ml /m^2/sec. at 2 hours.

The mortar shall have a minimum cement content of 400 kg/m^3, and a maximum water/cement ratio of 0.4.The total chloride content of the material shall not exceed 0.3 per cent of the mass of cement. Calcium Chloride or admixtures containing chloride salts shall not be used.

The sources of all constituents of the mortar shall be notified to the Engineer, for his approval. Water from the sea or tidal rivers shall not be used. Measures shall be taken to control alkali-silica reaction, as described in Appendix 3.

Handling, storage, mixing and placing of the material shall comply fully with the manufacturer's instructions. The material shall not be mixed or placed in the works at ambient temperatures lower than 5°C.

A bonding coat shall be applied to the concrete substrate when this forms part of the proprietary system chosen.

Curing of the mortar shall be achieved by covering with wet fabric and polythene sheeting, for the following minimum periods :

3 days in temperate weather,
or 7 days under hot drying conditions.

3) Concrete repairs using a proprietary polymer-modified concrete.

In situations where the size of repair is too large to permit the use of a mortar, satisfactory results can be achieved with a proprietary polymer-modified, free-flowing, non-shrink concrete. The use of a free-flowing concrete which does not require vibration to compact it avoids bleeding which can result in complete separation between old and new concrete.

A pre-batched polymer-modified, free-flowing, non-shrink concrete shall be used. It shall have the following material properties :

Minimum compressive strength = 50 N/mm^2 at 28 days

Minimum slant shear bond strength = 23 N/mm^2 at 28 days

Coefficient of linear thermal expansion = 7 to 13 x 10^{-6} /°C

Maximum initial surface absorption = 0.005 ml / m^2 / sec. at 2 hours

The concrete shall have a minimum cement content of 400 kg/m^3, and the total chloride ion content of the materials shall not exceed 0.3 per cent of the mass of cement. Any Chloride or admixtures containing chloride salts shall not be used.

The aggregate shall be well graded with the maximum size not exceeding 10mm.

The sources of all constituents of the concrete shall be notified to the Engineer, for his approval. Water from the sea or tidal rivers shall not be used. Measures shall be taken to control alkali-silica reaction, as described in Appendix 3.

Testing of Materials :

The successful application of this method of repair is dependent on the properties of the material chosen ; in particular its ability to flow freely and to fill voids. It is therefore important to ensure that the concrete behaves in a suitable way for the particular site conditions.

The method of demonstrating that the concrete will flow over a sufficient distance without segregation, and that it can be used for repairs to soffits without voids and cracks forming, shall be agreed with the Engineer.

In addition compressive strength tests shall be undertaken using samples of the concrete that have not been vibrated.

Delivery and Storage of Material :

Certificates shall be provided for each batch of the material delivered to the site, stating :

- the formulator's name and address
- the formulator's agent's name and address, where applicable
- material identification
- batch reference number, size of batch and number of containers in the delivery order
- date of manufacture

Containers shall be damp proof, and shall be marked with the following information :

- material identification
- batch reference number
- formulator's name
- net weight
- any warnings concerning the contents

The material shall be stored in a dry environment free from extremes of cold and heat. It shall not be removed from the store until immediately prior to mixing. Material older than 3 months, or less if specified by the formulator, shall not be used.

Site Mixing, Placing and Curing :

Mixing and placing shall be carried out strictly in accordance with the formulator's written instructions. The water/cement ratio shall not exceed 0.4. If the material has not been used within 20 minutes of mixing, it shall be disposed of.

The placing temperature shall be at least 5°C, and the surface temperature of the repair shall not fall below this temperature until the concrete strength reaches 5 N/mm^2. The concrete shall be protected against harmful effects of weather for 14 days after placing.

4) Sprayed concrete repairs using a proprietary polymer-modified cementitious mortar

Sprayed concrete repairs are suitable for large areas of relatively thin concrete, for example where extensive spalling of a slab soffit is to be repaired.

A pre-batched polymer-modified cementitious mortar shall be used. It shall have a minimum cement content of 400 kg/m^3, and the total chloride ion content of the materials shall not exceed 0.1 per cent of the mass of cement. Calcium Chloride or admixtures containing chloride salts shall not be used.
Maximum aggregate size shall be 3mm.

There shall be no expansion agents or set accelerators contained in or added to the repair material.

The sources of all constituents of the mortar shall be notified to the Engineer, for his approval. Water from the sea or tidal rivers shall not be used. Measures shall be taken to control alkali-silica reaction, as described in Appendix 3.

The compressive strength of the mortar shall be at least 40 N/mm^2 at 28 days, determined using cores taken from test panels. If it is considered necessary, cores can be taken from the repair itself to demonstrate the strength. The adhesive strength to the base concrete shall be at least 2 N/mm^2.

Delivery and Storage of Material :

The requirements for delivery and storage of polymer-modified concrete, described in section 6.2.3, 3) shall also apply to mortar for sprayed concrete repairs.

Application :

Only suitably experienced personnel shall be employed in the application of sprayed concrete. The material shall be applied by the dry spray process. Light timber profiles or guide wires shall be fixed on all main arises to ensure the correct line of the finished work. The surface of the substrate concrete shall be pre-wetted to achieve a saturated surface dry condition prior to the application of the spray mortar. Spraying shall not be carried out when the air temperature is less than 5°C. Freshly sprayed mortar shall be protected from rain and water until the surface is sufficiently hard to resist damage.

More than one coat of mortar may be necessary to achieve the required thickness. The surface of each coat shall be washed down before the next is applied. The overall covering must be dense and uniform, and must provide a minimum cover of 40mm to the steel reinforcement.