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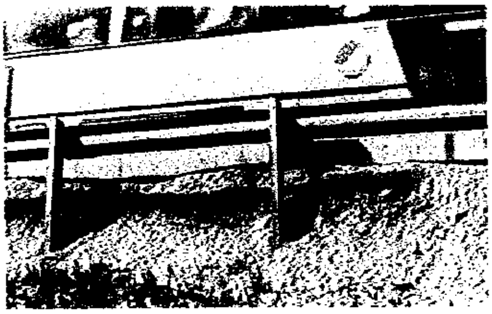
JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

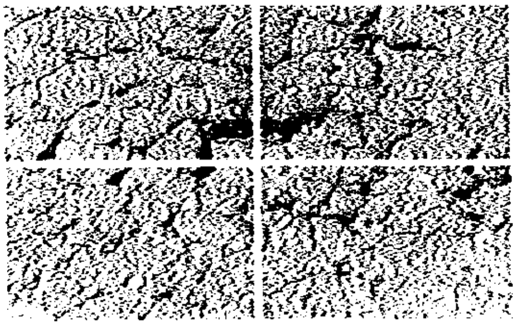
GENERAL DIRECTORATE OF HIGHWAYS
MINISTRY OF PUBLIC WORKS AND SETTLEMENT
THE REPUBLIC OF TURKEY(KGM)


THE STUDY ON ARTERIAL HIGHWAY MAINTENANCE IN THE REPUBLIC OF TURKEY

FINAL REPORT

EVALUATION AND REPAIR MANUAL



JULY 1998

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

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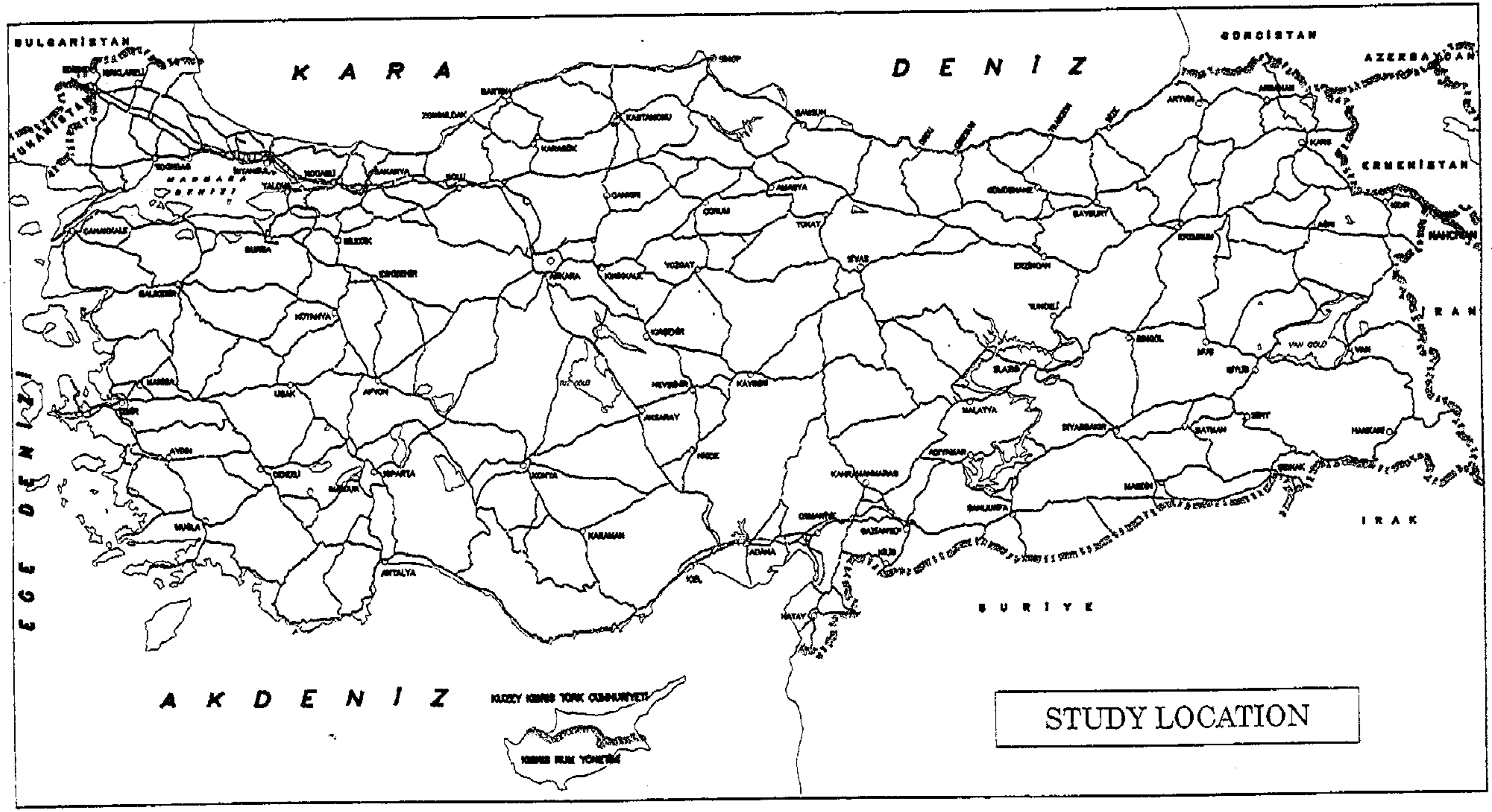
BULGARİSTAN
KARA DENİZ
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AZERBAYCAN
ERMENİSTAN
İRAN
IRAK
SURİYE
AKDENİZ
EGE DENİZİ
STUDY LOCATION

Table of Contents

CHAPTER 1 INTRODUCTION

1.1 General

This Evaluation and Repair Manual has been produced for the General Directorate of Highways to assist with the continued improvement in the management of the Maintenance works on the 60 000 km of State and Provincial Roads in Turkey. It has been based on a knowledge of the existing systems in use and is intended as a framework for developing common practices throughout Turkey. It has the flexibility to be changed and improved as the major maintenance issues are identified and also as more technology becomes available.

1.2 Objectives

The primary objective of the Evaluation and Repair Manual, is to take the information collected during the various inspections and surveys and to use the data to decide on the most appropriate repair method and when necessary, to assist in the design of the repair works.

An additional objective is to provide standard methods applicable throughout Turkey so that defects are assessed and repair works are carried out on a common basis.

This approach enables maintenance managers to prioritise repair works nationally, by Division or Sub-Division in the knowledge that the same approach has been used all over the country to decide on the necessary repair works. It also gives them confidence in the standards of repair work being carried out.

1.3 Structure of Document

Chapter 1 – provides a very brief introduction to the Evaluation and Repair Manual and its objectives.

Chapter 2 – provides an overview of the Evaluation and Repair Method covering all aspects; evaluation items, evaluation methods, cause and effects of damage, repair methods and the selection of the repair method and design and construction matters where appropriate.

This section should be read by those wanting to gain an overall appreciation of the evaluation and repair method.

Chapter 3 to 9

– explain the evaluation and repair method for each item; pavement, slope (cuttings and embankments), embankment, shoulder, drainage (side ditches, gullies and culverts), retaining walls, snow and ice facilities.

These sections will be used by those carrying out the evaluation and repair works and should be read in detail to have a thorough understanding of the requirements for each item.

CHAPTER 2 EVALUATION AND REPAIR METHODS

2.1 General

Fig. 2.1.1 shows a flow chart for the evaluation and repair process.

From the visual inspections, defects are ranked in terms of their severity (see The Management and Inspection Manual) and observations of the defects are made. From this information and from previous experience of the defect, the maintenance manager may be able to decide on the appropriate repair. For some defects, additional information is given in this manual which may assist in the decision. In this case, the repair works shall be included in the repair work programme.

Where it is not possible to decide on the appropriate repair method, a detailed inspection together with any supplementary surveys shall be carried out to collect the data needed to decide on the appropriate repair method and to assist with the design of the repair works.

Having established the type of defect and the cause of the defect, a suitable repair method can be selected and where necessary, the design of the repair works can be carried out. On completion of this exercise, the repair shall be included in the repair work programme.

When the repairs have been carried out, the details of the repair shall be entered onto the maintenance database.

2.2 Evaluation Items

This manual covers the following items:-

- pavement
- slopes
- embankments
- shoulders
- retaining walls
- side ditches
- gullies
- culverts
- snow and ice control facilities

Details of the evaluation and repair process for each of the inspection items are given in Sections 3.0 to 9.0.

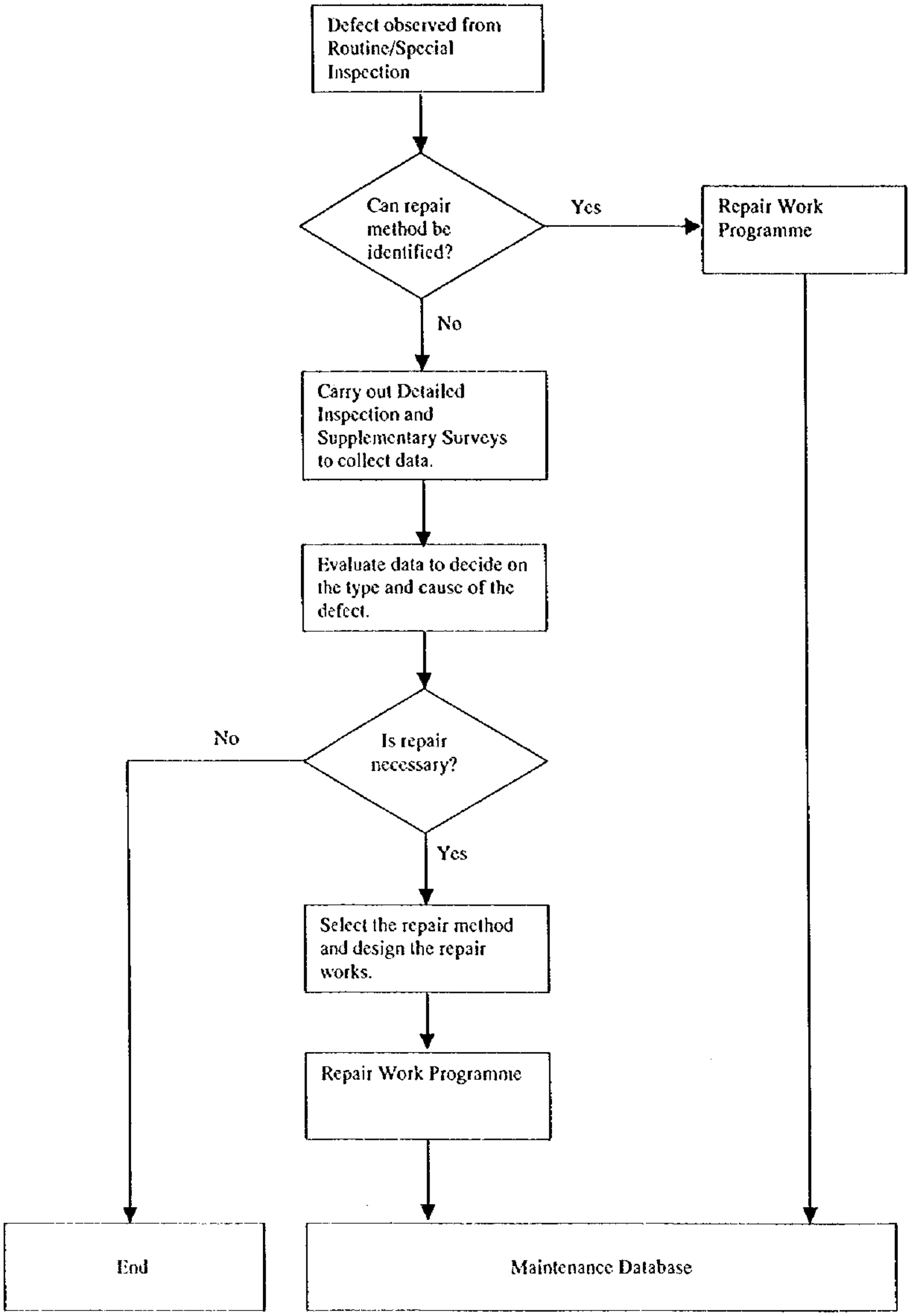


Fig. 2.1.1 Flow Chart for The Evaluation and Repair Process

2.3 Evaluation Methods

The process of evaluation and repair should be on the basis of past experience of the defects and of the repair methods available for each type of damage.

Where only basic information on ranking and severity of the defect is available from visual inspections, guidance tables are included in this manual to assist in the decision making process.

Where the defects are more serious and more data is available from the Detailed Inspections and Supplementary Surveys, standard methods and formulae are given where appropriate. The methods being recommended are well tried and tested and are used in many countries around the world.

2.4 Cause and Effect of Damage

For each maintenance item and for each damage type, the major causes and effects of the damage are listed to assist the maintenance staff in understanding the problems and to assist in the decision making process for repair works. This information will also assist in prioritising repairs as some of the defects can cause safety problems for motorists and others can create a rapid deterioration in the defect if left for any length of time.

2.5 Repair Methods

Alternative repair methods are listed for each damage type to cover the range of situations that may occur. Methods cover emergency and short term situations as well as the longer term repairs. The methods include best practice from around the world, much of which is already in use in Turkey. The methods include both basic and more advanced techniques using recent technology.

The purpose of each repair is discussed and where appropriate the application and sketches of typical repairs are also included.

2.6 Selection of Repair Method

Selection of the repair method depends on many factors related to the particular damage item. Of prime consideration is the safety of the members of the public using the road and also the integrity of the road pavement and associated earthworks and structures.

Flow charts are presented to assist in the selection of the repair method and recommendations on the suitability of the various methods are given.

2.7 Design and Construction Matters

Specific design and construction matters are also discussed to provide guidance in producing a consistent quality of work throughout Turkey.

2.8 Traffic Management

Safety must be the primary consideration at all roadworks. The arrangements for maintenance and repair works shall seek to minimise the disruption to traffic whilst ensuring adequate access for proper inspection and maintaining a safe working environment for the inspection personnel, the road user and the general public.

We have developed 9 standard layouts to deal works on 2 lane roads, 2 lane roads with a climbing lane, 3 lane roads and dual carriageways.

No works should commence until all of the traffic management is in place.

All staff involved in the works should be wearing a high visibility reflective jacket. These jackets enable staff to be clearly seen by motorists and reduce the potential accident risk for the inspection personnel.

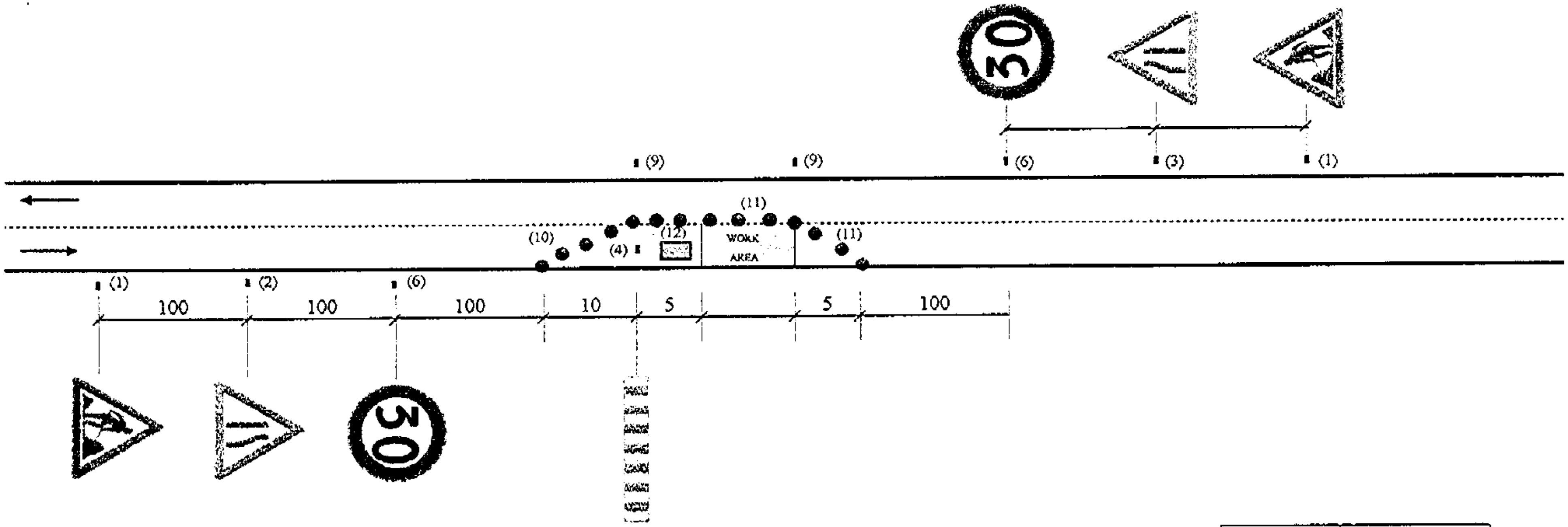
The standard traffic management drawings are shown on the following pages.

Traffic Management Drawings

Traffic Signs Schedule

Traffic Sign No	1	2	3	4	5	6	7	8	9	10	11	12
Traffic Sign Type									flagman	cones at 1.5m centres	cones at 3 m centres	KGM vehicle
Layout No	Number of Signs											
1	2	1	1	1	-	2	-	-	2	8	4+(W.A)/3	1
2	2	-	2	4	3	2	-	2	-	32	37+2(W.A)/3	1
3	2	-	2	2	2	-	2	2	-	16	18+2(W.A)/3	1
4	2	-	1	4	4	2	-	1	-	32	37+(W.A)/3	1
5	2	1	-	4	4	-	2	2	-	40	45+2(W.A)/3	1
6	2	-	2	2	2	-	2	2	-	16	15+2(W.A)/3	1
7	2	2	-	1	1	-	2	-	-	8	4+(W.A)/3	1
8	2	-	2	1	1	-	1	2	-	8	4+(W.A)/3	1
9	4	2	2	3	3	-	2	4	-	24	35+(W.A)/3	-

Detailed Inspection – Traffic Management
2-lane road - 1 lane closed

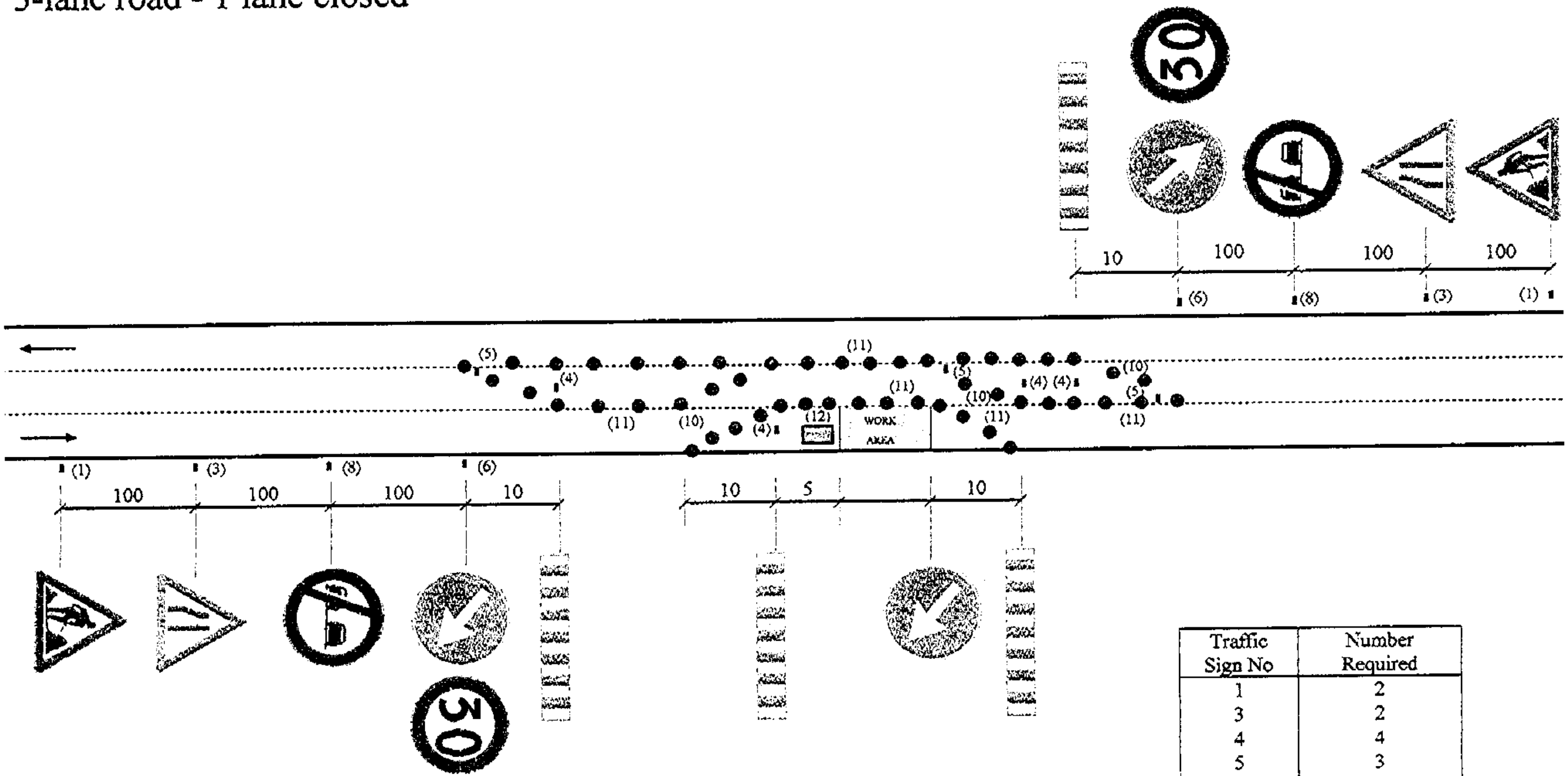


(9) flagman
(10) cones at 1.5 m centres
(11) cones at 3 m centres
(12) KGM vehicle

Traffic Sign No	Number Required
1	2
2	1
3	1
4	1
6	2
9	2
Cone	
10	8
11	4+(W.Area)/3

LAYOUT NO.1

Detailed Inspection – Traffic Management
3-lane road - 1 lane closed

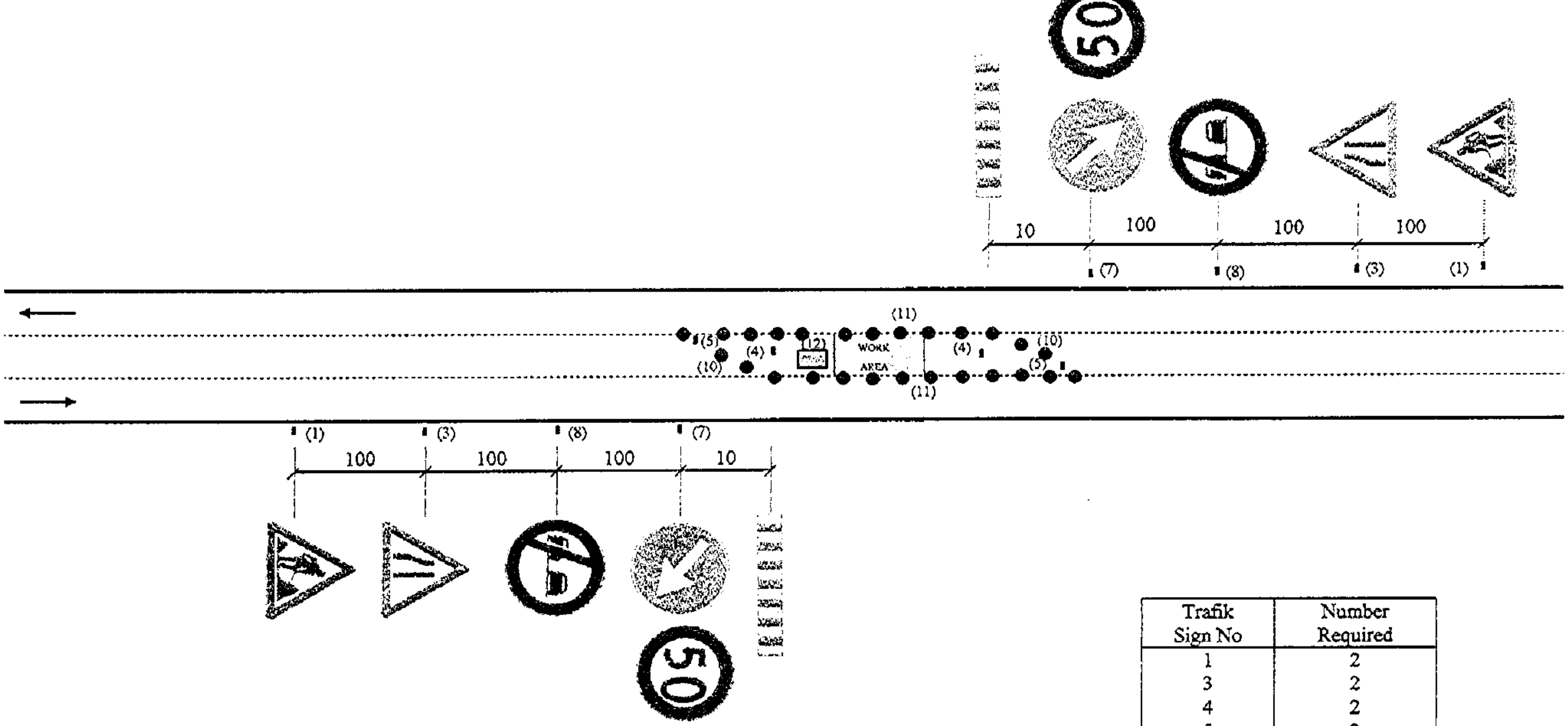


(10) cones at1.5 m centres
(11) cones at 3 m centres
(12) KGM vehicle

Traffic Sign No	Number Required
1	2
3	2
4	4
5	3
6	2
8	2
Cone	
10	32
11	37+2(W.Area)/3

LAYOUT NO.2

Detailed Inspection – Traffic Management
3-lane road – middle lane closed

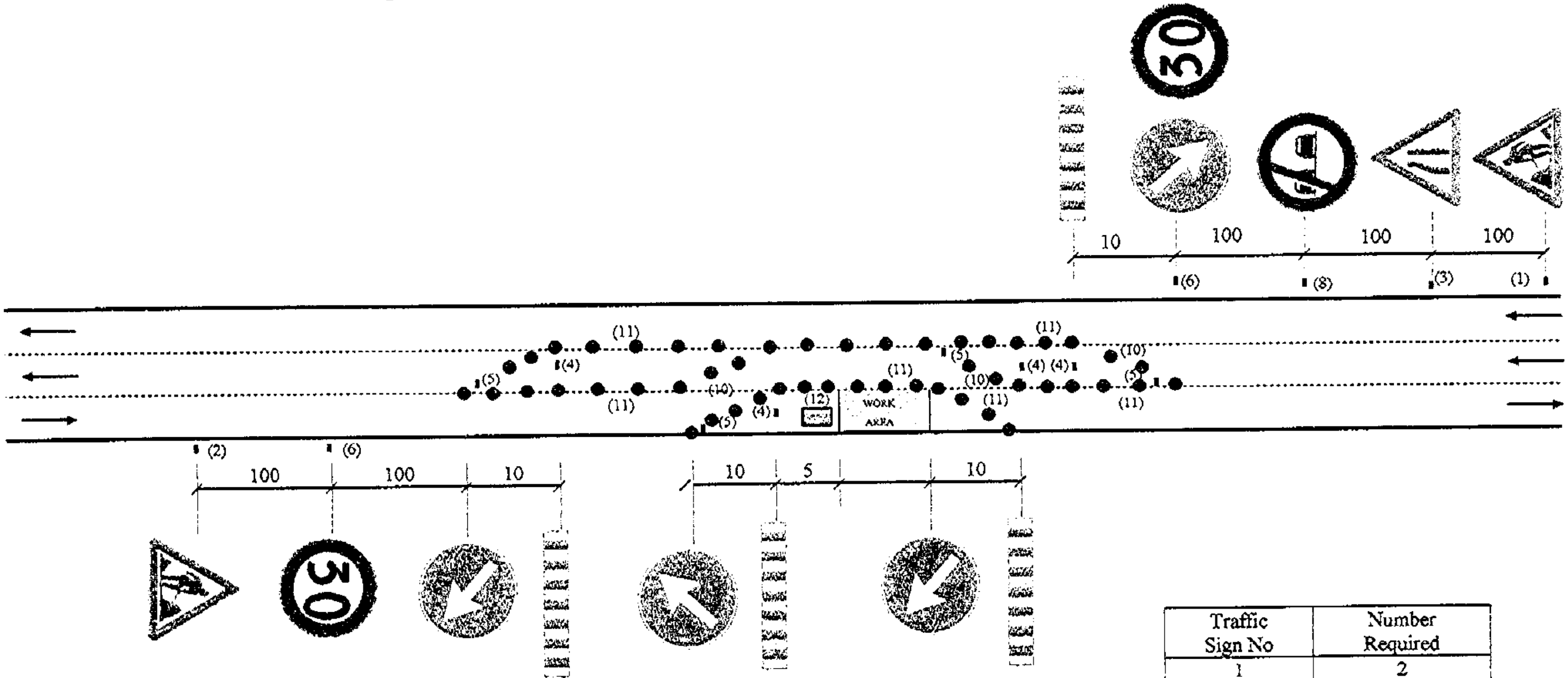


(10) cones at 1.5 m centres
(11) cones at 3 m centres
(12) KGM vehicle

Trafik Sign No	Number Required
1	2
3	2
4	2
5	2
7	2
8	2
Cone	
10	16
11	18+2(W.Area)/3

LAYOUT NO.3

Detailed Inspection – Traffic Management
2-lane road with climbing lane – 1 lane closed

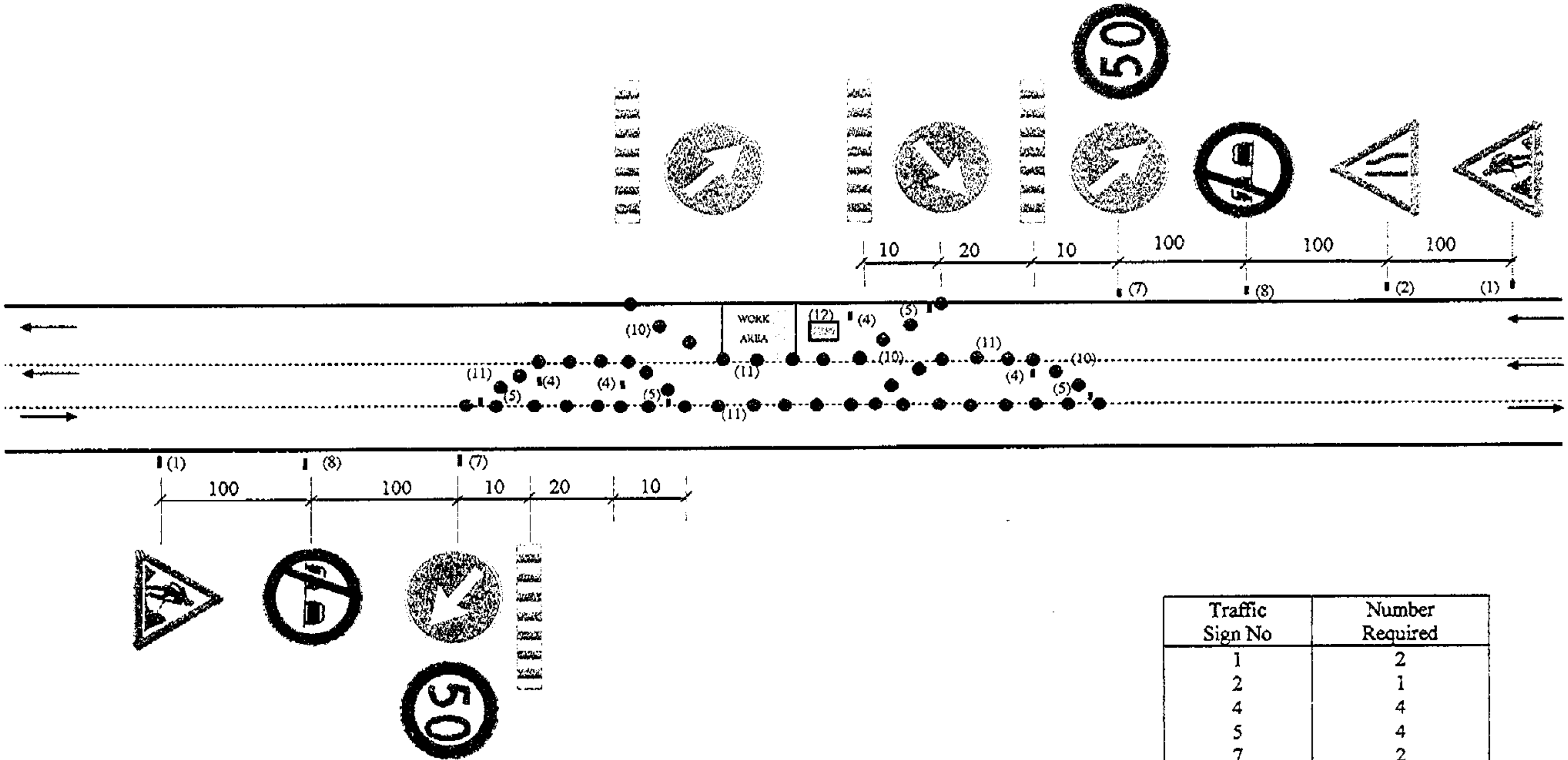


(10) cones at 1.5 m centres
(11) cones at 3 m centres
(12) KGM vehicle

Traffic Sign No	Number Required
1	2
3	1
4	4
5	4
6	2
8	1
Cone	
10	32
11	37+(W.Area)/3

LAYOUT NO.4

Detailed Inspection – Traffic Management
2-lane road with climbing lane – climbing lane closed

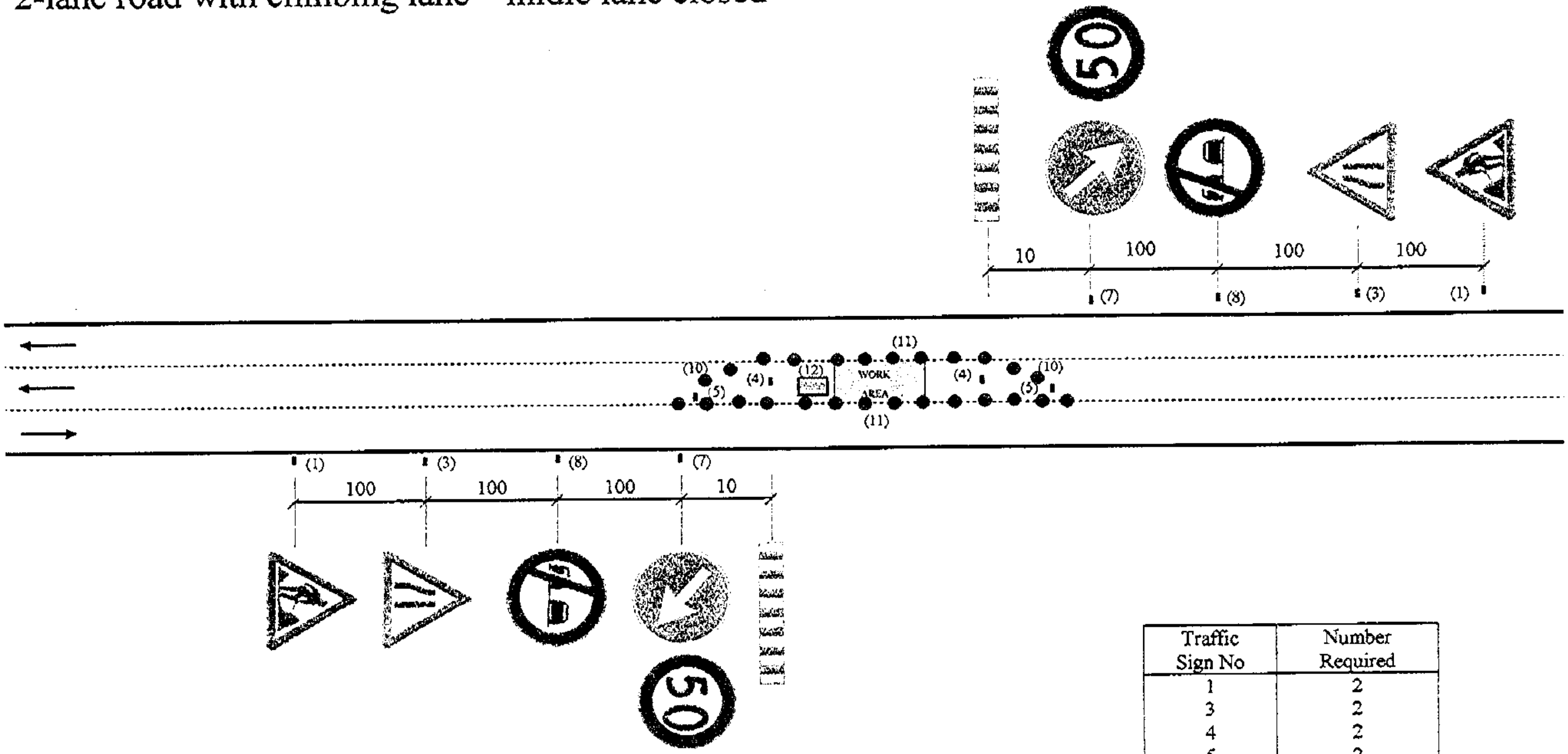


Traffic Sign No	Number Required
1	2
2	1
4	4
5	4
7	2
8	2
Cone	
10	40
11	45+2(W.Area)/3

(10) cones at 1.5 m centres
(11) cones at 3 m centres
(12) KGM vehicle

LAYOUT NO.5

Detailed Inspection – Traffic Management
2-lane road with climbing lane – midle lane closed

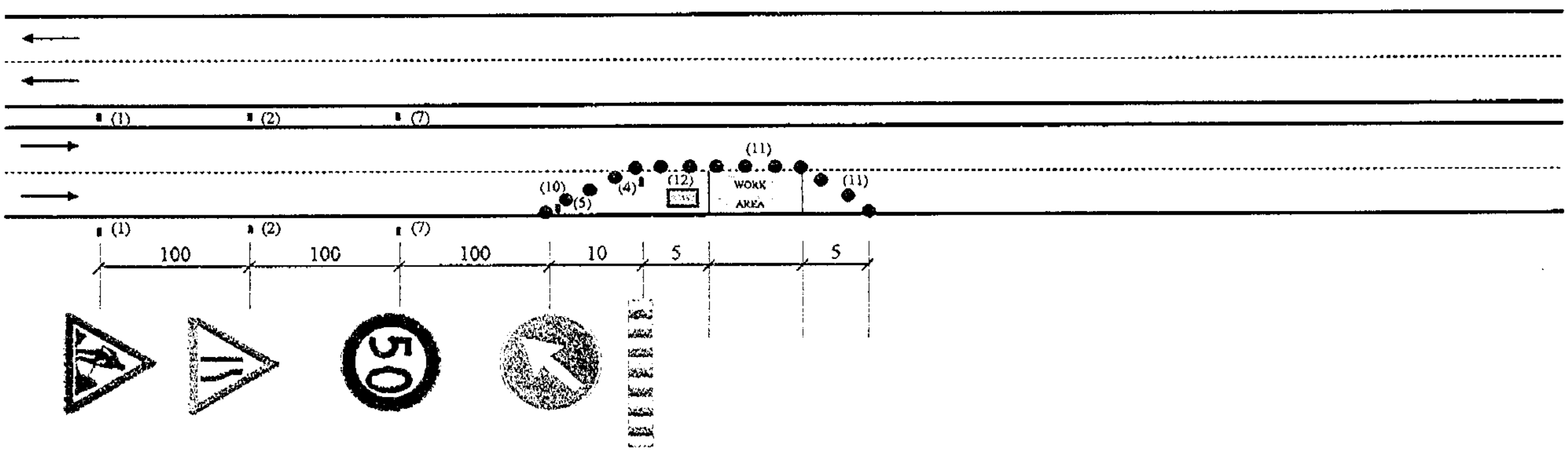


(10) cones at 1.5 m centres
(11) cones at 3 m centres
(12) KGM vehicle

Traffic Sign No	Number Required
1	2
3	2
4	2
5	2
7	2
8	2
Cone	
10	16
11	15+2(W.Area)/3

LAYOUT NO.6

Detailed Inspection – Traffic Management
Dual 2-lane road - 1 lane closed

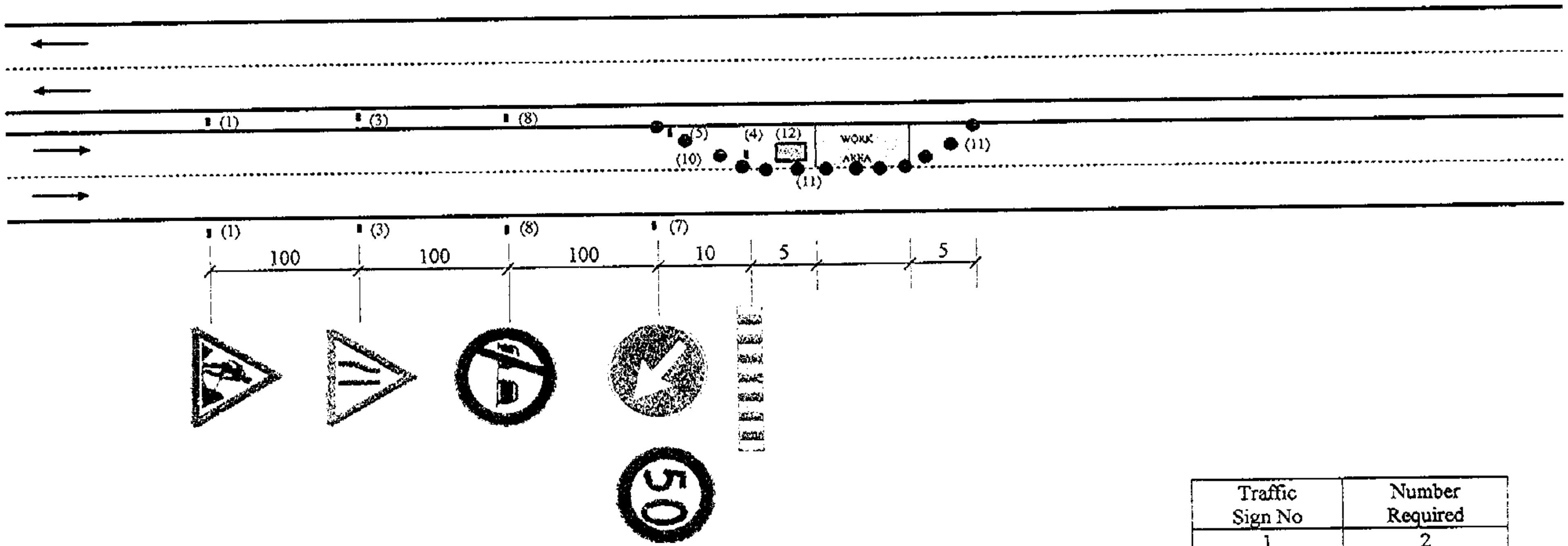


(10) cones at 1.5 m centres
(11) cones at 3 m centres
(12) KGM vehicle

Traffic Sign No	Number Required
1	2
2	2
4	1
5	1
7	2
Cone	
10	8
11	4+(W. Area) / 3

LAYOUT NO.7

Detailed Inspection – Traffic Management
Dual 2-lane road – 1 lane closed

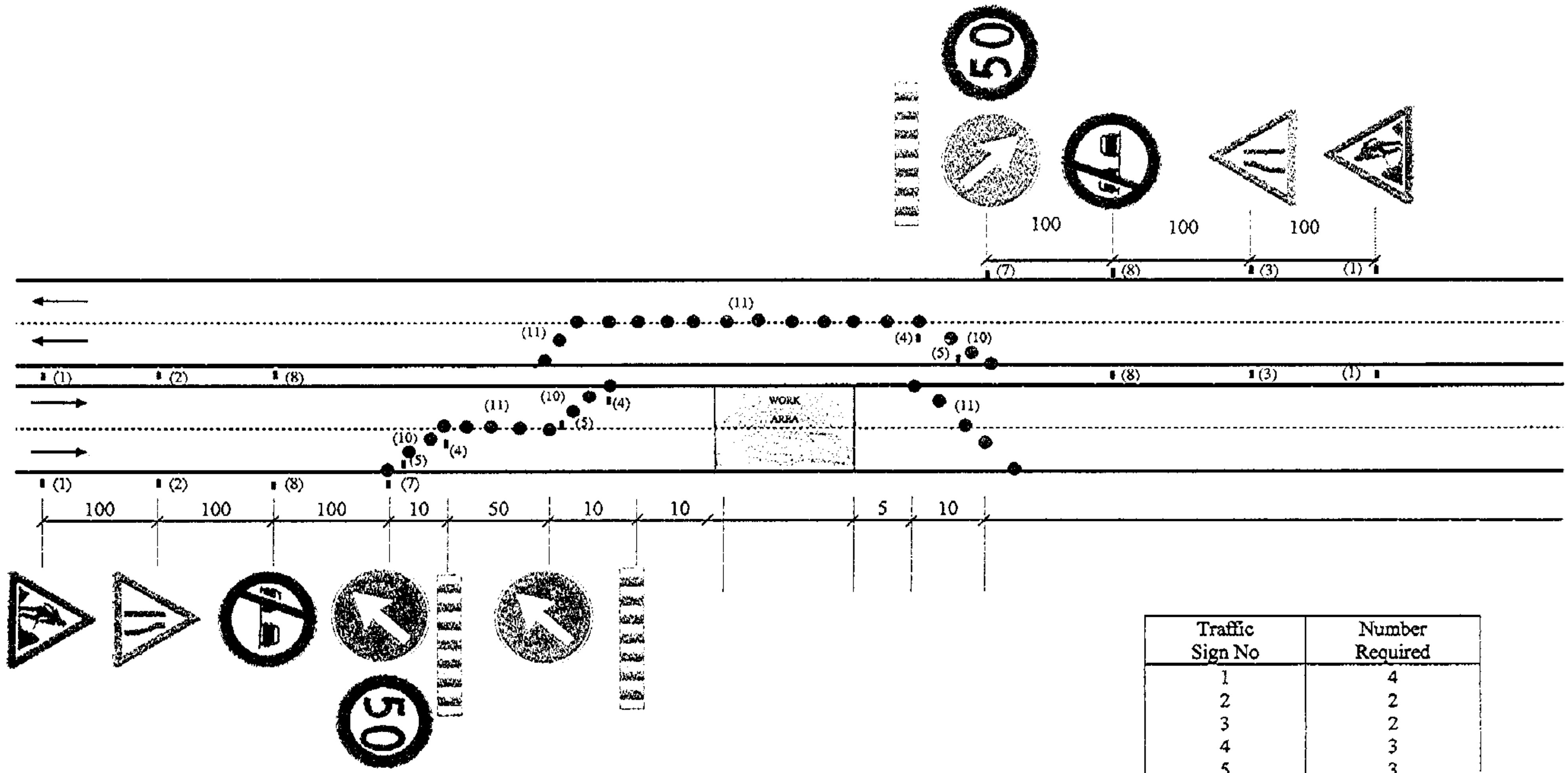


(10) cones at 1.5 m centres
(11) cones at 3 m centres
(12) KGM vehicle

Traffic Sign No	Number Required
1	2
3	2
4	1
5	1
7	1
8	2
Cone	
10	8
11	4+(W. Area) / 3

LAYOUT NO.8

Detailed Inspection – Traffic Management
Dual 2-lane road – 1 carriageway closed



(10) cones at 1.5 m centres
(11) cones at 3 m centres

Traffic Sign No	Number Required
1	4
2	2
3	2
4	3
5	3
7	2
8	4
Cone	
10	24
11	35+(W. Area) / 3

LAYOUT NO.9

CHAPTER 3 PAVEMENT

3.1 Evaluation Method

3.1.1 General

For pavement maintenance there are 2 aspects to consider.

- The first is the short term maintenance works needed to keep the road in a safe and serviceable condition for the road user and to prevent any rapid deterioration of the pavement.
- The second is the long term repair programme which is aimed at producing the optimum life from the pavement by considering programmes of overlaying or reconstruction.

3.1.2 Evaluation for Short Term Maintenance Work

Defects requiring short term maintenance will normally be identified during routine inspections. Any defect with an A ranking will be reported to the maintenance engineer at the Sub Division who will visit the site to decide on the appropriate repair method.

Data from the Detailed Inspection on cracking, potholes and rutting may also help to determine the appropriate short term repair works. A major benefit in carrying out the Detailed Inspections is to give the inspection staff as much experience as possible of relating physical measurements to the visual condition of the road. In this way, as more experience is gained, the inspection staff should be able to make decisions based on visual inspections alone.

Past experience of the defect and the available repair methods will be a major factor in the decision making process. To assist in developing good practice, tables showing the different damage types and severity together with the most appropriate repair method, are included in Section 3.5.2 of this manual.

3.1.3 Evaluation for Long Term Repair Work

Evaluation for long term repair work will be on the basis of the data collected during the Detailed Inspection. The data on cracking, potholes, rutting and wave shall be used to calculate a Present Serviceability Index (PSI) for the pavement. PSI is one of the performance criteria developed by AASHTO to provide a common index by which pavement performance could be judged.

Details of the surveys and data collected are given in Section 5.7 of the Management and Inspection Manual.

- From the crack survey (this includes pothole and patching areas), a cracking ratio is calculated for each section as shown in the Management and Inspection Manual.
- From the rutting survey, an average rut depth is calculated as shown in the Management and Inspection Manual.

- From the longitudinal roughness (wave) survey, level information for each inspection section is collected. The method for calculating the standard deviation is given in Appendix B of the Management and Inspection Manual.

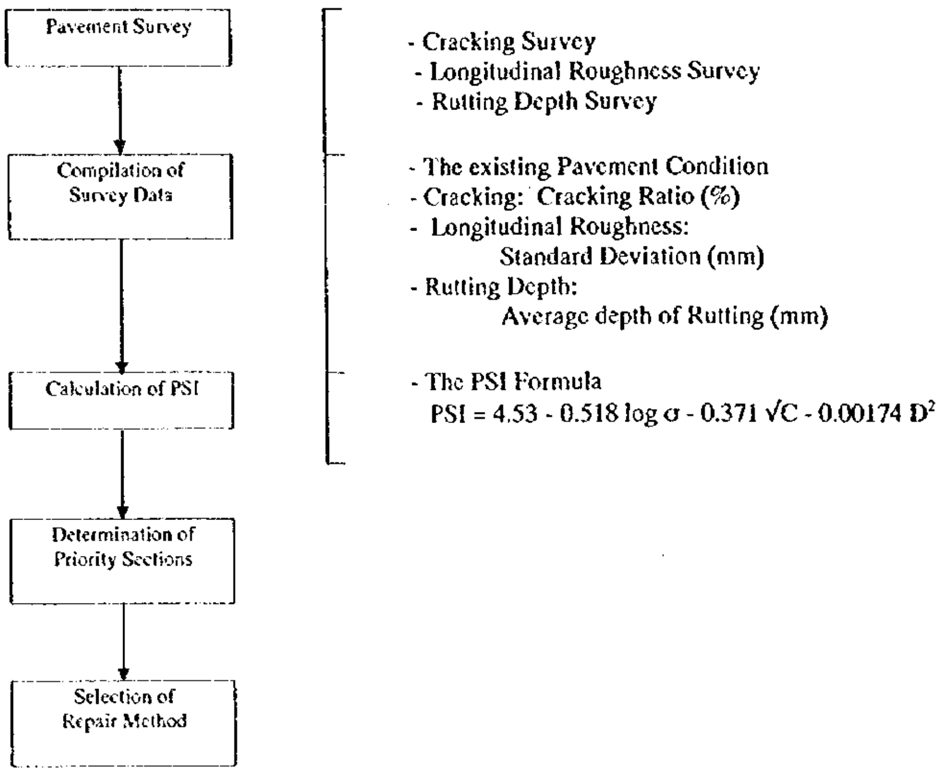


Fig. 3.1.1 Flow Chart for Pavement Condition Rating

The values for cracking ratio, average rut depth and the standard deviation for longitudinal roughness (wave) are inserted into the formula and a PSI value is calculated. A table is included in Section 3.5.2 of this manual to relate PSI value to the most appropriate repair method.

3.2 Effects of Damage

Table 3.2.1 defines each of the damage types and states the major effects of the damage.

Table 3.2.1 Damage Types for Pavement - Definitions and Effects

Items	Damage Type	Effects of Damage
Pavement	Settlement	. poor quality ride for the motorist. . may reduce traffic speed. . water may collect causing an accident risk.
	Cracking	. allows water to enter the pavement causing softening and weakening of the pavement and lower layers. This may cause early failure of the pavement. . in winter, water will freeze and expand to enlarge cracks and cause worsening damage. . if severe, causes uneven ride for the motorist and may reduce traffic speed.
	Potholes	. allows water to enter the pavement causing softening and weakening of the pavement and lower layers. This may cause early failure of the pavement. . in winter, water will freeze and expand to enlarge the pothole and cause worsening damage. . if left unrepaired, can rapidly expand the extent of the damage. . creates poor ride quality for the motorist and may reduce traffic speed. . if large can cause damage to vehicle wheels and tyres. . can create an accident risk.
	Rutting	. causes poor ride quality . water can collect in rut and cause aquaplaning problem for vehicles. This is a serious accident risk. . in winter, water collected in ruts may freeze causing an accident risk due to skidding.
	Wave	. poor ride quality for motorist. . in hot weather, surface stripping can occur.

3.3 Causes of Damage

The major causes of damage for each of the damage types listed in Table 3.2.1 are summarised in Table 3.3.1.

Table 3.3.1 Major Causes of Damage for each Damage Type

Item	Damage Type	Major Causes of Damage
Pavement	Settlement	. insufficient compaction of lower layers . differential settlement of sub grade
	Cracking	. poor quality workmanship . poor quality mixture . unsuitable compaction temperature . differential settlement at borders of different construction types (pavement/shoulder joint) . reflective cracks from cracks in lower layers . variations in compaction and bearing capacity of lower layers . pavement too thin . presence of ground water
	Potholes	. asphalt content too low . excessive heating of asphalt . poor quality mixture . lack of compaction allowing ingress of water
	Rutting	. axle loads in excess of the design loads (pavement too thin) . poor quality mixture . lack of compaction of pavement materials . low strength sub grade
	Wave	. poor quality mixture . variations in compaction and bearing capacity of lower layers . poor quality or lack of prime coat or tack coat . materials not suited to temperature range

3.4 Repair Methods

The main pavement repair methods and their definitions are listed below:-

Sealing	Bituminous materials are applied to cracks in the road surface.
Filling	The treatment of isolated potholes to maintain a safe road surface condition.
Patching	Materials are used to fill local depressions in the road surface or to replace areas of the pavement subject to extensive cracking or potholes.
Milling	The road surface is ground down using a machine.
Milling and Overlay	The road surface is ground down using a machine and a new surface layer is placed onto the milled surface.
Overlay	An additional surface layer is placed over the existing surfacing.
Reconstruction	The original pavement layers are fully or partially removed and the pavement is reconstructed to the required level.
Surface treatment	The pavement surface is covered with bituminous material, sand resin based material or epoxy based material.

Table 3.4.1 shows the most common repair methods for each of the pavement damage types.

3.5 Selection of Repair Method

3.5.1 General

Countries around the world have set out criteria to determine at what level of deterioration to carry out repair work on the highway pavement. The criteria vary depending on the materials in use which generally reflect the traffic and climatic conditions in the country or region of the country.

The intervention levels set out below represent the best practice from Turkey, Japan and America all countries using similar pavement materials and having wide climatic variations.

Intervention levels are given separately for asphalt concrete and surface treated roads as the repair method to be used may vary for the different road surface types.

Where more information is available from a detailed inspection and PSI values can be calculated, intervention levels are given as a guide to selecting the appropriate repair method.

Table 3.4.1 Repair Methods for Pavement Damage

Damage Type		Repair Method	Purpose
Settlement		- patching - overlay - reconstruction	- temporary repair whilst settlement continues - permanent repair when settlement is not excessive and lower layers are still sound - permanent repair when settlement is excessive and has destroyed the integrity of the pavement
Cracking	Hairline	- sealing - surface treatment	- to prevent the ingress of water and dust - to prevent the ingress of water and dust - to improve the surface texture
	Line	- sealing - surface treatment - milling and overlay - reconstruction	- to prevent the ingress of water and dust - to prevent the ingress of water and dust - to improve the surface texture - longer term repair to remove the cracks and provide a new road surface - where lower layers are cracked
	Alligator	- patching - reconstruction	- temporary repair to remove the cracks and provide a new road surface - permanent repair
Potholes		- filling - patching - reconstruction	- used on individual potholes to prevent the ingress of water and improve the ride quality - used where potholes are grouped together to prevent the ingress of water and improve the ride quality - permanent repair
Rutting		- milling - milling and overlay - reconstruction	- used to remove transverse undulation to improve surface condition - long term repair to restore surface ride quality - long term repair to restore surface ride quality
Wave		- patching - overlay	- used to improve the surface ride quality - longer term repair to improve surface ride quality

3.5.2 Intervention Levels

Table 3.5.1 shows the intervention levels and repair methods for each damage type for asphalt concrete roads.

Table 3.5.1 – Intervention Levels for Asphalt Concrete Roads

Damage Type		Intervention Level	Repair Method
Settlement		50mm>d<100mm	- cut and patch
		d>100mm	- cut and patch if lower layers are in good condition. - full or partial reconstruction where lower layers are damaged by the settlement.
Cracking	Hairline	<5mm	- seal individual cracks - surface treat where more widespread
	Line	Crack width 5mm to 15mm	- seal cracks
		Crack width >15mm	- (temporary) seal cracks -(permanent) when the pavement requires work due to other defects; carry out detailed study; milling and overlay or full/partial reconstruction depending on the results of the study.
	Alligator	Crazing is clearly visible with some breaking up and potholes appearing.	- cut and patch for small areas - reconstruct larger areas after detailed pavement study.
Potholes		Depth <50mm Diameter <100mm	- cut and fill
		Depth 50 to 100mm Diameter 100 to 300mm	- cut and patch for small areas - cut and patch as temporary repair for larger areas - partial/full reconstruction depending on the results of the pavement study
		Depth >100mm Diameter >300mm	- cut and patch with 2 layers for small areas - cut and patch as temporary repair for large areas - partial/full reconstruction depending on the results of the pavement study
Rutting		Depth 15-30mm	- milling
		Depth 30 -50mm	-milling and overlay with same material
		Depth > 50mm	- milling and overlay or reconstruct following pavement study.
Wave		Ride comfort reduced	- cut and patch
		Ride comfort severely reduced and safe traffic speed affected.	- cut and patch or overlay following pavement study.

Table 3.5.2 shows the intervention levels and repair methods for each damage type for surface treated roads.

Table 3.5.2 Intervention Levels for Surface Treated Roads

Damage Type		Intervention Level	Repair Method
Settlement		50mm>d<100mm	- fill low spots
		d>100mm	- apply base overlay with new surface treatment
Cracking	Line	Crack width 5 to 15mm	- seal - local surface treatment if extensive
		Crack width >15mm	- seal as temporary measure - cut out and renew surface treatment repairing the base where necessary
	Alligator	Crazing is clearly visible with some breaking at the corners of the polygons.	- cut out and patch - where more extensive, cut out and renew the surface treatment.
		Polygon blocks breaking up with potholes appearing.	- cut out and patch - where more extensive, cut out and renew the surface treatment repairing the base where necessary. .
Potholes		Depth <50mm Diameter <100mm	- cut and fill
		Depth >50mm Diameter >100mm	- cut and fill - where more extensive, cut out whole area, use base overlay and renew the surface treatment.
Rutting		Depth >30mm	- patch
		Depth >50mm	- milling, base overlay and renew the surface treatment
Wave		Ride comfort significantly reduced so that running speed is reduced.	- cut out, repair or recompact base as necessary and renew surface treatment.

Table 3.5.3 shows the intervention levels where a PSI Value is known.

Table 3.5.3 – Intervention Levels for Asphalt Concrete Roads based on PSI Values

PSI Value	Repair Method
PSI ≤1	Reconstruction
1 < PSI ≤2	Overlay
2 <PSI ≤3	Surface Treatment
PSI > 3	No repair necessary

3.5.3 The Selection Process

The selection of the appropriate repair method will depend on a number of factors:-

- the type and severity of the defect
- the effect on traffic flow during repair works
- the volume of traffic; this will affect the rate of deterioration of the defect
- cost effectiveness considering short and long term options

Urgent repairs may be required in order to reopen a road closed by the damage, or to prevent the damage from developing into a more serious situation.

Short term options:-

for isolated defects
- crack sealing
- pothole filling

when defects are more extensive
- patching
- surface treatment
- milling

Long term options:-
- overlay
- partial or full reconstruction

The available budget must be considered. Also the cost effectiveness of different repair options should be considered e.g. repeated short term repairs must be compared with a higher cost long term repair which will have lower ongoing costs (Whole Life Costing). Alternatives such as overlaying and full or partial reconstruction must be evaluated.

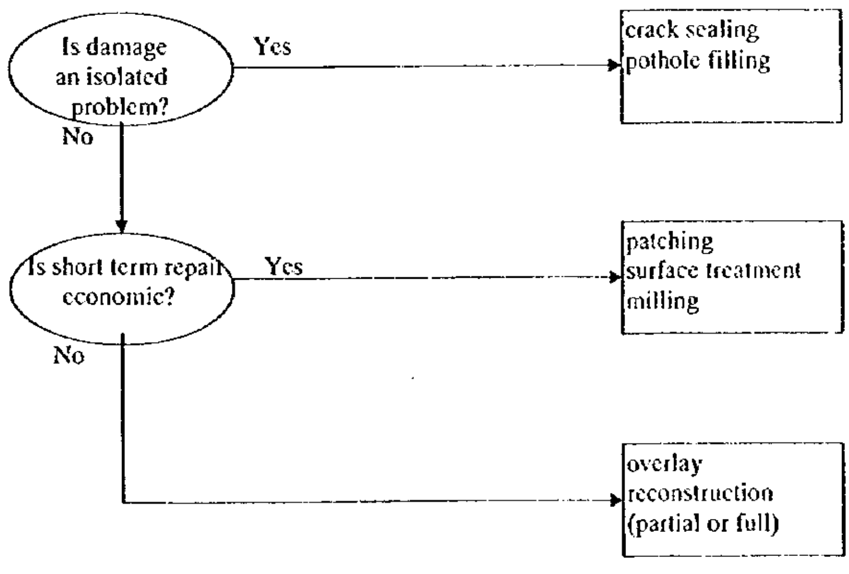


Fig. 3.5.1 Selection of Repair Method for Pavement

In selecting the repair method, careful attention must be paid to the data collected from the supplementary surveys. The core samples should give a clear indication of the pavement and individual layer condition. It should also be used to check how far the cracking or rutting has penetrated into the sample. The actual layer depths should be considered and compared with the designed depths as this may quickly highlight a problem where the construction is not as per the design. The CBR results should also be taken into consideration.

The use of all this data in the calculation of overlay designs is shown in Chapter 3.6.1.

3.6 Design Matters

3.6.1 Overlay Design

Overlay design can be carried out using the equivalent layer thickness method or using pavement deflection values. We have selected the equivalent layer thickness method for this manual.

Overlay design is dependent on a number of factors as follows:-

- the existing and future traffic flow, particularly the heavy vehicle flow
- the depth of the existing pavement layers
- the material of the existing pavement
- the condition of the layers
- the sub-grade CBR value

1. Traffic Flow Classification

Traffic flows on the road under examination must be established either from existing data or by carrying out classified traffic counts. The growth factors for each of the vehicle classes must be agreed with the appropriate department.

When the traffic data is available, the road is classified in accordance with table 3.6.1. If the road has more than two lanes in one direction, 80% of the traffic may be used for the distribution of traffic loads among the lanes.

Table 3.6.1 Road Classification by the Volume of Heavy Vehicles

Classification	Volume of Heavy Vehicles Vehicles/day/direction
L	<100
A	≥100 and <250
B	≥250 and < 1000
C	≥1000 and < 3000
D	≥3000

The traffic flow is critical to the overlay calculation, so particular attention should be paid to the values when they are near to the limit of a classification. Where there is some uncertainty, the calculation should also be checked using next higher band.

'Heavy Vehicles', includes Trucks, Trailers and Buses. The flow to be used for classification is the average flow over the expected life of the overlay. If the overlay is to last 10 years, the average daily heavy vehicle flow should be calculated for the 10 year period by applying the growth factors for each vehicle type to the base year flows.

2. The Existing Pavement

The core samples should be used to establish the following data:-

- layer depths
- layer condition
- materials, either from a visual inspection or from laboratory tests

Sufficient cores should be taken along the section under examination to ensure that any changes in construction are identified.

Pits may be dug at the coring sites to establish the full pavement depth and materials. These pits may also be used to carry out in-situ CBR tests on the sub-grade or to gather samples for laboratory CBR tests. Where the tests in the pits would create excessive traffic delays, the CBR tests may be carried out at the edge of the road or in the verge to get an indicative value.

3. Overlay Calculation

This method first calculates the equivalent thickness of asphalt concrete for the existing pavement (T_{AO}) based on the damaged condition.

Then, based on the sub-grade CBR and the traffic classification, the equivalent thickness of asphalt concrete needed to carry the future heavy traffic loading (T_A) is calculated.

The thickness of overlay required is the difference between theses two depths and is calculated as shown below:-

Thickness of overlay(cm) $t = T_A - T_{AO}$

(i) Using the layer coefficients in Table 3.6.2 and a knowledge of the condition of the existing layers, the layer depths are converted to an equivalent thickness (T_{AO}) of Asphalt Concrete.

The coefficients need to be selected based on the existing layer condition. Three damage condition levels are used to describe the condition of the existing pavement.

Level 1: The pavement is in excellent condition only requiring routine maintenance (cracking ratio 15% or less).

Level 2: Some maintenance and repair are needed (cracking ration 15% to 30%).

Level 3: Major repair or overlay is needed (cracking ration >35%)

It is advisable to set down criteria for selecting the different values of the coefficients for overlay calculations. This ensures a consistent set of results and allows the values to be adjusted as more experience is gained of the rate of deterioration of the various layers and materials. Examples of the selection criteria are included with the sample calculations (see Appendix A) carried out as part of this study.

Table 3.6.2 Layer Coefficient for the calculation of T_{AO}

Pavement Course	Existing Pavement	Layer Condition	Coefficient	Remarks
Surface and Binder Course	Hot mix asphalt concrete	*C	0.9	*A
		*D	0.65 - 0.6	
			0.6	
		*E	0.5	
Base Course	Hot asphalt treated base		0.8 - 0.4	*B
	Cement stabilised base		0.55 - 0.3	
	Lime stabilised base		0.45 - 0.25	
	Hydraulic mechanically stabilised slag		0.55 - 0.3	
	Mechanically stabilised crushed stone		0.35 - 0.2	
Subbase course	Pit-in gravel and crusher run		0.25 - 0.15	*B
	Cement or lime stabilised sub base		0.25 - 0.15	
Concrete Slab		*F	0.9	
		*E	0.85 - 0.5	

*A Highest value for damage level 1, lowest value for damage level 3
*B The highest value is for a new road, lower values relate to current condition
*C Damage level 1 with a risk of going to level 2
*D Damage level 2 with a risk of going to level 3
*E Damage level 3
*F Damage level is 1 or 2

(ii) The target asphalt concrete depth (T_A) is determined from Table 3.6.2 having first established the sub-grade CBR value and the road traffic classification.

Table 3.6.3 Target Value T_A (cm) from Sub-Grade CBR and Traffic Classification

Design CBR	Traffic Volume Classification				
value of subgrade	L	A	B	C	D
2	17	21	29	39	51
3	15	19	26	35	45
4	14	18	24	32	41
6	12	16	21	28	37
8	11	14	19	26	34
10	-	*13.5*	*18*	*24.5*	32
12	-	13	17	23	30
20	-	-	-	20	26

(iii) The overlay depth (t) is calculated from the formula above.

Sample calculations are included in Appendix A.

3.7 Construction Matters

Crack Sealing

The sealing and resealing of cracks in pavements is an important and often underestimated aspect of pavement maintenance. Serviceability and pavement life may be extended through proper resealing by preventing the entry of surface water and debris.

The objective is to fill the cracks as completely as possible with bituminous binder to prevent water entry.

The method and materials used will depend on the equipment available for the work. Viscous binders will need a hand lance with a relatively fine jet capable of getting the binder into the cracks. The use of a watering can or similar may be used when the binder viscosity is suitable.

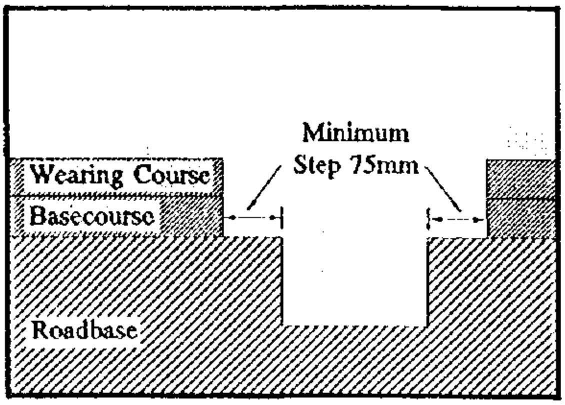
Work Sequence:-

- the crack should be cleaned by brushing and using a compressed air hose to remove dust and debris from the crack to be sealed.
- the surface must be clean and dry before the application of the sealant.

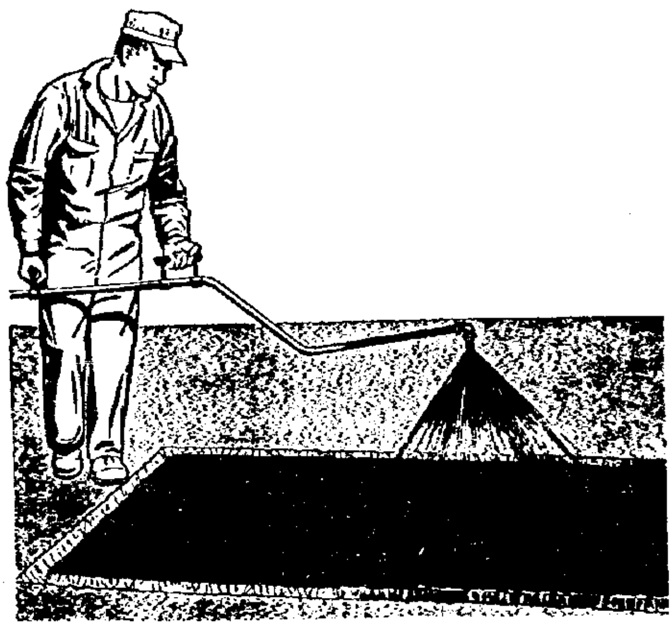
- sealant is applied to the crack using appropriate equipment
- where necessary, the sealant should be finished with a hand asphalt tool.

- the sealant may be blinded with dry sand or dry fine aggregate to provide a surface texture and to assist with the curing process
- sealant must be allowed to set before allowing traffic to run on the road

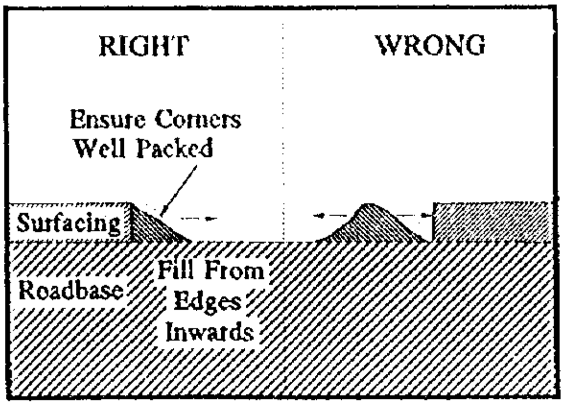
- form the edges of the area by saw cutting on straight lines to a firm undisturbed vertical edge. The depth of the patch excavation will not normally exceed the wearing course depth.
- for deeper excavation, no step is required between the wearing and binder courses, although a minimum of a 75mm step should be made between the binder course and the base course.

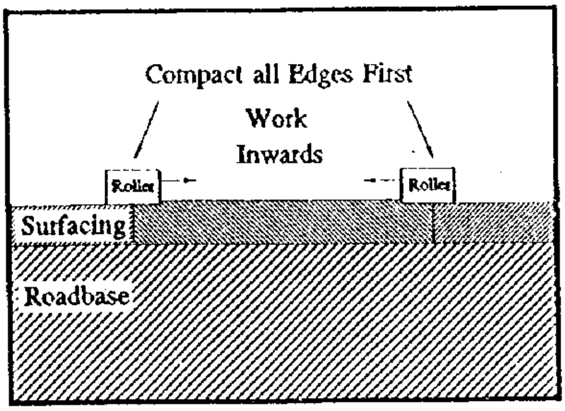


- ensure all edges are trimmed and sweep clean; where possible use a compressed air line.
- paint the edges of the area with asphalt emulsion.
- spray the base of the area with tack coat.

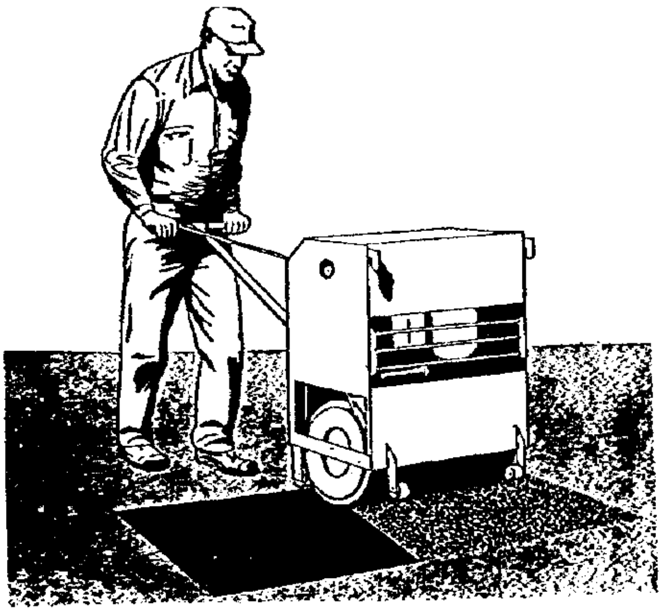


- place patching material in a uniform layer, levelled and shaped to maintain existing carriageway camber /crossfall after compaction. The new material must be flush with all joints, channels and projections and be level or not more than 3mm above adjoining pavement surfaces.





- compact all parts of the patch to refusal using a tamper, hand rammers or a small vibrating roller avoiding roller marks on the surface and damage to adjacent sound material.
- on completion of the operation, clean the site thoroughly.



Filling

This is used for isolated pothole repairs.

In order to maintain the surface in a safe condition, a rapid repair can be carried out. Loose material should be removed from the hole, the exposed surfaces coated with a tack coat and the hole filled with material, compacting in layers.

However, this type of filling may not last very long. As soon as is possible, the repair should be repeated but the surface should be cut back around the pothole to sound material, the sides squared off and the hole should be cleaned out with a compressed airline. The exposed material should be coated with a tack coat and the hole backfilled with appropriate material, compacting in layers.

Patching

The need for patching is usually the first sign of major pavement deterioration. It may be carried out on a repeat basis or prior to the application of a surface treatment or overlay. The repeat patching process is used to extend the life of the existing pavement and so defer the more expensive overlay or reconstruction works.

The cause of the local failure requiring patching will often be related to problems with drainage both on and off road. It is essential that these problems are identified and remedied before any patching work is carried out.

There are two types of bituminous patching mixtures:-

(a) those mixed hot and compacted while still hot

(b) those mixed and then stockpiled for a period before use

Although cold asphalt mixture is more convenient for transport, storage and placing, its initial stability and durability are inferior to the hot mixture. Hot mix asphalt is therefore preferable for the repairs on heavily trafficked roads.

These mixtures vary widely in quality and costs. The performance of a bituminous patch depends on both the quality of the materials comprising the patching mixture and the quality of the construction in the preparation, placing and compaction of the mixture. The best bituminous patching mixture will only last a short time if good construction practice is not followed.

Work Procedure:-

- mark out a square or rectangular area for the patch extending beyond all the unsound material.
- remove all loose and failed material.

Milling

Milling has been successful in removing as much as 75mm to 100mm of asphalt concrete surfacing in a single pass. The major uses are as follows:-

- removing material in readiness for overlays
- removing material to restore surface and cross section profile
- restoring the kerbline area
- restoring the cross slope to improve drainage or to correct drainage inlet cover problems
- improve friction resistance of the surface

After removal of surface material through milling, most pavements are overlaid. Some pavements however, have been milled and opened to traffic without an overlay but tyre noise may generate public complaints so this will generally only be suitable on low traffic volume roads. If the pavement is structurally sound but rough from various non load related distresses, this may be a very cost effective means of delaying overlaying for a few years.

Overlay

For asphalt concrete, the surface should be prepared by sealing cracks and filling potholes and where necessary, milling the surface. A new surface course is laid to current specifications and should be of sufficient depth to extend the life of the pavement to suit the long term maintenance programme. This might involve a further overlay before reconstruction.

For surface treated roads, surface defects such as cracks and potholes should be repaired prior to the application of a new surface course. Where practical this should be in asphalt concrete material but this should only be the case where the overall pavement will withstand the expected traffic loading for a number of years to make the repair economic.

Reconstruction

Reconstruction involves the removal of some or all layers of the pavement layers and the replacement with new materials to the current specification allowing for known and projected traffic conditions.

Surface Treatment

Surface treatment involves the application of an asphalt/aggregate mix to the road surface. The surface treatment provides little or no structural improvement in the pavement but it provides other benefits:-

- provides a new road surface
- seals the surface against water penetration
- seals cracks

This treatment should not be used where the pavement structure is not strong enough to carry the projected traffic load for the next 3 to 5 years. Also if the pavement has any structural problems resulting from poor drainage or an unstable base, this treatment should not be considered.

There are many forms of surface treatments, the most common are as follows:-

- Slurry seal

  This consists of the application of a diluted emulsion mixed with a sand sized aggregate. The slurry is spread onto the road surface using squeegee type brushes. The thickness is generally less than 10mm.

- Asphalt-aggregate surface treatment

  This consists of sequential application of asphalt and stone chips which can be made either singly or in repetitive layers, sometimes called armour coating.

  The use of mechanised surface treatment methods offers important advantages over manual methods. Mechanical bitumen sprayers allow the close adjustment of the rates of application so that these can be accurately controlled and the adverse effects of excessive, insufficient or variable amounts of binder can be avoided. The rate of progress of a mechanised unit is much higher than can be achieved by manual methods.

  Chippings

  The use of rounded gravel aggregates should be avoided if possible because it is difficult for the binder film to hold them in place and because of their poor surface friction properties. If their use cannot be avoided, adjustments must be made to the rate of spread of the bitumen. The rounded aggregates do not interlock and more bitumen is required to hold particles firmly to the road surface than is required for cubical aggregates.

  Binder
  The performance and qualities of a surface treatment binder makes the choice of binder critical.

  The binder must:-
  - be sprayable at a reasonable temperature
  - 'wet' the surface of the road and remain in a continuous film waterproofing the road structure
  - not run off a steep gradient or cambered road or form pools of binder
  - 'wet' and adhere to the stone chippings at road temperature
  - be strong enough to resist the traffic forces and retain the chippings even at the highest ambient temperatures
  - be flexible at the lowest temperature, neither cracking and allowing water to enter nor brittle thus allowing the chippings to break free
  - resist excessive weathering and hardening once the initial hardening has taken place

  Modified binders may be considered where chip retention is a problem.

CHAPTER 4 SLOPE (CUTTINGS AND EMBANKMENTS)

4.1 Evaluation of Data

In order to assess the slope condition and decide on the appropriate repair method, the following data collected during the detailed inspections will have to be evaluated:-

- soil type
- slope gradient
- slope stability
- existing drainage system
- the presence of surface water
- existing vegetation
- observed defects

The following sections provide the detail as to selecting the appropriate repair method.

4.2 Effects of Damage

Table 4.2.1 defines each of the damage types and states the major effects of the damage.

Table 4.2.1 Damage Types for Slope - Definitions and Effects

Items	Damage Type	Effects of Damage
Cut slope	Landslide	. may cause serious problems for third parties . may close road to traffic long term . urgent countermeasures required
	Rock Avalanche	. road may be closed causing traffic disruption . side ditch and other concrete structures may be damaged, and cause drainage problems
	Collapse of Slope Protection	. causes poor countermeasure function for slope defects . rain water causes softening and weakening of the slope . may cause erosion, rock avalanche and landslide
	Cracking	. allows water to enter the slope and cause landslide and rock avalanche
	Slope Erosion	. road may be closed causing traffic disruption . side ditch and other concrete structures may be damaged, and cause drainage problems
Embankment Slope	Landslide	. road may be closed causing traffic disruption . side ditch and other concrete structures may be damaged, and cause drainage problems
	Collapse of Slope Protection	. may close road to traffic or create a hazard and disturb the traffic flow . side ditch and other concrete structures may be damaged, and cause drainage problems
	Slope Erosion	. shoulder and roadbed may collapse . may cause landslide . side ditch and other concrete structures may be damaged, and cause drainage problems

4.3 Causes of Damage

The major causes of damage for each of the damage types listed in Table 4.2.1 are summarised in Table 4.3.1.

Table 4.3.1 Major Causes of Damage for each Damage Type

Item	Damage Type	Major Causes of Damage
Cut Slope	Landslide	• too steep slope gradient • lack of drainage system • lack of berm and berm ditch • rain water and underground water runoff between cover soil and foundation rock • dip of rock or weathered rock tends to slide. • in winter seepage water freezes in layer joint causing sliding when it melts
	Rock Avalanche	• dip of rock causes rock fall • poor quality control of construction works • weathering rock causes rock fall • developing joint of rock • seepage water makes rock layer slippery
	Collapse of Slope Protection	• poor quality materials • lack of bearing capacity of structure. • caused by rock fall • lack of proper compaction of the surface allowing slope to crack. • unstable cut slope deforms and causes defects.
	Cracking	• slope too steep • poor quality materials • lack of drainage system on slope
	Slope Erosion	• slope too steep • poor quality materials • no protection of slope surface • runoff water, spring water and seepage water • weathering surface of slope • lack of proper compaction during construction.
Embankment slope	Landslide	• water running between natural ground and fill material • poor construction methodology • on talus cone or landslide area • slope too steep • lack of berm and berm ditch • lack of proper compaction of slope • lack of bearing capacity of lower layers
	Collapse of Slope Protection	• unstable embankment causes slope protection defects • poor quality fill materials • poor quality control of construction • weathering surface of slope • washing out underneath of embankment by river water
	Slope Erosion	• slope too steep • lack of drainage system • poor construction methodology or quality of materials • no protection, no vegetation on slope surface • runoff water, spring water and seepage water • water force of river and sea • weathering surface of slope • lack of proper compaction of surface soil causes surface landslide

4.4 Repair Methods

a) Earthworks

- To set up the standard slope gradient, refer to Chapter 4.6 in the Evaluation and Repair Manual.
- When the cut slope gradient is too steep, carry out recutting or refilling to achieve the right gradient.
- When the embankment slope is too steep, make benching on the existing fill slope and refill to the right gradient.
- When the height of the cut slope is more than 15 metres, create a berm or berm ditch.

b) Drainage

- For cut slopes, set up ditches at the top and bottom of the slope and on the berms to collect the runoff water.
- For embankment slopes, set up the ditches at the shoulder to collect the road surface water.
- Table 4.4.1shows the suitability of drainage provision for different soil types

Table 4.4.1 Suitability of Drainage Provision for Different Soil Types

Location of Drainage Provision	Soil type				Application
	Cutting Slope			Embankment Slope	
	Hard rock	Soft rock	Earth	Earth	
Top of slope	B	A	A	A	
On the berms	C	B	A	A	
Toe of slope	A	A	A	A	

A : very suitable
B : suitable
C : not suitable

c) Vegetation

Slope vegetation is used to prevent defects occurring and also to harmonise with the surrounding environment. However, vegetation is not suitable for the prevention of landslides. In selecting the vegetation method, consideration must be given as to whether the vegetation works efficiently in preventing erosion and collapse and also whether it is compatible with soil type. Table 4.4.2shows the suitability of the different vegetation methods for each soil type.

Table 4.4.2 Suitability of Vegetation Methods for Different Soil Types

	Soil type				Application
	Cutting Slope			Embankment Slope	
	Hard rock	Soft rock	Earth	Earth	
Block Sodding	D	D	A	A	
Stripe Sodding	D	C	B	A	
Seed Packet Work	D	A	A	D	
Seed Spraying	D	B	A	A	
Tree planting	D	C	A	A	

A : highly recommended
B : recommended
C : difficult to recommend
D : not recommended

d) Structures

If the slope is unsuitable for vegetation and vegetation will not provide long term prevention of erosion, slope structures should be considered for long term countermeasure. Table 4.4.3 shows suitability of slope protection methods for each soil type.

Table 4.4.3 Suitability of Slope Protection Methods for Different Soil Types

	Soil type				Application
	Cutting Slope			Embankment Slope	
	Hard rock	Soft rock	Earth	Earth	
Stone riprap revetments	D	C	A	A	
Articulated concrete revetments	D	C	A	A	
Cylinder Gabon Wall	D	D	C	B	
Shotcrete	A	A	C	C	
Concrete Crib	A	A	A	A	

A : highly recommended
B : recommended
C : difficult to recommend
D : not recommended

e) Recutting in Rock Avalanche

Recutting is carried out to stabilize the existing cut slope. Recutting involves cutting back the slope to a flatter gradient to suit the rock structure. Where the instability is isolated, the pockets of unstable rock may be removed without recutting.

f) Protection for slope erosion and weathering

Erosion and weathering may cause a rock avalanche and the slope surface should be protected against them. Suitable slope protection works are as follows:-

- Drainage of surface water
- Vegetation
- Concrete or shotcrete cover

g) Rock Avalanche countermeasures

Countermeasures are as follow:-

- In situ concrete fixes and stabilizes the rock
- Rock net covers the unstable rock slope
- Retaining wall, stone masonry or mat gabion reduces the damage by rock avalanche
- Concrete crib or shotcrete covers the slope surface

The suitability of the countermeasures for different scales of rock avalanche is shown in Table 4.4.4. All loose and unstable rock should be removed before starting any repair works.

Table 4.4.4 Suitability of the Countermeasure for Different Scales of Rock Avalanche

Estimated size of falling rock		Large (1.0m dia.) few tons		Middle(0.4mdia.) few hundred kilos		Small few kilos	
Measure	type	toppling	under-cutting	toppling	under-cutting	toppling	under-cutting
Slope protection from erosion	Surface drainage	♦	♦	♦	♦	□	♦
	Shotcrete	□	-	♦	-	♦	-
	Vegetation	-	□	-	□	-	♦
Structural support	Foot protection	□	♦	-	-	-	-
	Concrete revetments	□	□	♦	♦	♦	♦
	Cribwork	□	□	♦	♦	♦	♦
	Rock Bolts	♦	□	-	-	-	-
Rockfall prevention device	Prevention net	-	-	-	-	♦	♦
	Prevention fence	-	-	-	-	♦	♦
	Retaining wall barrier	-	-	♦	♦	♦	♦

♦ Recommend
□ Suitable
\- Not Suitable

h) Control of discharge water

The following two measures are applicable for controlling discharge water:-

- Prevention of runoff water from permeating into the ground using surface drainage or surface covering of vegetation.
- Lowering of ground water : a temporary repair would be the use of underground drainage by constructing horizontal drain holes.

i) Weight shifting

Weight shifting aims to keep the mechanical balance of a slope by removing or filling in some portion of the slope. Specific measures are given below:-

- Removal of all or part of the slide debris
- Removal of scarp portion
- Apply a counterweight by using earth fill, gabions or concrete walls

j) Structural support

A retaining wall may be used at the foot of a sliding slope or alternatively, a landslide prevention pile may be driven into the ground deeper than the slip surface in the middle of the slope.

k) Application of restoration measures for Landslides

Restoration measures can be selected from the various possible measures in Table 4.4.5.

Table 4.4.5 Restoration Measures for Different Geological Formations

Type of slope	Geology	Surface drainage	Horizontal drain hole	Earth removal	Counter weight	Retaining wall	Prevention pile
Cut slope	Rock	-	□	♦	♦	♦	□
	Weathered Rock	-	□	♦	♦	♦	□
	Alluvium	□	□	♦	♦	♦	♦
	Clayey soil	♦	□	-	♦	♦	□
Fill slope	Alluvium	-	□	-	♦	♦	♦
	Clayey soil	-	-	-	♦	♦	□

♦ Recommend
□ Suitable
- Not Suitable

Table 4.4.6 Types Repair Work for Slope Damage

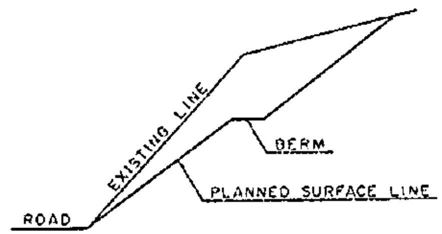
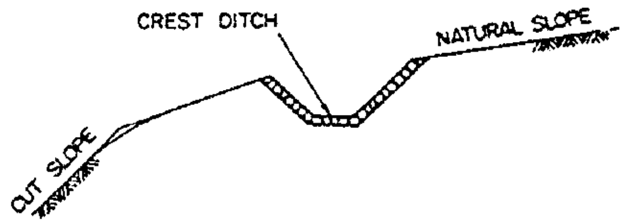
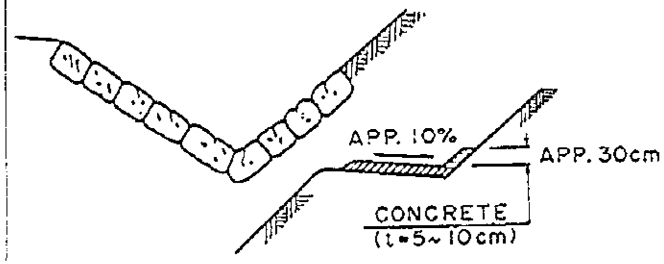
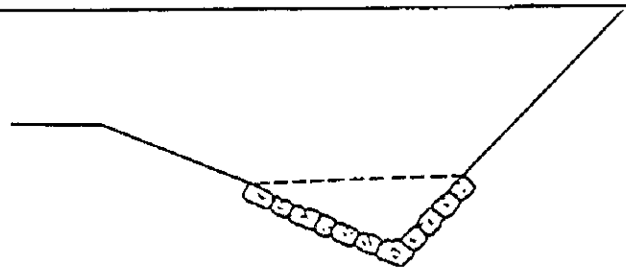
Damage Type	Repair Method	Purpose	Application	Sketch
Erosion	Recutting and Berm	-To stabilize a slope by cutting it to its optimum gradient. -To prevent the erosion and scouring of a slope surface by collecting surface water in berm	-Usually applied with drainage work and slope protection work -Cut slope -Weathered rock, soil	
	Crest ditch	-To prevent the erosion and scouring of a slope surface by collecting runoff water along the top of a cut slope	-Cut slope - Weathered rock, soil	
	Berm Ditch	-To prevent the erosion and scouring of a slope surface by collecting surface water in berm	-Cut slope, Fill slope - Weathered rock, soil	
	Toe Ditch	-To prevent runoff water from reaching a road's surface	-Cut slope -Rock, soil	

Table 4.4.7 Types Repair Work for Drainage Damage

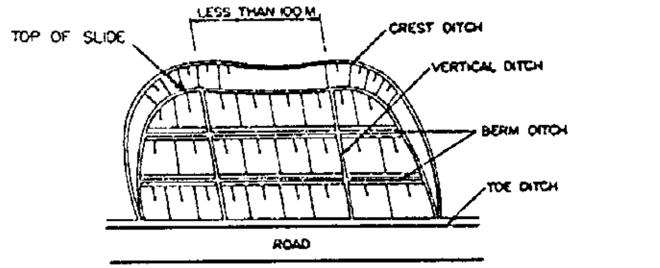
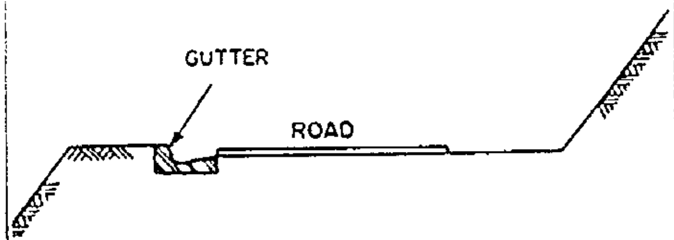
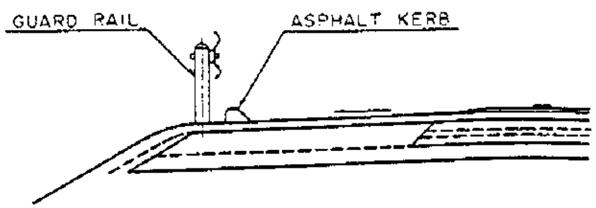
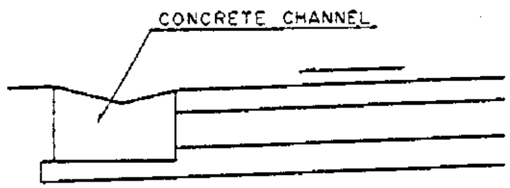
Damage Type	Repair Method	Purpose	Application	Sketch
Erosion	Vertical Ditch	-To collect and drain surface water on a slope with a vertical ditch to prevent the erosion and scouring of the slope's surface	-Generally applied on a slope surface -Cut slope, fill slope	
	Gutters	-To prevent embankment slope from being scoured due to the flow of surface water. -To collect road surface water at the shoulders using a gutter	-Road shoulder of fill slope side.	
	Kerbstone	-To prevent embankment slope from being scoured due to the flow of surface water. -To collect road surface water at the shoulders using an asphalt curb or concrete kerb.	-Road shoulder of fill slope side.	
	V shape ditch	-To prevent embankment slope from being scoured due to the flow of surface water. - To collect road surface water at the shoulders using V shaped ditch.	-Road shoulder of fill slope side.	

Table 4.4.8 Types Repair Work for Drainage Damage

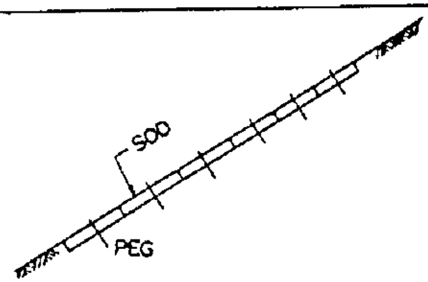
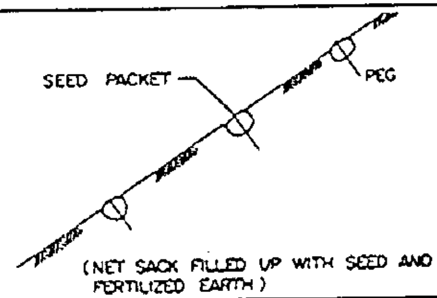
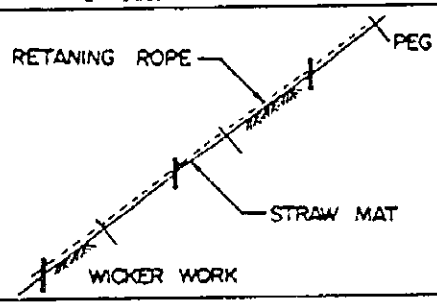
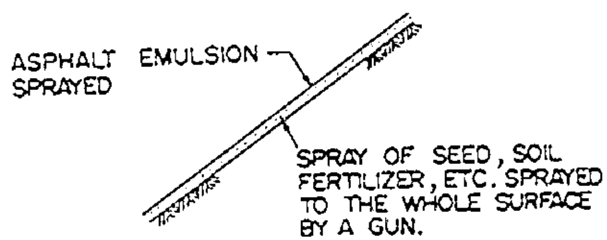
Damage Type	Repair Method	Purpose	Application	Sketch
Erosion	Block Sodding	-To prevent the erosion, scouring and weathering of a slope by covering it with vegetation. -To place sod directly on a slope	-Cut slope, fill slope -Soil	
	Seed packet work	-To prevent the erosion, scouring and weathering of a slope by covering it with vegetation. -To place bags filled with seeds and fertilized soil on a slope.	-Applied to a slope relatively unsuitable for growing grasses. -Cut slope -Weathered rock, soil	
	Erosion control with local material	-To prevent the erosion, scouring and weathering of a slope by covering it with vegetation. -To cover seed with a straw mat	-Cut slope, fill slope. -Soil surface.	
	Seed-mix spraying with a gun (hydroseeding)	-To prevent the erosion, scouring and weathering of a slope by covering it with vegetation. -To spray mixed slurry or mud composed of seed, water, fertilizer, soil, etc., with a spray gun.	-Mainly applied to the weathered rock, soft rock and soil surface of a cut or fill slope.	

Table 4.4.9 Types Repair Work for Drainage Damage

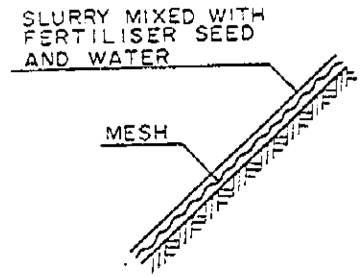
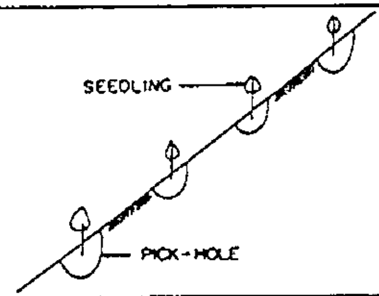
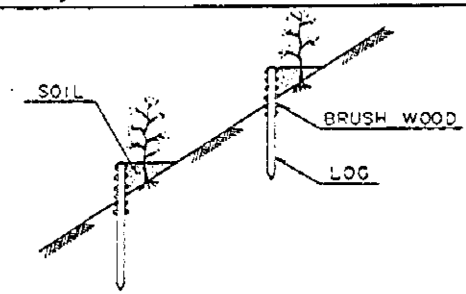
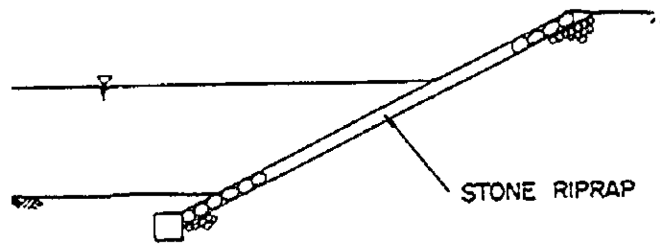
Damage Type	Repair Method	Purpose	Application	Sketch
Erosion	Seed-mix spraying with a gun	-To prevent the erosion, scouring and weathering of a slope by covering it with vegetation. -Spraying slurry mixed with seed, water, fertilizer, soil, and steel wire with gun.	-Soil and weathered rock is mostly applicable.	
	Pick-hole seedling work	-To prevent the erosion, scouring and weathering of a slope by covering it with vegetation. -To fill holes on a slope with seeds and fertilized soil	-Applied to a slope relatively unsuitable for growing grass. -Generally applied to a cut slope. -Weathered rock, soft rock	
	Wicker work	-To prevent the erosion, scouring and weathering of a slope by covering it with vegetation.	-Cut slope, fill slope. -Weathered rock, soil.	
	Stone pitching	-To prevent a slope by covering it by stone pitching.	Usually applied to a slope surface gentler than 1.5:1	

Table 4.4.10 Types Repair Work for Drainage Damage

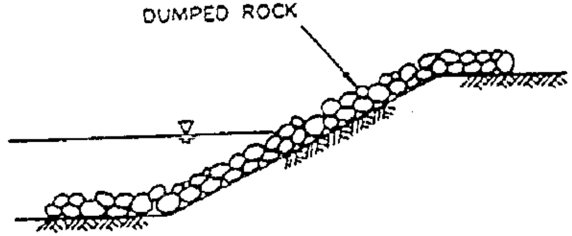
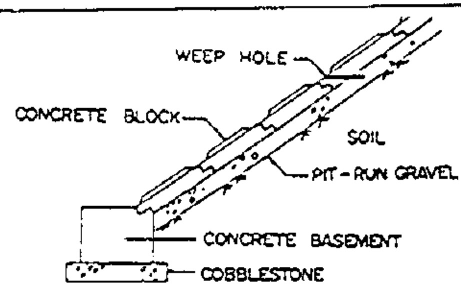
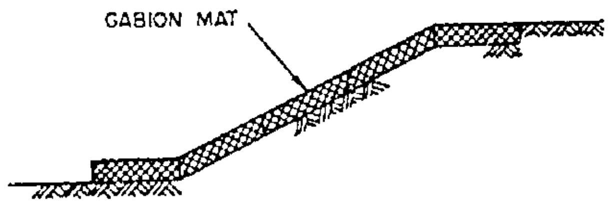
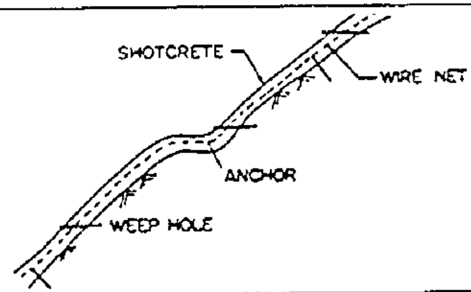
Damage Type	Repair Method	Purpose	Application	Sketch
Erosion	Dumped rock	--To prevent a slope from scouring by high velocity water flows.	-Usually applied to a slope surface gentler than 1.5:1	
	Concrete block pitching	-To protect a slope by covering it with cast-in place concrete.	-Usually applied to a slope surface gentler than 1.5:1	
	Gabion	-To protect an embankment by resisting earth pressure.	-Mainly applied to an embankment slope with seepage water.	
	Shotcrete	-To protects a slope by covering it with sprayed concrete.	Not applicable to a slope surface with much seepage water.	

Table 4.4.11 Types Repair Work for Drainage Damage

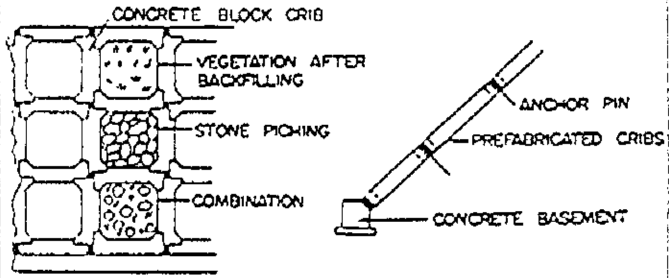
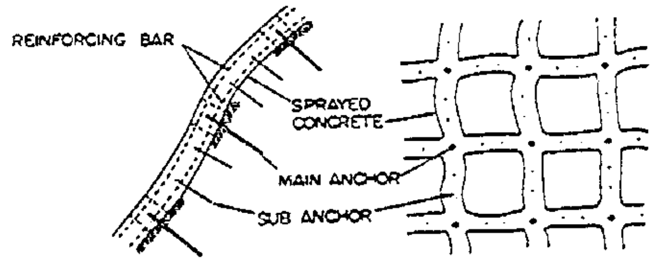
Damage Type	Repair Method	Purpose	Application	Sketch
Erosion	Concrete block crib	_To prevent a slope by covering it with a precast concrete block crib.	-Usually applied to a slope surface gentler than 1:1	
	Sprayed concrete crib	To protect a slope by covering it with a crib made by spraying concrete with a gun.	-Applicable to a slope surface steeper than 1:1. -Applicable to an undulated surface	

Table 4.4.12 Types Repair Work for Drainage Damage

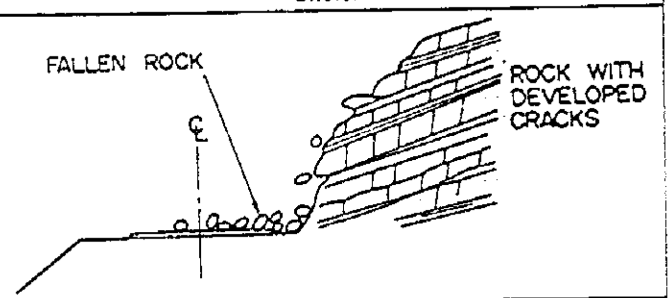
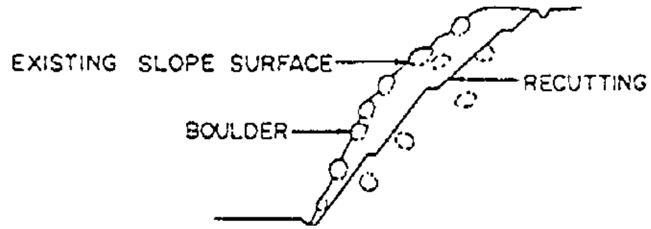
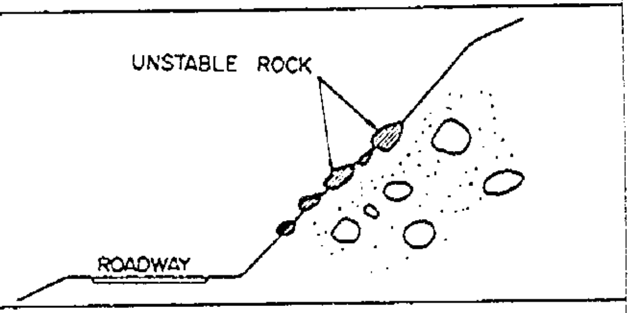
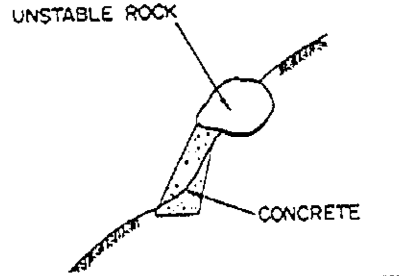
Damage Type	Repair Method	Purpose	Application	Sketch
Rock Avalanche	Removal of fallen rock	-To remove fallen rock from a road surface	-Cut section -Generally applied to urgent work	
	Recutting	-To remove fallen rock from a roads surface.	-Cut section	
	Removal of unstable rock	-To remove unstable rock before they fall down	-Generally applied to huge and medium-size rocks.	
	Foot protection with concrete	-To prevent unstable rock from falling down by supporting it with a concrete structure.	Applied to huge rocks that are accessible.	

Table 4.4.13 Types Repair Work for Drainage Damage

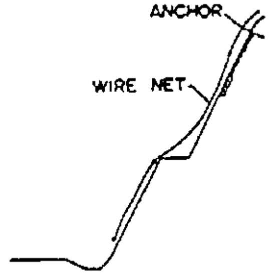
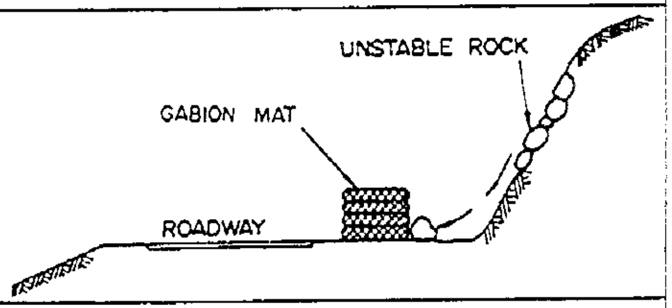
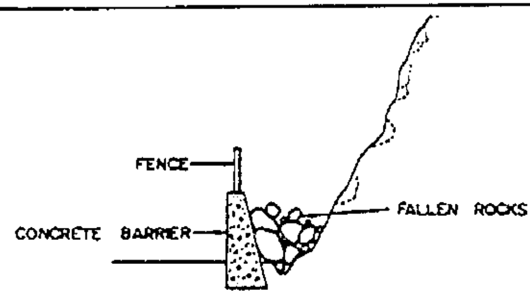
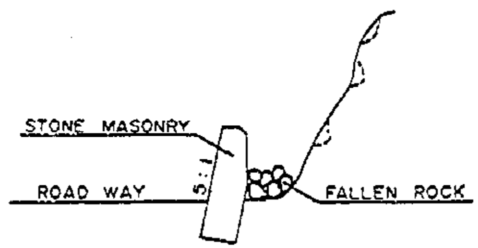
Damage Type	Repair Method	Purpose	Application	Sketch
Rock Avalanche	Prevention net	-To prevent falling rock from reaching a road by providing a catch wire net.	-Applied where there is no roadside space. -Unsuitable for a slope with rocks that easily weathers.	
	Barrier with mat gabion	-To prevent falling rock from reaching a road by providing a gabion barrier.	-Applied where there is sufficient roadside space to contain fallen rock	
	Barrier with concrete wall	-To prevent falling rock from reaching a road by providing a concrete wall	-Applied where there is sufficient roadside space to contain fallen rock	
	Barrier with stone masonry	-To prevent falling rock from reaching a road by providing stone masonry.	-Applied where there is sufficient roadside space to contain fallen rock	

Table 4.4.14 Types Repair Work for Drainage Damage

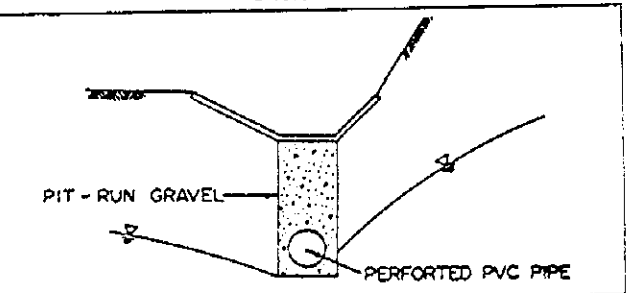
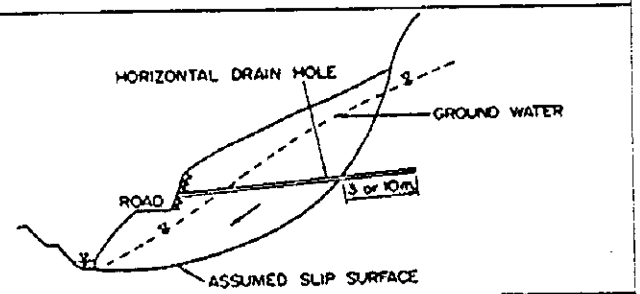
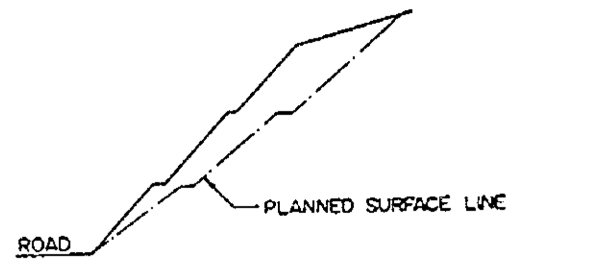
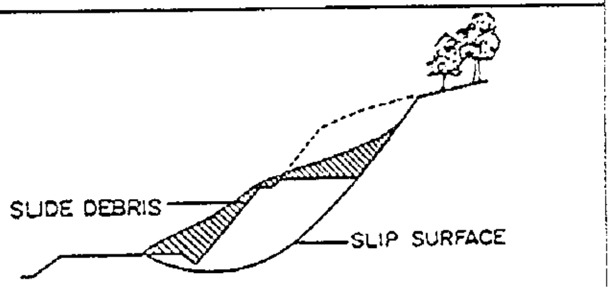
Damage Type	Repair Method	Purpose	Application	Sketch
Landslide	Underground drainage with pits and pipes	-To drain shallows ground water and thus stabilize a slope.	-Usually used in combination with surface drainage. -Generally applied to a slope with much seepage water.	
	Horizontal drain hole	-To stabilize a landslide-prone slope by draining ground water	-Generally applied to a cut or fill slope with high ground water pressure	
	Recutting	To stabilize a slope by cutting it to its optimum gradient.	-Usually applied with drainage work and slope protection work.	
	Removal of head of slide debris	-To reduce the sliding force of slide debris by removing the head portion.	-Generally applied to a cut slope.	

Table 4.4.15 Types Repair Work for Drainage Damage

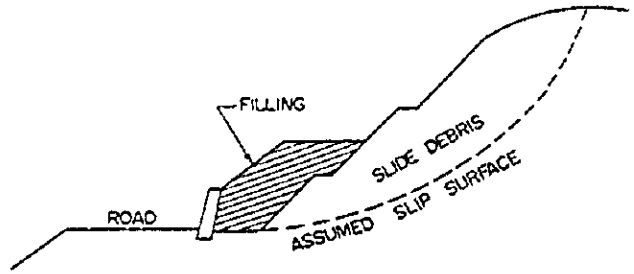
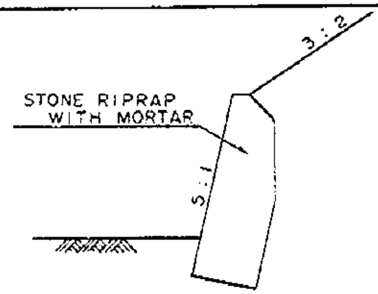
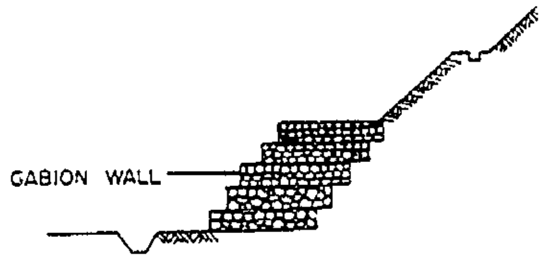
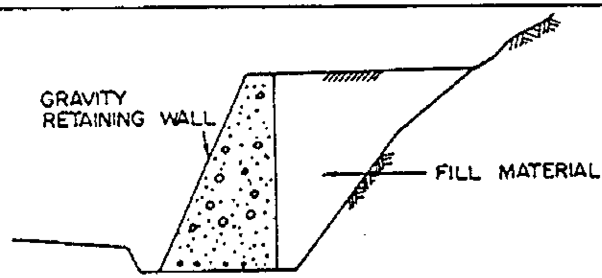
Damage Type	Repair Method	Purpose	Application	Sketch
Landslide	Counterweight fill	-To resist a landslide's force with a counterweight fill at the foot of a slope	-Cut slope, fill slope.	
	Stone riprap wall	-To protect a slope from landslides by resisting earth pressure	-Applicable to a riprap wall less than 5 m high -Generally applied to a cut or fill slope.	
	Gabion wall	-To protect a slope from landslides by resisting earth pressure.	-Mainly applied to the toe of a fill slope with seepage water.	
	Gravity-type retaining wall	-To protect a slope from landslides by resisting earth pressure	-Applicable to a wall less than 3 m high -Generally applied to a cut or fill slope.	

Table 4.4.16 Types Repair Work for Drainage Damage

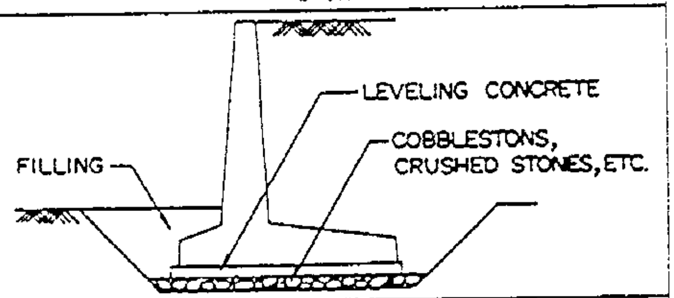
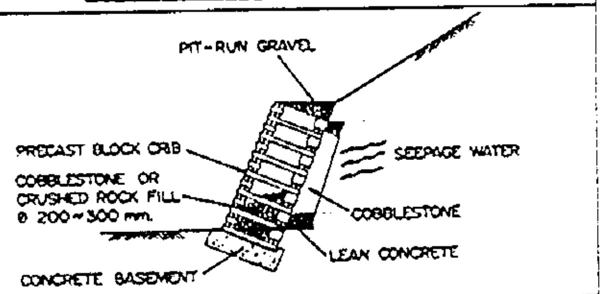
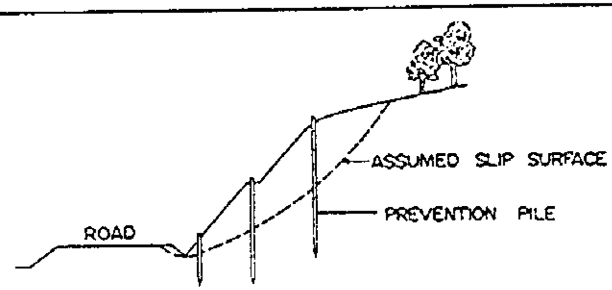
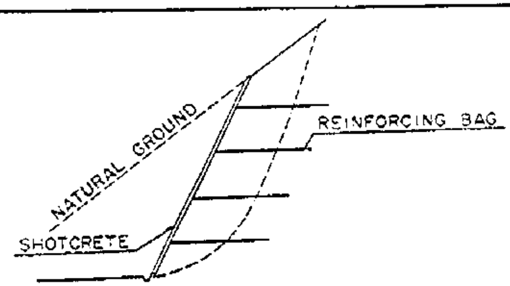
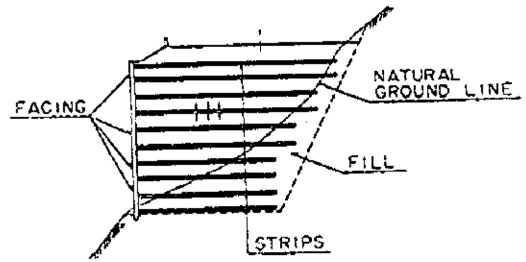
Damage Type	Repair Method	Purpose	Application	Sketch
Landslide	T-shaped retaining wall	-To protect a slope from landslides by resisting earth pressure	-Usually applied to a wall 3 to 10 m high -Generally applied to a cut or fill slope	
	Crib retaining wall	-To protect a slope from landslides by resisting earth pressure with a precast concrete block crib.	-Mainly applied to a cut slope with spring water	
	Prevention piles	-To protect a slope from landslides by resisting earth pressure with piles	-Generally applied to a cut or fill slope	
	Nailing Method	-To be stable the cut slope when not to follow a proper slope gradient because of surrounding restriction.	-Cut slope -Weathered rock, soil	

Table 4.4.17 Types Repair Work for Drainage Damage

Damage Type	Repair Method	Purpose	Application	Sketch
Landslide	Reinforced Earth Wall Method	-To be stable the embankment slope in case of impossible to follow a specified slope gradient because of surrounding restriction.	-Fill slope	

4.5 Selection of Repair Method

4.5.1 General

This section deals with methods for selecting the most appropriate repair method for the particular damage type.

4.5.2 The Selection Process

Flow charts and tables are given to show the selection method and the preferred repair methods in various situations.

(a) Slope Erosion

Fig. 4.5.1 shows the flow chart of selection of repair method.

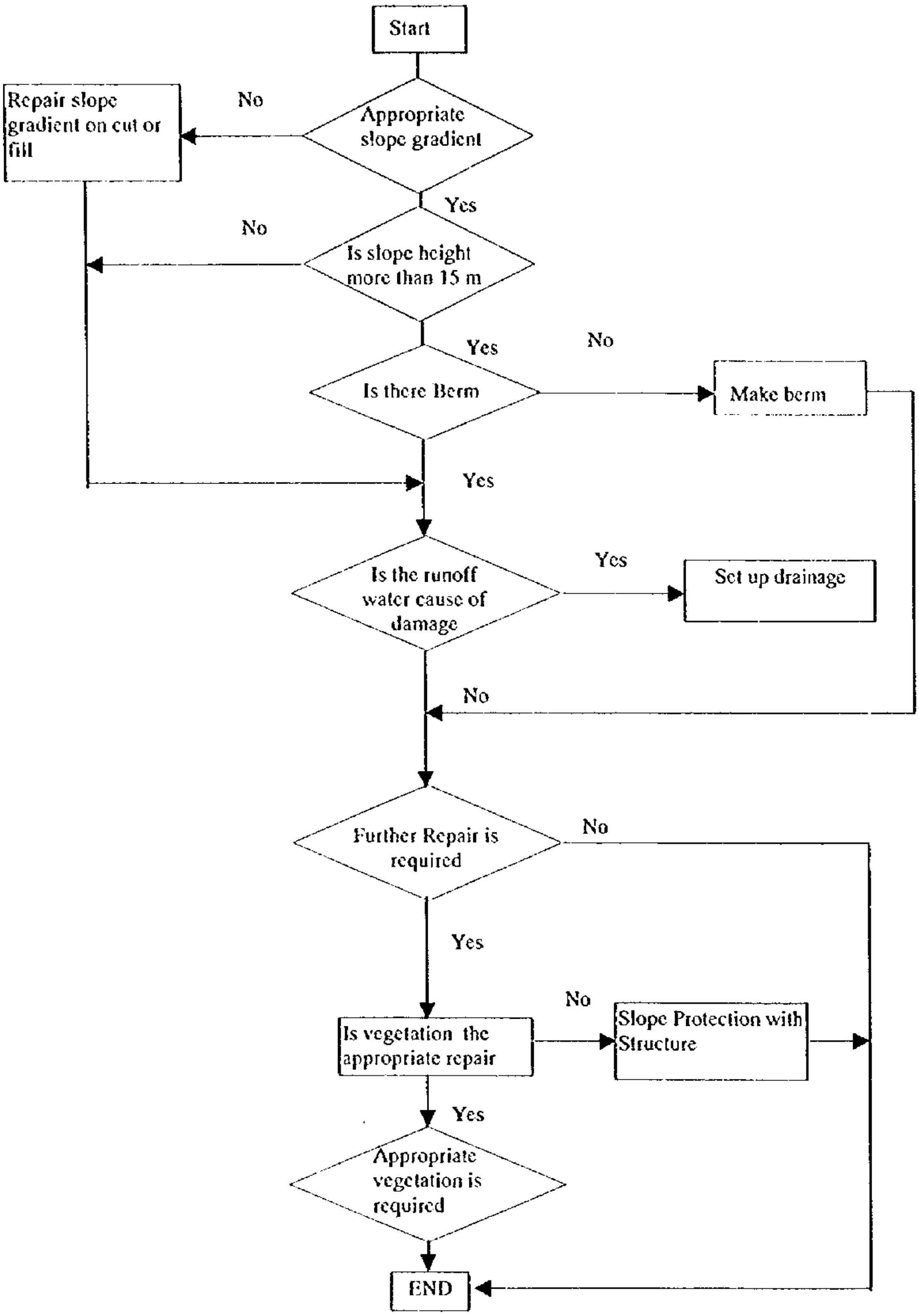


Fig. 4.5.1 Selection of Repair Methods for Erosion

(b) Landslide

Fig. 4.5.2 shows the flow chart for the selection of suitable temporary and permanent repairs for landslides.

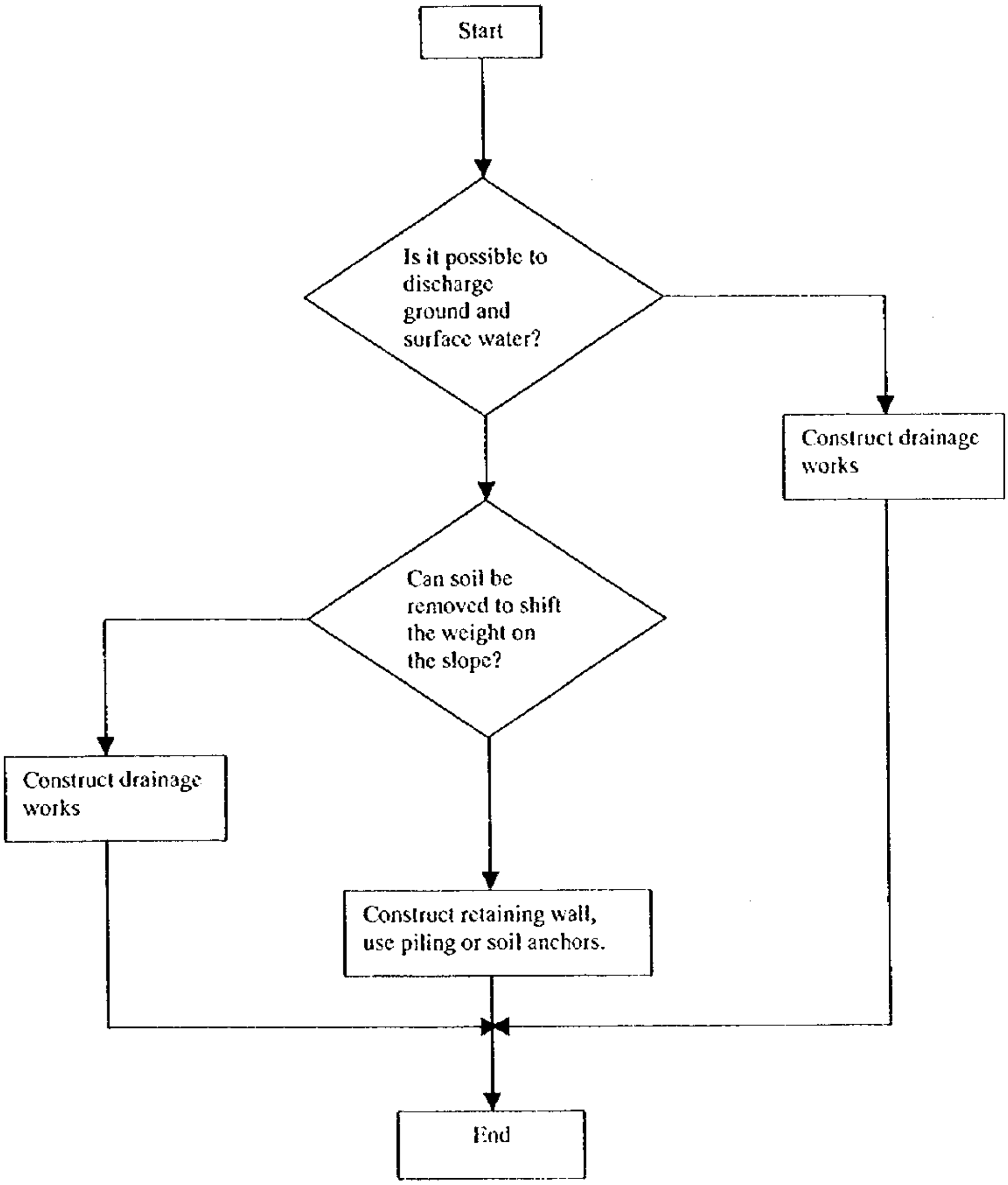


Fig. 4.5.2 Selection of Restoration Measures for Landslides.

4.6 Design and Construction Matters

4.6.1 Slope Erosion

(A) Refilling

(1) Refilling of Cut Slope

(i) Application

The refilling of a cut slope is carried out to eliminate the problem of extensive gully erosion caused by runoff water flowing down the slope or by spring water seeping through to the slope surface.

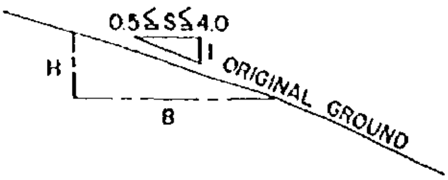
(ii) Materials

Soil, soil cement, gabion wall, stone masonry

(iii) Design and Construction Summary

(a) Rock and soil in gullies are first removed and then bench cutting is carried out. In the case of a gully having a steep slope, construction work shall be carried out in accordance with Table 4.6.1. However, if the bench cutting will cause instability in the gully, then such work should not be carried out.

Table 4.6.1 Bench Cutting



(in metres)

S	B	H
0~4.0	2.5	0.5~0.6
4.0~2.0	2.0	0.5~1.0
2.0~0.5	1.0	0.5~2.0

(b) The maximum thickness of a single refill layer should be 20 cm

(c) The standard gradient, berm width, and slope heights between berms of the refilled portion of cut slope are determined by the slope's geology as shown in Table 4.6.2.

Table 4.6.2 (1) Structure of Refilled Cut Slopes Based on Geological Conditions

Soil Type			Height of Cut	Slope Gradient(h:v)
Rock		Hard		0.25 : 1 ~ 0.5 : 1
		Soft		0.33 : 1 ~ 1.0 : 1
Gravel (GW,GP)		Hard	~10m	1.0 : 1
			10m~15m	
		Loose	~10m	1.5 : 1
			10m~15m	
Fine Particle Sand and Gravel(GM)		Hard	~10m	1.5 : 1
			10m~15m	
		Loose	~10m	2.0 : 1
			10m~15m	
Sand(SW,SP)	SW	Hard		1.0 : 1
		Loose		1.5 : 1
	SP	Hard		1.5 : 1
		Loose		2.0 : 1
Fine Grain Soil (ML,CL)		Hard (N=20)	~9m	1.5 : 1
			9m~15m	2.0 : 1
		mid hard (N=10)	~5m	1.5 : 1
			5m~9m	2.0 : 1
			9m~15m	2.0 : 1 ~ 3.5 : 1
		soft (N=5)	~5m	1.5 : 1
			5m~9m	1.5 : 1 ~ 3.0 : 1
Coarse Grained Soil (SM,SC)		hard (N=20)	~7m	1.0 : 1
			7m~15m	1.5 : 1
		mid hard (PI<10, N<10)	~7m	1.5 : 1
			7m~13m	1.5 : 1
			13m~15m	2.5 : 1
		soft (N=5)	~5m	1.5 : 1
			5m~9m	2.0 : 1 ~ 2.5 : 1
			9m~15m	3.0 : 1 ~ 3.5 : 1

Note: Assumes no ground water effects.

Table 4.6.2 (2) Structure of Refilled Fill Slopes Based on Geological Conditions

Embankment Material		Height of Cut	Slope Gradient (h:v)
Rock		10m~20m	1.0 : 1
Gravel - Sand	GW , (GP, GM), SW	5m~15m	1.5 : 1
	GC	5m~15m	2.0 : 1
Sand	SP	~10m	2.0 : 1
Silty, Clayey Sand	SM, SC	~15m	2.0 : 1
Clay	ML, CL	~9m 10m~15m	2.0 : 1 1.5 : 1
		9m~13m	2.5 : 1
	MH-CH	~10m	2.0 : 1
		11m~13m	2.5 : 1

Note: Assumed no ground water effect.

(d) From past experience, the height of a cut slope having berms should be less than 15 m. When this condition cannot be satisfied, the fill slope materials, berm width, slope gradient between berms, structural work, etc. to be applied should be reconsidered from the design stage.

(e) When filling a gully, working space is limited and so compaction equipment should consist of tampers and rammers as shown in Fig 4.6.1

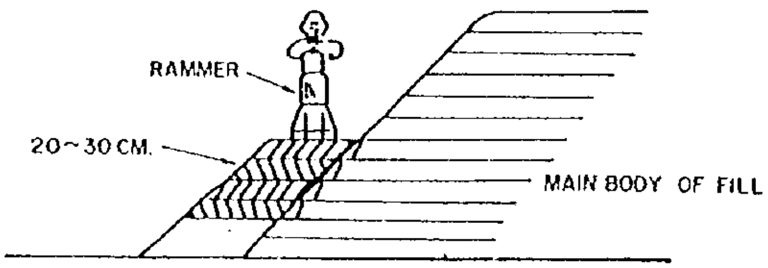


Fig. 4.6.1 Slope Compaction with Tamper or Rammer

(f) When refilling is difficult to carry out due to the slope gradient, which is predetermined by the composition of the soil, then gabion wall or stone masonry will be placed on the slope's surface after refilling to prevent the refilling material from moving (see Fig. 4.6.2).

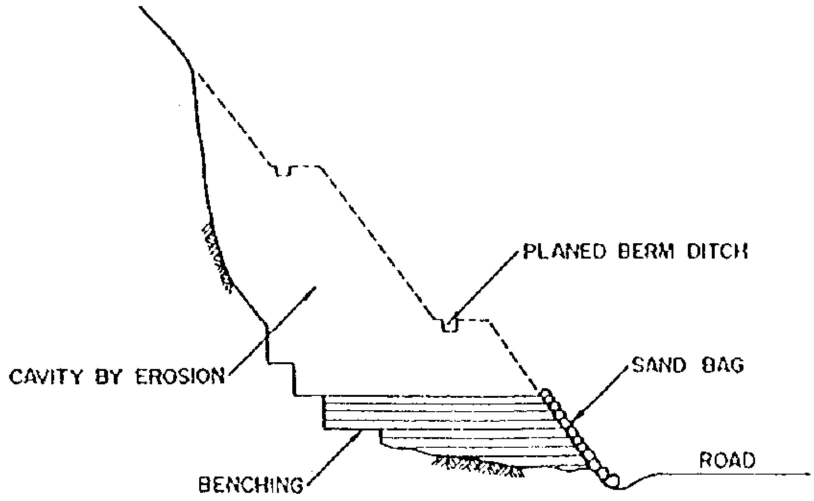


Fig. 4.6.2 Protection of Refilling Material with Stone Masonry

(g) To protect a refilled cut slope from erosion and weathering, the condition of the slope should be confirmed at the design stage and a countermeasure such as surface drainage, subsurface drainage, vegetation, or structural work should be selected.

(2) Refilling of Fill Slope

(i) Application

The refilling of a fill slope is carried out to restore the portion of the slope that has collapsed due to scouring.

(ii) Materials

Soil, soil cement, and sand.

(iii) Design and Construction Summary

(a) Benches shall be cut into the original slope to form a key between the new and the old slope works. When the collapsed portion of a slope has a steep gradient, bench cutting will be carried out in accordance with Table 4.6.1.

(b) The maximum thickness of a single refill layer will be 20 cm

(c) The standard gradient, berm width, and the height between berms of the refilled portion of a fill slope are determined by the slope's geology as shown in Table 4.6.2.

(d) Based on past experience, fill slopes with berms should be less than 30 m in height. If this condition can not be satisfied, the fill slope materials, berm width, slope gradients between berms and structural work to be used should be reconsidered from the design stage

(e) In the case of refilling a fill slope, large-scale compaction equipment, such as that shown in Fig. 4.6.3 may be used. However, where space is restricted, it is recommended that smaller equipment be used.

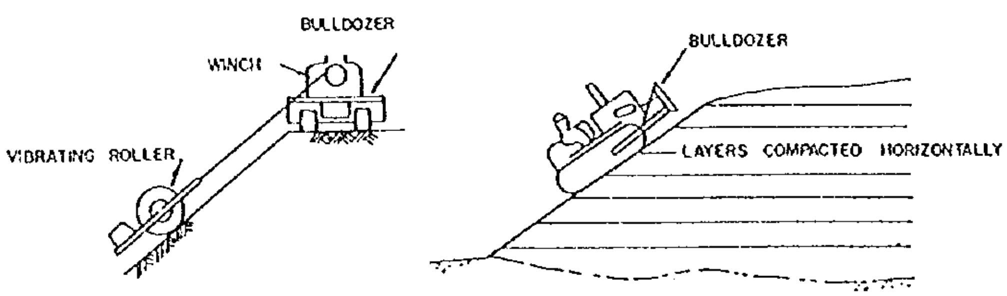


Fig. 4.6.3 Slope Compaction with Vibrating Roller and Bulldozer

(f) When refilling is being executed on sloping ground which contains groundwater, drainage layers will be included in the construction of each berm as shown in Fig. 4.6.4.

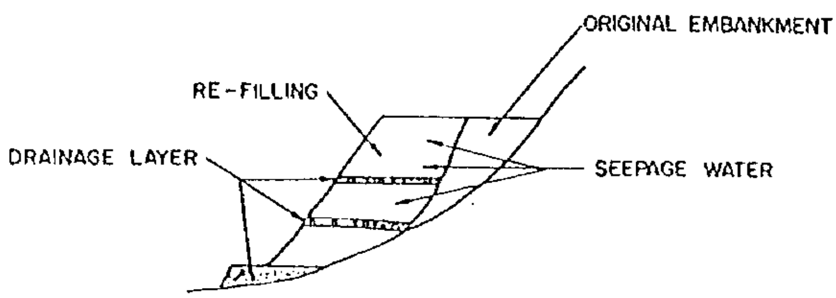


Fig. 4.6.4 Berm Drainage Layer for Refilling a Fill Slope

(g) To protect a refilled fill slope from erosion and weathering, the conditions of the slope should be confirmed at the design stage and a countermeasure such as surface drainage, subsurface drainage, vegetation, or structural work should be selected.

(B) Recutting

(1) Application

Recutting is carried out to stabilize an unstable cut slope. Instability can be mainly attribute to the following factors:

- advanced slope erosion
- landslides
- the existence of unstable rock on a steep slope

(2) Design and Construction Summary

(i) When recutting is being executed on a stable cut slope, refer to Table 4.6.3 in Section 4.6.1 to decide on the berm pitch, berm width and the slope gradient between berms.

(ii) Recutting should only be done if the erosion is so advanced that the application of a drainage system, vegetation or structural work is impossible. However, when there are restraints on right of way, cribwork should be used to ensure a stable slope (see Fig. 4.6.5). In this case, the cost effectiveness of construction work should be considered from the design stage. Furthermore, drainage and vegetation work should be carried out to prevent erosion.

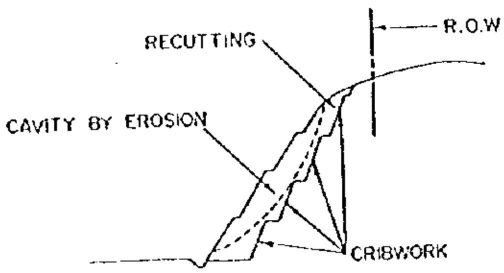


Fig. 4.6.5 Cribwork

(iii) For landslides, a new cut slope should be cut with a gradient gentler than that of the original cut slope. However, even if the cut slope gradient is gentler overall, it is still possible that a landslide will reoccur as a result of the recutting work by removing too much material from the foot of the original landslide (see Fig. 4.6.6). For this reason, it is very important to remove the debris from the head of a landslide when recutting a cut slope with a gentler gradient

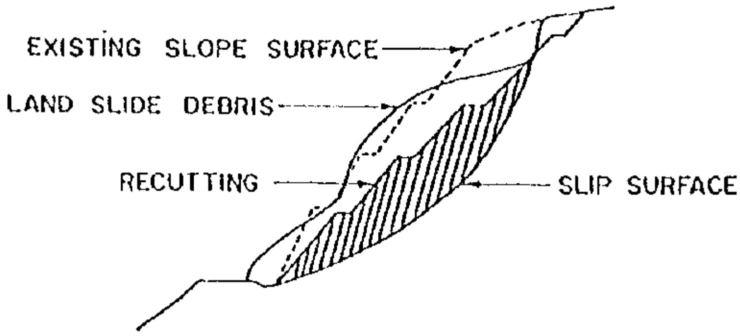


Fig. 4.6.6 Trimming of Landslide Debris

(iv) When recutting in unstable rock on steep ground, it is very important to decide on a stable slope gradient by considering the hardness of the rock(see Fig. 4.6.7). In addition, a survey should be carried out to determine the cause of the instability. A comparison of the cost effectiveness and technical feasibility of recutting compared to other construction methods should also be carried out to select the most suitable method.

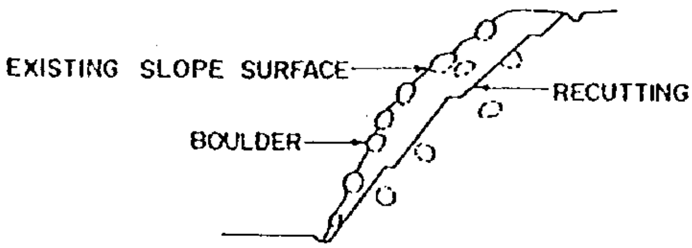


Fig. 4.6.7 Recutting on Unstable Rock Slope

(C) Slope Surface Drainage

(1) Crest Ditch

(i) To prevent rainwater or spring water at the top of a cut slope from seeping into the slope, a crest ditch is constructed at the top of the slope. When constructing the crest ditch, it should have a large capacity as crest ditches are often difficult to reach and therefore difficult to maintain (see Fig. 4.6.8). The discharge of the water in a crest ditch must be carefully considered.

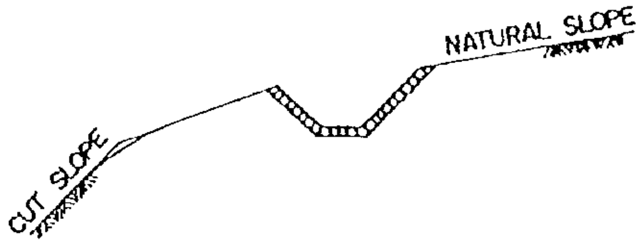


Fig. 4.6.8 Crest Ditch

(ii) Construction material such as stone riprap should be used.

(iii) The crest ditch at the top of a cut slope should be located 1m to 3 m away from where the slope rounding was carried out.

(2) Berm Ditch

(i) To prevent erosion by rainfall or spring water flowing down a cut or fill slope, berm ditches are constructed on each berm of the slope.

(ii) The longitudinal gradient of a berm ditch is usually the same as that of the adjacent road, but it is desirable to achieve 0.3% to 5%. As for the latitudinal gradient, as shown in Fig. 4.6.9 it is 1:15 going in the opposite direction of a slope.

(iii) For a berm ditch, U-shaped reinforced concrete is used. The function of a berm ditch is to connect crest and vertical ditches to assist in the disposal of rainwater or spring water. It also prevents excessive wash down from surface water on large slopes.

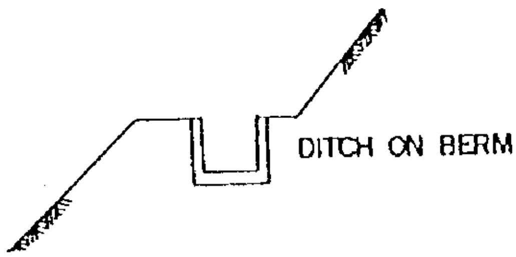


Fig. 4.6.9 Berm Ditch

(iv) As shown in Fig. 4.6.10 to assist the flow of rainwater on a slope with hard rock, the transverse gradient on the berm is set to 5% in the direction of the slope.

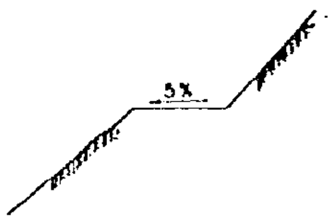


Fig. 4.6.10 Gradient on Berm where the Slope is in Hard Rock

(3) Toe Ditch

(i) A toe ditch is constructed to prevent the scouring of the toe of the slope by rainwater and the intrusion of rainwater onto a road pavement. Fig. 4.6.11 shows a toe ditch for a cut slope. For fill slopes, the cross section is determined by the size of the fill slope.

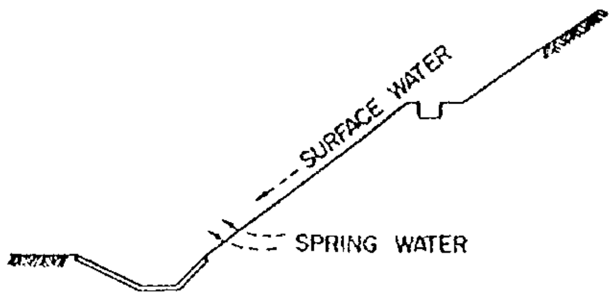


Fig. 4.6.11 Toe Ditch

(4) Gutter

(i) A gutter, as shown in Fig. 4.6.12 is constructed at the shoulders of a road to to collect and control the water from the road surface. Gutters also prevent water from flowing down the surface of a fill slope causing washing out.

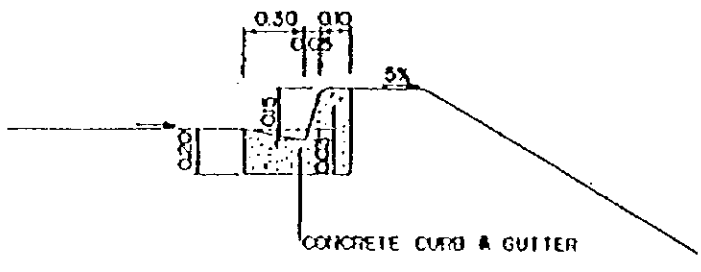


Fig. 4.6.12 Gutter

(5) Vertical Ditch

(i) Vertical ditches are constructed to channel water from the crest or berm ditches of a cut slope to the toe ditch, taking into consideration slope gradient. Vertical ditches are also constructed if the capacity of the berm ditches is insufficient or if the topography warrants it. However, even if the capacity of crest ditches, berm ditches and gutters is sufficient, if the length of berm ditch is more than 100 m, then vertical ditches are constructed every 100m or less, as shown in Fig. 4.6.13 U-shaped reinforced concrete or stone riprap should be used.

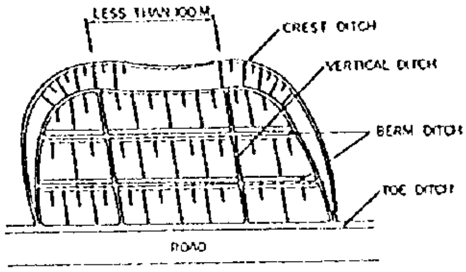


Fig. 4.6.13 Vertical Ditch

(6) Surface Drainage

(i) Surface drainage is constructed to prevent the reoccurrence of a landslide by preventing the seepage of rainwater into previous landslide debris. This is done by collecting the rainwater in the area of a landslide and disposing of it outside that area. Wherever possible the surface water should be prevented from reaching the landslide area by using suitable cut off drainage ditches.

(ii) Surface drainage is made up of numerous horizontal and vertical drains that cut up and down the entire length of the landslide debris.

(iii) Stone riprap or concrete is generally used for such drainage.

(iv) For horizontal drains, the interval depends on the topography but it is recommended to have one every 10m. For vertical drains, the interval should be determined by calculation of the amount of rainfall and allowing a 20% safety margin. The recommended interval for vertical drains is 100m.

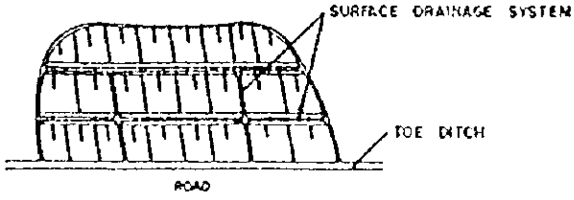


Fig. 4.6.14 Surface Drainage System

(D) Vegetation Work

(1) Purpose

The purpose of vegetation work is to protect the slope surface from erosion by reducing the velocity of runoff water and to enhance the environmental quality of the area.

(2) Application

(i) Depending on the condition of a slope, the appropriate type of vegetation work is chosen. However, in the five situations below, vegetation work can not be applied.

- Where neither sunlight or rain can reach an area because of the adjacent structures such as bridges and viaducts.
- Where the acidity of soil is very strong.
- Where the moisture of soil is extremely limited.
- Where the soil is extremely hard.
- Where a slope is extremely steep (0.6:1 or less)

(ii) In order to select the appropriate type of vegetation work, a slope survey should be carried out considering the following items:-

(a) Slope gradient

When the slope gradient is less than 1.2:1 in soft rock or clay, or less than 1.5:1 in sand or sandy soil, it is possible to prevent erosion due to runoff or the collapsing of top soil by vegetation work only.

However, if the gradients for these soil types become steeper, it is difficult to ensure slope stability using vegetation only. Therefore, measures such as cribwork and wicker work must also be carried out.

(b) Slope rock, soil and soil hardness

Using the results of a slope survey, the types of vegetation work that are applicable for the slope can be determined by referring to Table 4.6.

Table 4.6.3 Applicable Vegetation Work by Soil Type

Type of Work	CUT SLOPE						FILL SLOPE	
	Sand	Sandy soil, sandy soil with gravel or rock		Clayey soil, clayey soil with gravel or rock, clay		Hard clay, weathered soft rock, Mudstone	Sandy soil, clayey soil with gravel or rock Mudstone	Sand
		Hardness of Soil		Hardness of Soil				
		□27mm	□27mm	□27mm	□27mm			
Block Sodding	A	A		A			A	A
Stripe Sodding							A	
Seed Packet Work			A		A	A		
Pick-Hole Seedling Work			A		A	A		
Seed Spraying with a Pump	B	B		B			A	C
Seed-mix Spraying with a gun	A	A	A	A	A	A		A

A: Suitable
B: Suitable for fertile soil
C: Suitable for top soil

(c) Soil acidity

When soil is highly acidic (pH ≤ 4), there are usually adverse effects on vegetation growth. Therefore the pH of soil should be measured and action taken when it is found to be acidic.

When material used for a fill slope is highly acidic in nature, the alkaline carbonic acidic calcium is mixed with the material to neutralize the acidity.

For cut slopes, it is generally difficult to reduce the acidity of the soil. However, there is the method where new soil is laid, which is mixed with carbonic acidic calcium and seed packet and pick-hole seedling work is carried out.

When there is spring water on either a fill slope or cut slope, a thick spray of seed-mix is effective. The seeds are mixed with binder to prevent them from being easily washed away. Cribwork can also be an effective measure that in both soil and rock..

(3) Characteristics and Materials by Vegetation Work Type

The characteristics and materials for the different kinds of vegetation work are described below.

(a) Block Sodding

Outline : As shown in Fig. 4.6.17 blocks of sods are laid tightly next to one another on the surface of the slope and anchored down with pins, starting from the top and going down to the toe of the slope. Sod blocks should be placed with a gap between adjacent blocks and a mixture of Fertilizer and soil is then lightly scattered over the sods filling in the gaps to encourage growth.

Characteristics: Applicable to erosion-prone soil.

Materials: Blocks of sod, sodding anchor pins, fertilizer.

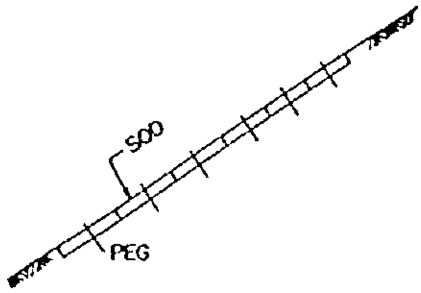


Fig. 4.6.15 Block Sodding

(b) Stripe Sodding

Outline: As shown in Fig. 4.6.16 rectangular sod blocks are placed tightly next to each other to form a row starting from the toe of a slope. After a row of sod blocks has been laid, two-thirds of each block is covered with 30 cm of top soil and a new row begun. This results in what is called stripe sodding.

Characteristics: Stripe sodding is used for fill slopes.

Materials: Blocks of sod, top soil.

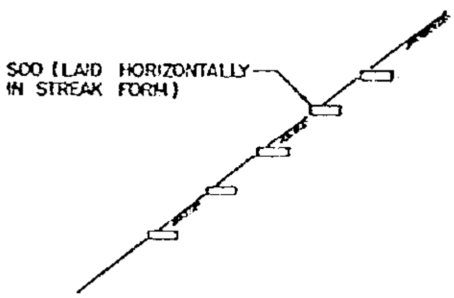


Fig. 4.6.16 Stripe Sodding

(c) Seed Packet Work

Outline: As shown in Fig. 4.6.17 holes are dug at regular intervals to form rows and a packet containing fertilizer, soil, seed and cut straw is put into each hole and fastened with an anchor pin. The distance between each hole is approximately 50 cm and about 6 packets per square metre are used.

Characteristics: Seed packet work is applied to cut slopes. As packets are used, the seed, fertilizer, and soil are not easily washed away. It is also possible to carry out seed packet work on relatively steep slopes.

Material: Polyethylene bags, seed, fertilizer, soil, anchor pins

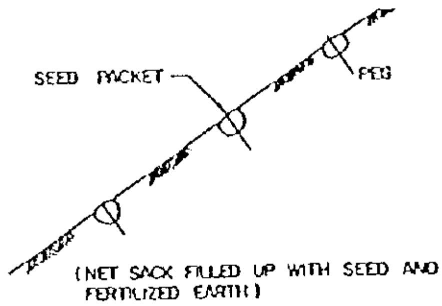


Fig. 4.6.17 Seed Packet Work

(d) Pick-Hole Seedling Work

Outline: As shown in Fig. 4.6.18 a hole is dug, some fertilizer is put in the hole and a tree seedling is inserted together with a supporting rod.

Characteristics: Pick-hole seedling work is carried out on cut slopes, to protect the environment and improve the landscape. Other types of vegetation work would be carried out where seedlings are not planted.

Materials: Tree seedlings, fertilizer, support rods

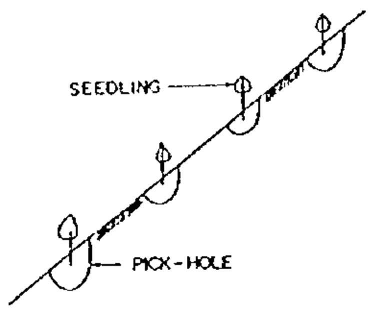


Fig. 4.6.18 Pick-hole Seedling Work

(e) Seed Spraying

Outline: As shown in Fig. 4.6.19 seed, fibre and binder is mixed with water and sprayed over the slope using a pump.

Characteristics: Seed spraying is applied to cut and fill slopes with soft soil. This method requires a vehicle or alternative spraying equipment and so is only suitable where vehicle access is available.

Materials: Seed, high quality fertilizer, fibre (pulp, woody cellulose, etc.) binder (polyvinyl alcohol, polyvinyl acetate, etc.)

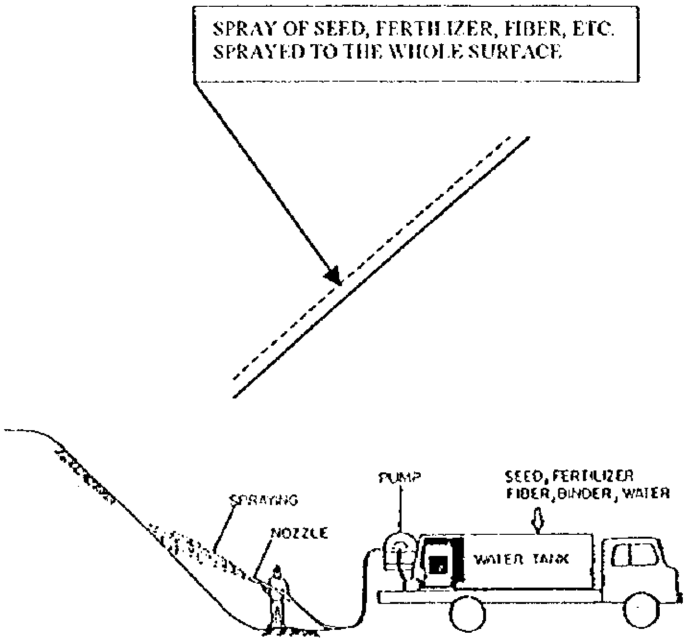


Fig. 4.6.19 Seed Spraying

(f) Hydroseeding

Outline: As shown in Fig. 4.6.20 a mixture of seed, fertilizer, soil, and water is sprayed thickly over a slope with a mortar gun. An anti-erosion agent is then sprayed over the slope.

For a slope with a soil surface, the mixture is sprayed until there is a 1 to 2 cm layer. For a soft rock surface, a net is spread tightly over the rock surface to retain the mixture which is sprayed on top of the net until there is 2 to 3 cm layer. Where the surface is hard rock, this method should not generally be used. However, when for environmental reasons it is necessary that this process be carried out, the mixture is sprayed over a tightly spread net until there is a layer of 5 cm or more. Note that in this case the soil of the original mixture is replaced with binder to ensure that the mixture does not fall off the rock.

Characteristics: Hydroseeding is applied to cut slopes and uses a seed, fertilizer and soil mixture having a high soil content. As this method uses a pump and pipe system it can be used on higher slopes provided the equipment can reach, as well as on slopes with gravelly soil.

Materials: Seed, high quality fertilizer, soil (with less than 5% of its contents made up of gravel 6mm or less in diameter and mixed with compost or something similar in nature), anti-erosion agent (asphalt emulsion), binder (Portland cement, high polymer plastics), water and netting.

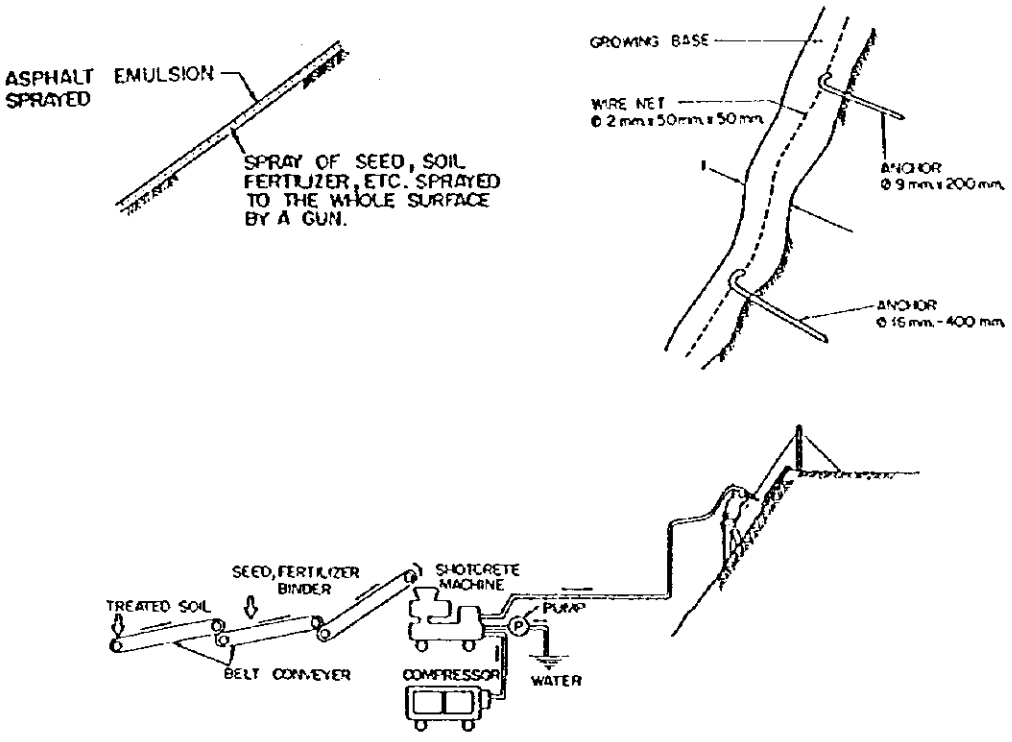


Fig. 4.6.20 Hydroseeding

(E) Cribwork

There are three types of cribwork in general use:-

- precast concrete
- cast-in place
- sprayed concrete

The following sections cover the application, materials and design work for these three types of cribwork.

(1) Precast Concrete Cribwork

(i) Application

Precast concrete cribwork can be used on slopes with a gradient flatter than 1.0:1 and is effective in the following situations:-

(a) a cut slope having spring water

(b) where there is advanced erosion and weathering due to runoff from rainwater

(c) where the soil is not conducive for vegetation but vegetation is required by the surrounding conditions

(d) where vegetation work has been carried out but there is still the fear of the slope collapsing

(ii) Materials

Precast concrete cribwork blocks, concrete blocks for structures and foam.

(iii) Design

(a) The span of a crib is to be 1m. The dimensions of crib members are 15cm x 15cm or 15cm x 20cm.

(b) To prevent the cribs from sliding, the spaces between the cribs are filled with mortar after 50- 100cm long anchor pins are inserted into the ground and steel wires extruding from the crib ends are tied together tightly (see Fig. 4.6.21).

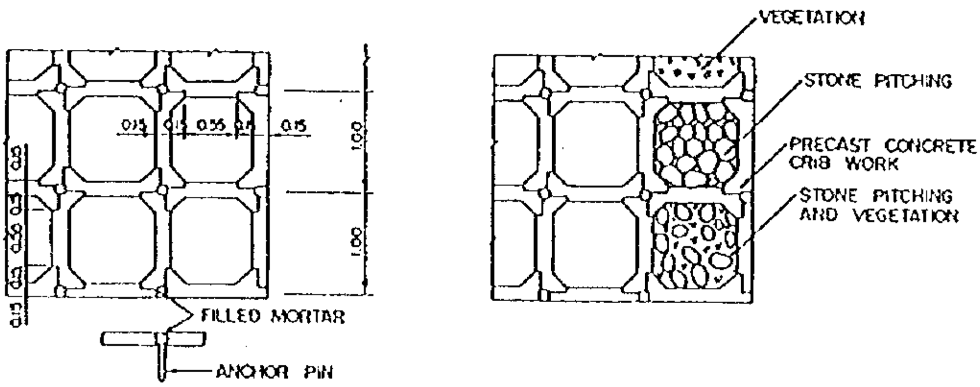


Fig. 4.6.21 Sample of Precast Concrete Cribwork

(c) New soil, rich in nutrients, is placed inside the cribs to ensure that the new vegetation takes strong hold. In certain conditions, stone pitching or concrete block pitching should be used (see Fig. 4.6.22):-

- the gradient of the slope is steeper than 1.2:1, and
- there is a considerable amount of seepage

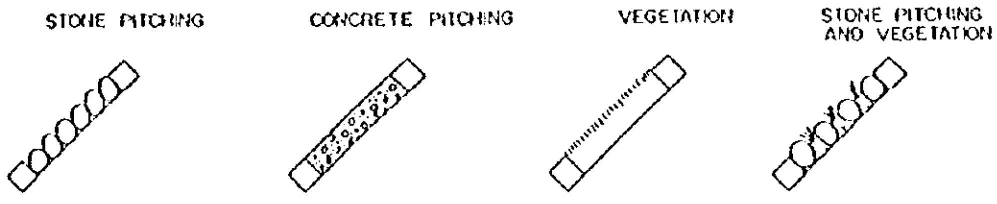


Fig. 4.6.22 Examples of Work inside the Crib

(d) Where there is spring water on a slope, either a branch-like underground drainage system or water-absorption mats are put into place to prevent the soil on the slope from being washed away before precast concrete cribwork is completed.

(e) It is necessary to consider at the design stage the size and grading of the stones used to fill the cribwork the problem of weathering and small stones being washed away.

(2) Cast-in-place Concrete Cribwork

(i) Application

Cast-in-place concrete cribwork is used on slopes with a gradient flatter than 1.0:1 and is effective in the following situations:-

(a) when the future stability of the slope is questionable (e.g. weathered rock slope with spring water),

(b) when there is a danger that precast concrete cribwork would collapse, and

(c) when unstable rock can not be anchored to bedrock by shotcrete because of joints and cracks in the bedrock

(ii) Materials:

Concrete for structures, foam and reinforcing bar.

(iii)Design:

(a) Cribs will made up of cast-in-place reinforced concrete.

(b) The dimensions of crib members will be from 0.3m x 0.3m to 0.6m x 0.6m with a span of 5 to 10 times that size.

(c) The slope gradient will depend on the hardness of the soil, and anchor bars will be used at the intersections of cribs to prevent cribs from sliding (see Fig. 4.6.23).

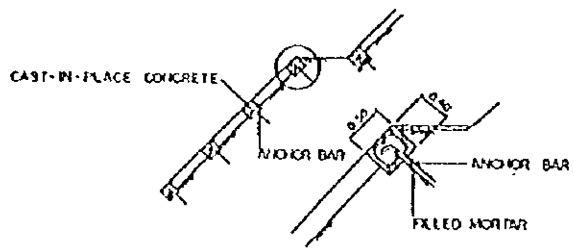


Fig. 4.6.23 Cast-in-place Concrete Cribwork

(d) Depending on the condition of the slope, stone pitching, concrete pitching, stone riprap with mortar or vegetation work may be used to protect the slope.

(3) Sprayed Concrete Cribwork

(i) Application

(a) Sprayed concrete cribwork is used in the same situations as cast-in-place concrete cribwork but it is easier to apply and can be used on rough slopes. In addition, this type of cribwork can be made to fit the shape of a slope.

(b) It is applicable to an undulating slope.

(c) Sprayed concrete cribwork is highly useful in reinforcing prefabricated light-weight cribs.

(ii)Materials

Concrete used for spraying, light-weight steel net crib, concrete sprayer.

(iii)Design

(a) Cribs will be made on site of reinforced concrete via shotcrete.

(b) The members of crib will be from 0.15m x 0.15m to 0.5m x 0.5m , with span width being 5 to 10 times that size.

(c) For crib intersections and members, anchor bars will be applied to prevent cribs from sliding (see Fig. 4.6.24).

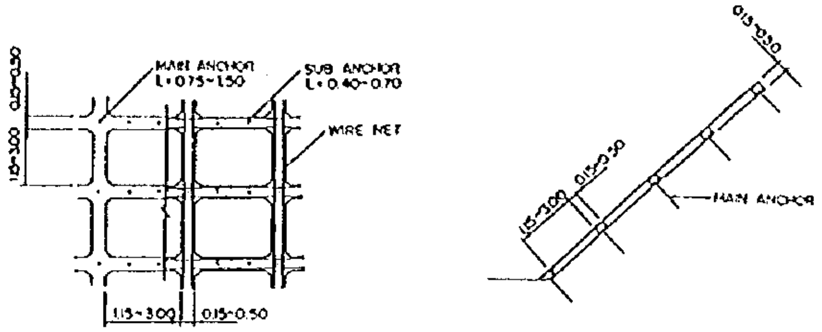


Fig. 4.6.24 Sprayed Concrete Cribwork

(d) Depending on the condition of the slope, stone pitching, concrete pitching, shotcrete, stone riprap with mortar or vegetation work will be applied to protect the slope.

(e) The concrete mixture is the same as for shotcrete. The weight ratio of cement, sand and gravel is 1:3:2 and the water cement ratio is 45%.

(F) Shotcrete

(1) Application

(a) For slopes with no spring water and rock that weathers easily

(b) For slopes with weathered rock which is about to fall

(c) For slopes with cracked and jointed rock

(d) For slopes having an overhang

(e) For newly constructed, stable cut slopes where there is a danger that seepage will cause instability in the slope surface.

(f) For slopes where topsoil and vegetation work are unsuitable.

(2) Materials:

Spray-type concrete, diamond-shaped wire mesh (2mm x 50mm), anchor pins (16mm x 40 cm), PVC pipe (50mm) and a concrete spray gun.

(3) Design:

(a) Generally, a concrete layer of 10 cm is sprayed on the slope. Where the surface of the slope is rock and extremely bumpy, the layer thickness should be increased to 15cm.

(b) To prevent cracking in the sprayed concrete after it has dried and to prevent the concrete from peeling off, diamond-shaped steel wire netting (2mm x 50mm) shall be used . Where necessary, steel bars can be used instead.

(c) Before spraying concrete, the steel wire netting is attached to the slope with anchor pins (16mm x 40cm) at intervals of 1 or more square metre.

(d) To construct weep holes, 50mm diameter PVC pipe is used and a weep holes are located every 2 to 4 square metres.

(e) The concrete should have a weight ratio of 1:3:2 for cement, sand and gravel, with a water cement ratio of 45%.

(f) Where the area of operation is large and the slope relatively flat, concrete shrinkage and cracking may occur. To prevent the spread of cracking, a vertical expansion joint is placed every 20 metres as shown in Fig. 4.6.25. Where the rock surface is very bumpy, the number of expansion joints can be reduced as temperature-induced stress will be partially absorbed.

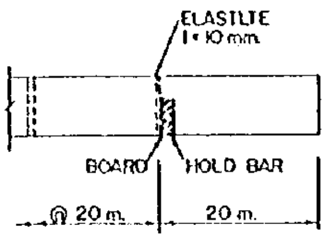


Fig. 4.6.25 Vertical Expansion Joint

To prevent seepage after covering the surface of the slope with shotcrete, either the partial shotcrete method (see Fig. 4.6.26 (1)), or the complete shotcrete method (which includes the use of a crest ditch) (see Fig. 4.6.26 (2)) can be used.

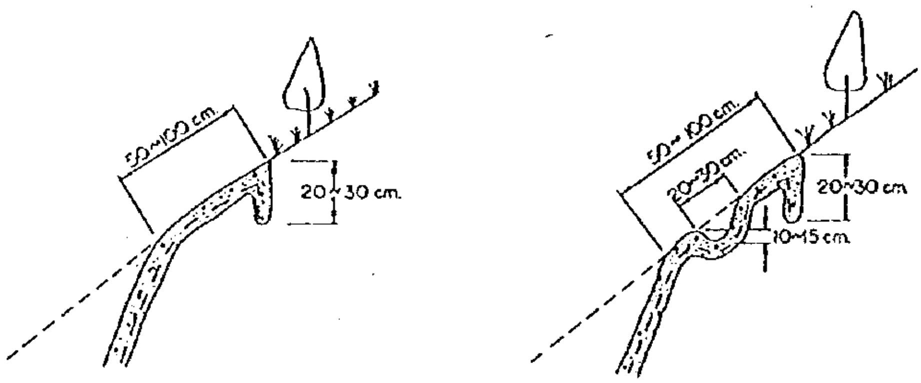


Fig. 4.6.26 (1) Partial Shotcreting Method

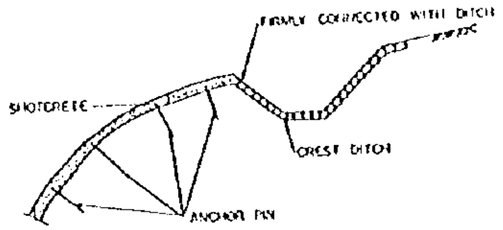


Fig. 4.6.26 (2) Complete Shotcreting Method

(4) Construction

(a) The surface life of the shotcrete is highly influenced by the weather at the time of construction. It is important that the timing of shotcreting be taken into consideration and shotcreting should not carried out when any one of the following conditions exists:-

- strong wind that will blow away the shotcrete
- strong rain that will wash away shotcrete
- strong wind during fine weather causing extreme dryness

(b) Pressurized water or air should be used to remove unstable rock and dust. Wire netting is then attached to the surface of the slope and the shotcreting can be sprayed onto the netting..

(c) Spraying of shotcrete should be a continuous process until a vertical expansion joint is reached.

4.6.2 Rockfalls

(A) Removal of Unstable Rock

The purpose of this method is to remove rock that is in danger of falling. Two typical methods are shown below.

1. Use of manpower

   Loose rock that is inaccessible to large construction machinery is broken off with a breaker and falls down to the road where it can be collected and removed. As shown in Fig. 4.6.27, this work is done in high places, requires traffic restrictions for safety reasons and often requires a lot of time.

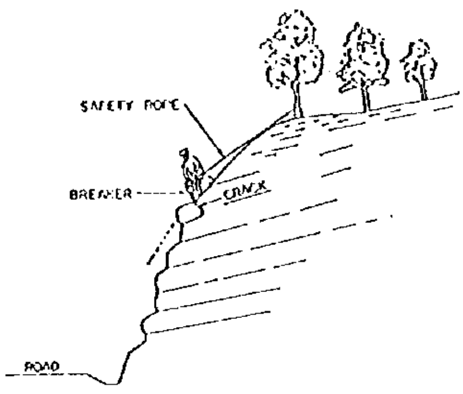


Fig. 4.6.27 Removal of Loose Rock using Manpower

2. Use of construction machinery

   Loose rock which is accessible to large construction machinery is removed from the slope using a back hoe (see Fig. 4.6.28). This work can usually be completed in a short amount of time.

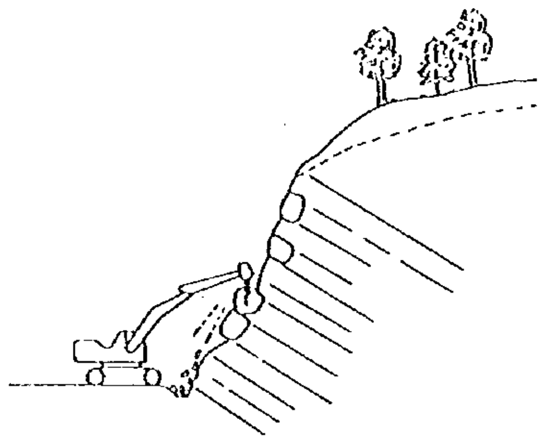


Fig. 4.6.28 Removal of Loose Rock using a Back Hoe

When selecting a method to remove unstable rock, it should be based on surveys of the places experiencing rockfalls and the most suitable method for each location chosen.

(B). Rockfall Prevention Net

(1) Application

1. A rockfall prevention net is used on cut slopes where scouring, weathering or erosion by rainfall is increasing the probability of a rockfall occurring.

2. In addition to trying to prevent rockfalls, it is also important to prevent rocks from falling onto the road and to guide them to the toe of the slope.

3. To prevent rocks from falling onto a road, there are two types of rockfall prevention nets (see Fig. 4.6.29) :-

   (a) a cover-type rockfall prevention net (which is made of wire netting, wires, anchor concrete blocks and anchor bolts) that prevents rock from falling by trapping them between the cut slope and the wire netting

   (b) a pocket-type rockfall prevention net (which is made of hanger wire, netting, steel supports and concrete anchor blocks) that catches falling rock in a pocket-like area by absorbing the force of the falling rock through the wire netting.

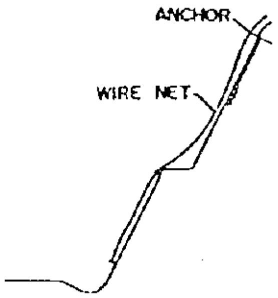


Fig. 4.6.29 Rockfall Prevention Nets

(2) Materials:

1. Wire net (wire diameter: 2.6 mm – 4.0mm, netting grid: 50mm x 50mm)

2. Wire 3 x 7 galvanized and stranded with petroleum grease: main wire with maximum tensile strength of 12 000 kg (diameter: 16mm), sub-wire with a maximum tensile strength of 7 000 kg (diameter 12mm)

3. Anchor bolts 1.5 m in length (diameter: 25 mm)

4. Concrete anchor blocks (1m wide, 1.2m deep, 2.0m long in direction of rope)

5. H-shaped steel support (pocket-type rock prevention net only)

(C) Rockfall Prevention Barrier

There are basically three types of rockfall prevention barriers: fence, wall and combination of fence and wall. Wall barriers can be earth fill, mat-gabion or concrete whereas fences are almost always made of concrete.

(1) Fence

(i) Application

A fence is effective in stopping small rocks from reaching the surface of the road. There are two kinds of fence; a wire mesh fence and a H-shaped steel fence shown below in Fig. 4.6.30 and Fig. 4.6.31 respectively.

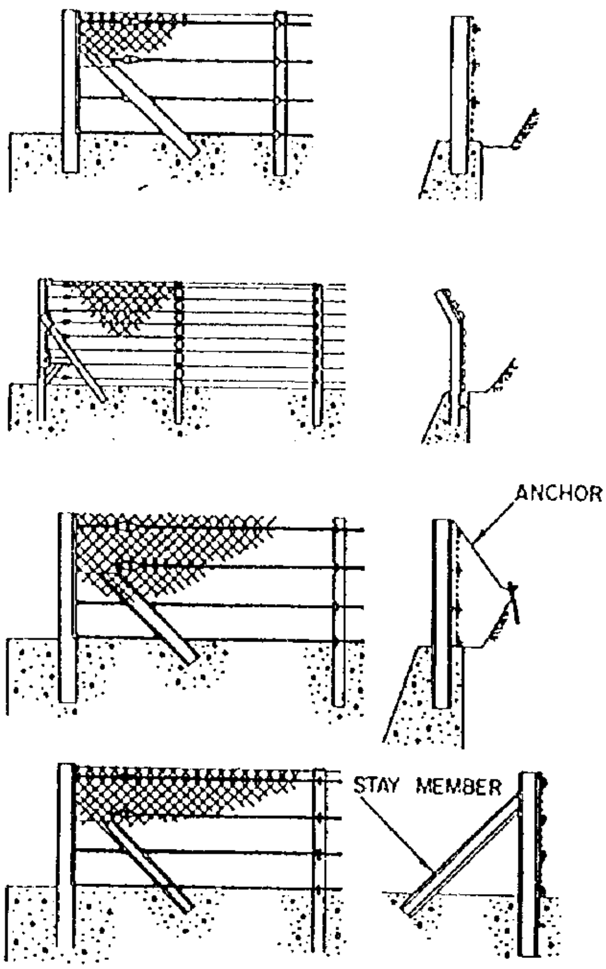


Fig. 4.6.30 Wire Mesh Fence

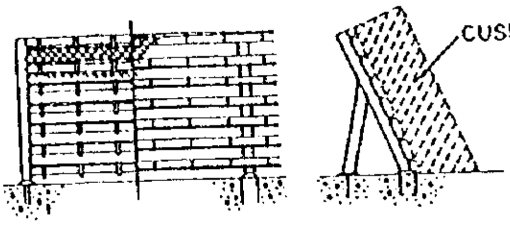


Fig. 4.6.31 H-Shaped Steel Fence

As shown in Fig. 4.6.30, for wire mesh fence, the wire and wire mesh are strung between H-shaped steel supports. The fence can have either straight or angled supporting posts.

As shown in Fig. 4.6.31, for the H-shaped steel fence, the H-shaped steel beams are laid between H-shaped steel supports with wire mesh attached on top. In addition, old tyres and sand are usually used as cushion material.

(2) Wall

(i) Application

Wall barriers are relatively effective for preventing medium size rocks from reaching the surface of the road but they require a relatively wide area adjacent to the road for installation.

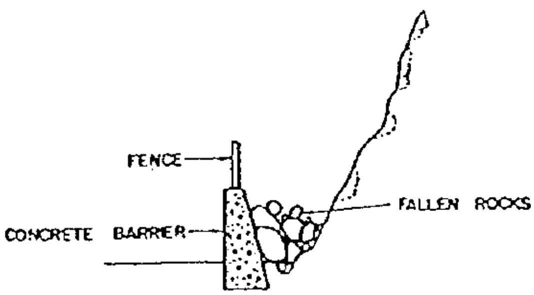


Fig. 4.6.32 Wall Barrier

4.6.3 Landslide

(A) Calculation of Slope Stability

(1) Present Safety Factor Values

1. The safety factor for a slope where a landslide is predicted to occur or for the debris after a landslide has occurred is determined by on-site inspection of the

soil, boring, etc. Generally the safety factor (F_S) when a landslide is occurring is said to be around 0.9.

(2) Required Safety Factor

The required safety factor is said to be the value needed to stabilize the location where a landslide has occurred. Its value is determined by considering the damage and/or injuries suffered by road users and road facilities as a result of the landslide, as well as the adverse socioeconomic impacts of the landslide. The value of the required safety factor should be as described below:-

1. For urgent repair work: 1.00 □ F_S □1.10

2. For long term measures: F_S =1.50

(3) Analysis of Landslides

Based on the results of on-site surveys, the direction, depth and planar surface of a landslide or possible landslide are estimated.

1. Slope and Landslide Debris Slices

   To calculate stability, slopes with a potential landslide problem or those already covered with landslide debris are devided into slices.

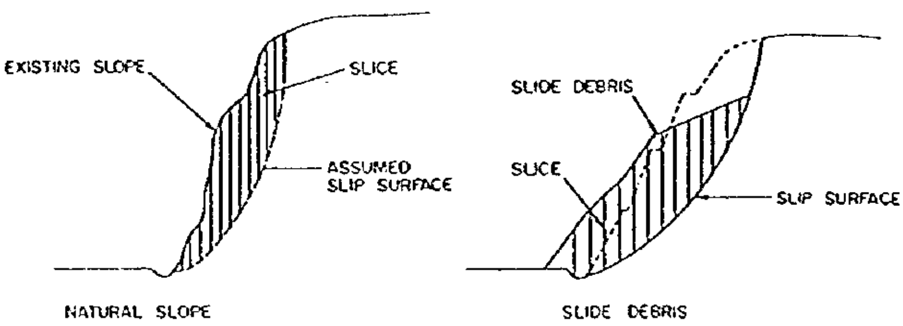


Fig. 4.6.33 Slicing of Slope and Slide Debris

2. Estimation of Landslide Slip Surface

   The direction of a landslide, as shown in Fig. 4.6.34, is in most cases along the maximum angle of a slope. The shape of the slip surface is in most cases circular and most stability calculations are carried out for this case.

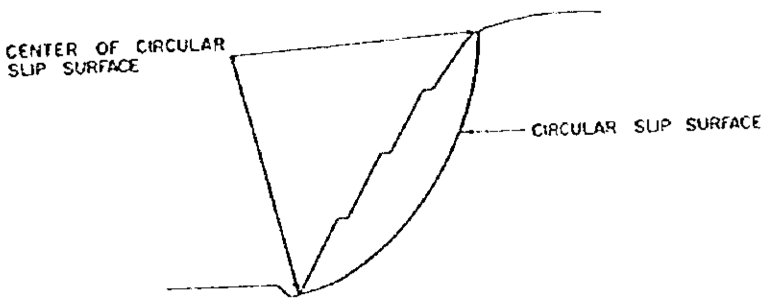


Fig. 4.6.34 Hypothetical Slip Surface

3. Pore Water Pressure of Soil

When carrying out restoration work, the pore water pressure in the soil should be taken into account. Where it is possible some peizometers should be installed in the slope to establish the ground water levels and the variation due to different rainfall intensities. Where this is not feasible, the groundwater level should be assumed to be at or close to the ground level.

(4) Calculation of Stability

1. Soil Mechanics Constant

When the soil mechanics constant can not be calculated, the relationship between cohesion and internal friction can be used (see Fig. 4.6.35).

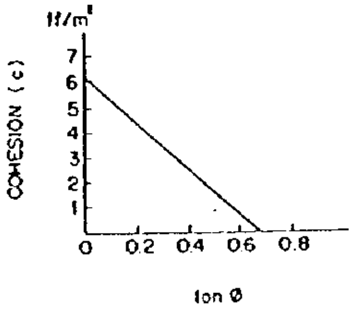


Fig. 4.6.35 Relationship between Cohesion and Internal Angle of Friction

For convenience, the value of cohesion (C), is set by using the average of the slip surface and slide debris vertical thickness (see Table 4.6.4)

Table 4.6.4 Relationship between Average Vertical Thickness and Cohesion

Average Vertical Thickness (m)	Cohesion (t/m^2)
5	0.5
10	1.0
15	1.5
20	2.0
25	2.5

The strength of a weathered slip surface is shown in Table 4.6.5.

Table 4.6.5 Strength of Weathered Slip Surface

Classification		Cohesion	Internal Angle of Friction
Metamorphic Rock		0~0.2	20~28 (26)
Igneous Rock		0	23~36 (29)
Sedimentary Rock	Palaeozoic	0~0.4	23~32 (29)
	Mesozoic	0~1.0	21~26 (24)
	Palaeogene	0~2.0	20~25 (23)
	Neogene	0~2.5	12~22 (12.5)

Where the groundwater is near a slip surface, the pore water pressure rises and for safety reasons, the cohesion should be assumed to be zero.

Here, the unit volume of landslide debris is set at $1.8t/m^3$. In areas having Shirasu and large rock, or porous and volcanic altered rock, on-site tests should be carried out.

2. Calculation of Stability

As shown in Fig. 4.6.36, the model used to calculate stability does so by dividing up the possible slip surface or slide debris mass into slices.

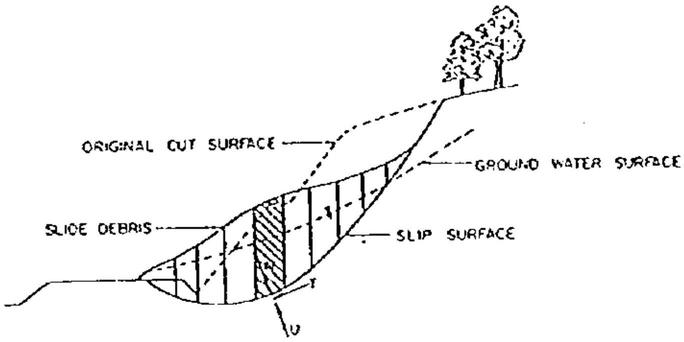


Fig. 4.6.36 Stability Calculation Model

The basic equation for estimating stability is shown below:-

$$F_S = \frac{\Sigma \{ c \cdot L + (W \cdot \cos \alpha - \mu \cdot L) \tan \phi \}}{\Sigma W \cdot \sin \alpha}$$

Where,

F_S : safety factor
c : cohesion (tf/m^2)
ϕ : shear resistance angle (Deg)
L : total length of slip surface (m)
W : weight of a slice (tf/m)
α : angle between a slice and the slip surface (Deg)

(B) Counterweight

As shown in Fig. 4.6.37, the counterweight is made up of gabion mats having a heavier unit volume weight than debris at the bottom part of a landslide mass. The gabions allow the spring water to drain in order to prevent future landslides.

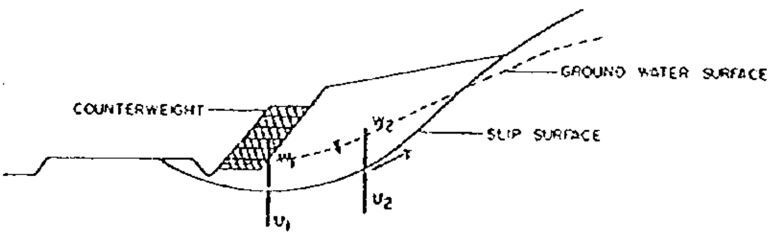


Fig. 4.6.37 Counterweight Work

When carrying out such work, the weight of counterweight can result in the collapse of the ground under the counterweight (see Fig. 4.6.38).

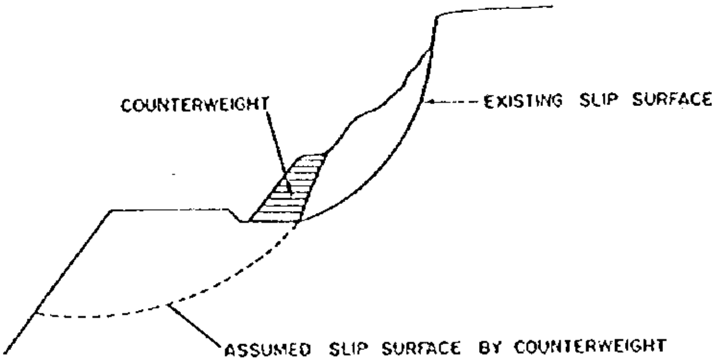


Fig. 4.6.38 Collapse of Ground under Counterweight

When carrying out counterweight work, it is first necessary to carry out stability calculations for the slide debris. After confirming the level of safety of the debris, the construction and restoration work may begin in order to resolve the present damage and to prevent future landslides.

(C) Removal of Slide Debris

One of the most reliable methods to remove landslide debris is as shown in Fig. 4.6.39. Generally, this method is used for small and medium scale landslides.

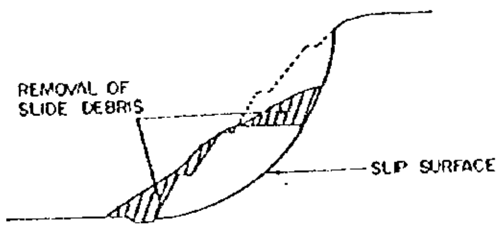


Fig. 4.6.39 Removal of Landslide Debris

When disposing of landslide debris, it is first necessary to ensure that the work can be carried out in safety by making debris stability calculations based on the results of a survey to determine the scale of the landslide, its distribution and soil strength.

When disposing of debris, either all or part of it can be disposed of. Generally, when partial disposal is carried out, the top part of a debris mass is removed for the following reasons:-

- Landslide Debris Disposal Method

1. Location of debris to be disposed of: Debris at the top of a landslide mass will be disposed of. However, if debris at the bottom is extremely weak, then soil shall be removed from there as well to achieve a safe balance. Stability calculations shall be carried out to determine the safety factor.

2. Slope gradient at debris removal site: The slope gradient at a debris removal site at the top of the debris mass shall be as shown in Fig. 4.6.40, a gentle 2.0:1 – 4.0:1 .

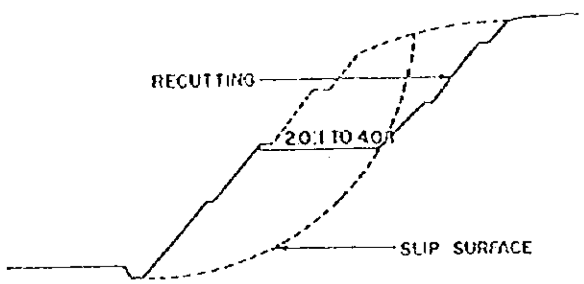


Fig. 4.6.40 Slope Gradient at Debris Removal Site

3. Slope work after debris removal: After the landslide debris is removed, a slope usually becomes susceptible to seepage and erosion due to rainwater. Therefore drainage and vegetation work , as shown in Fig. 4.6.41, shall be carried out

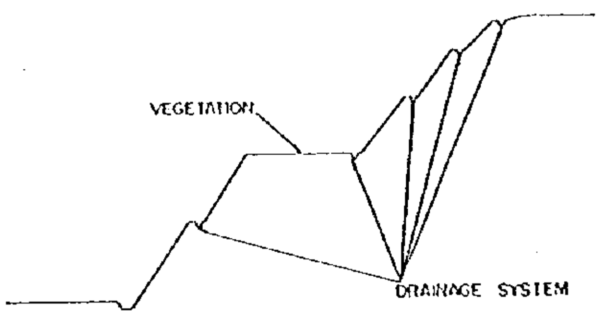


Fig. 4.6.41 Slope Work after Landslide Removal

(D) Horizontal Drain Hole

(1) Purpose

The purpose of a horizontal drain hole is to prevent landslides from occurring by reducing the groundwater level for unstable landslide debris and for unstable slopes predicted to have a landslide.

(i) Method to Confirm Slip Surface

To properly install a horizontal drain hole for groundwater drainage, it is necessary to confirm the slip surface from a soil survey.

The boreholes for the slope survey shall be carried out in at least three spots on the potential or actual landslide surface. Sliding occurs in many cases along the boundaries between colluvium and bedrock and between severely weathered rock and lightly weathered rock. The boring is carried out to confirm these boundaries and the changes in soil types.

(ii) Design of Horizontal Drain Hole

It is usual to install 4 or 5 drain holes per location. Drain holes will be 66mm in diameter and are inserted at an angle of 5° to 10° to the horizontal to assist in the drainage of groundwater(see Fig. 4.6.42).

The installation is carried out using a boring machine to drill the holes, as shown in Fig. 4.6.43. Where the soil is made up gravel or soil, a casing pipe is to prevent the collapse of the drill hole.

Drain holes shall be every 5m along the slip surface as shown in Fig. 4.6.44.

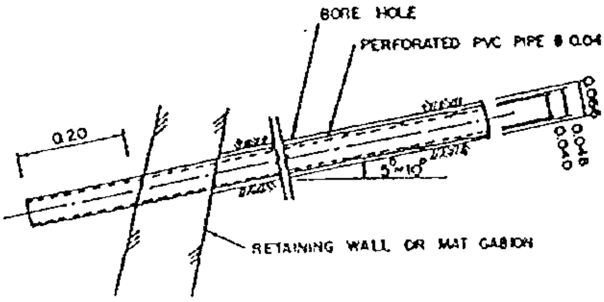


Fig. 4.6.42 Angle of Drain Hole

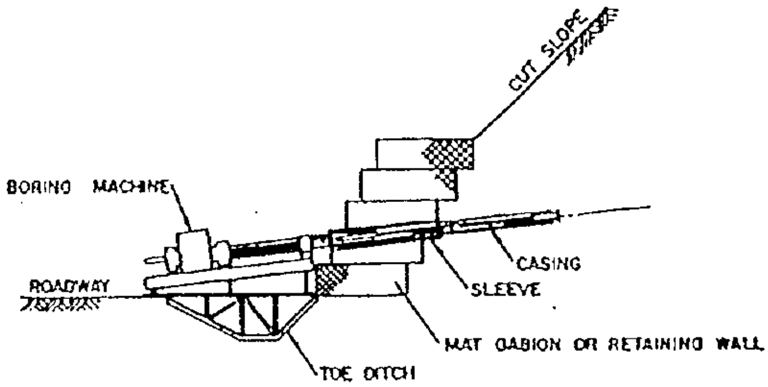


Fig. 4.6.43 Boring Machine

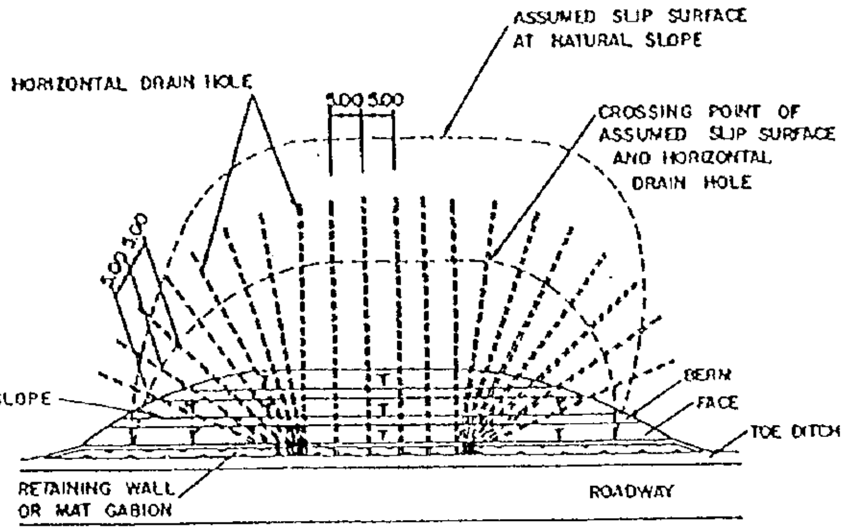
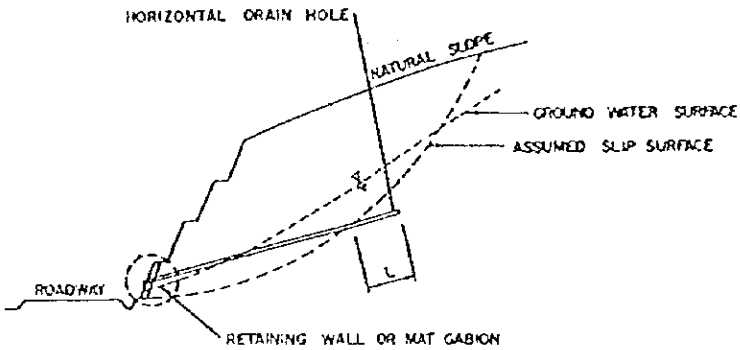


Fig. 4.6.44 Drain Hole Arrangements

As shown in Fig. 4.6.45, the boring depth from the slip surface will 10m for soil slopes and 3m for rock slopes.



ORIGINAL GROUND CONDITION	L
SOIL	10.00
ROCK	3.00

Fig. 4.6.45 Boring Depth from Slip Surface

(3) Materials:

Perforated PVC pipe will be inserted in the bored holes (see Fig. 4.6.46).

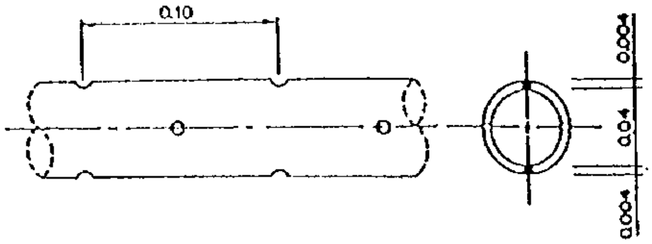


Fig. 4.6.46 Perforated PVC Pipe

(4) Reduction of Groundwater Level

Generally, horizontal drain holes reduce the groundwater by approximately 3m. Therefore, when carrying out stability calculations for groundwater planning where drain holes have been or will be installed, the level shall be assumed to be 3m less than the maximum groundwater level.