CHAPTER 5 EMBANKMENTS

5.1 Evaluation of Data

For a flooded embankment, it is important to collect all the recent data on the flood levels and rainfall patterns so that this can be used to compare with historic data to establish the highest likely flood level in the design return period. It is also necessary to check the stability of the embankment after the flooding has subsided as saturation of the embankment could weaken the materials and lead to a potential collapse.

For a collapsed embankment, borehole and cross section data will normally be available. The borehole data and laboratory tests from borehole samples, will be used to establish the soil strength parameters to assist in redesigning the embankment on a stable formation taking account of any necessary additional drainage measures that may be required.

5.2 Effects of Damage

Table 5.2.1 defines each of the damage types and states the major effects of the damage.

Table 5.2.1 Damage Types for Embankments - Definitions and Effects

Item	Damage Type	Effects of Damage
Embankment	Submerge (Flooding)	. risk of scour of embankment as water level lowers . risk of scour of bridge foundations . embankment will be saturated and this may reduce its strength and risk a serious collapse
	Collapse	. road must be closed causing traffic disruption . difficult and expensive reconstruction

5.3 Causes of Damage

The major causes of damage for each of the damage types shown in Section 5.1 are summarised in Table 5.3.1.

Table 5.3.1 Major Causes of Damage for each Damage Type

Item	Damage Type	Major Causes of Damage
Embankment	Submerge (flooding)	. embankment too low for highest flood levels blockage on river or flood channel downstream of embankment . blocked culvert or bridge opening . culvert or flood opening has insufficient capacity for flood flow
	Collapse	. lack of compaction . poor materials . saturation due to lack of drainage or flooding . softening of sub grade due to groundwater or lack of drainage . scouring of toe by water action . earthquakes or other natural disasters

5.4 Repair Methods

Tables 5.4.1 to 5.4.4 show the various repair methods for each of the damage types listed in Table 5.2.1.

Table 5.4.1 - Repair Methods for Embankment Damage

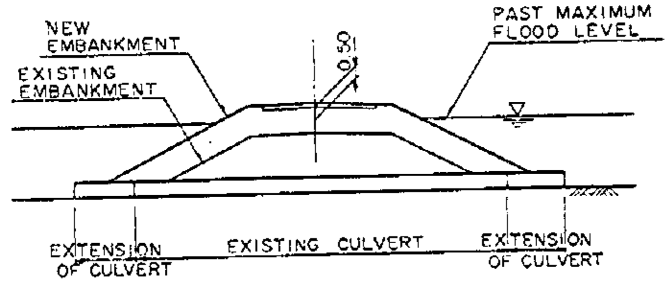
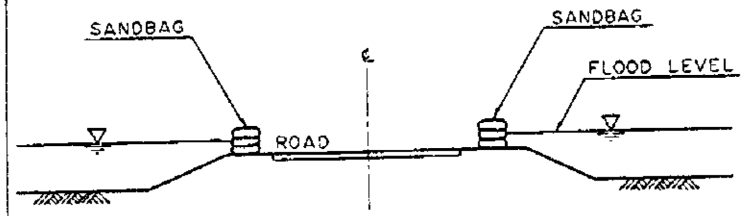
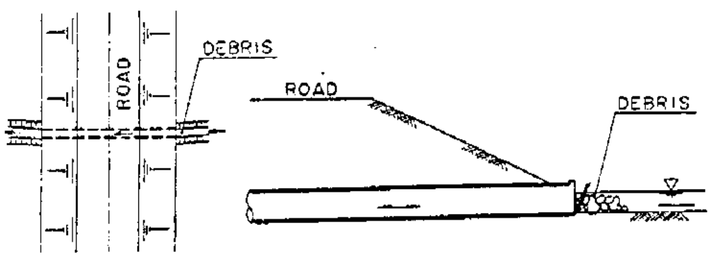
Damage Type	Repair Method	Purpose	Application	Sketch
Submerge (flooding)	Increase height of embankment	- to lift the road surface above the normal flood level	- low embankment in a flood plain	
	Use of sandbags	- to avoid flooding of road	- temporary measure for embankment in flood plain	
	Removal of debris or sediment	- to increase discharge capacity by the removal of debris and sediment from the culvert inlet	- culvert inlets	

Table 5.4.2 - Repair Methods for Embankment Damage

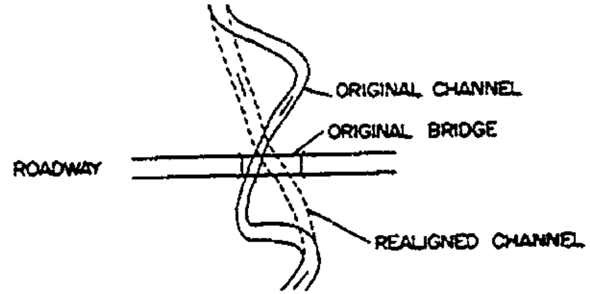
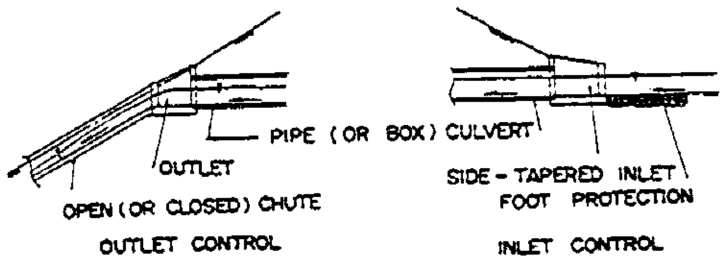
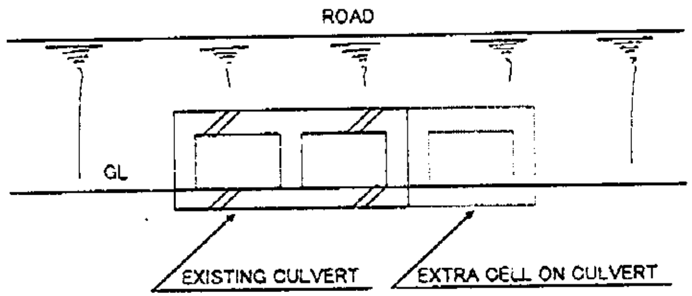
Damage Type	Repair Method	Purpose	Application	Sketch
Submerge (flooding)	Downstream improvements	- increase downstream flow/capacity by the removal of debris or improving the river channel	- downstream river channel	
	Construct additional culverts (consider upstream channelisation)	- to provide a new passage for water through or alongside the embankment	- where regular flooding occurs away from culvert locations	
	Increase cross sectional area of culvert	- to increase the capacity of the flood flow	- where regular flooding occurs at existing culverts that is not caused by debris/sediment or downstream problems	

Table 5.4.3 - Repair Methods for Embankment Damage

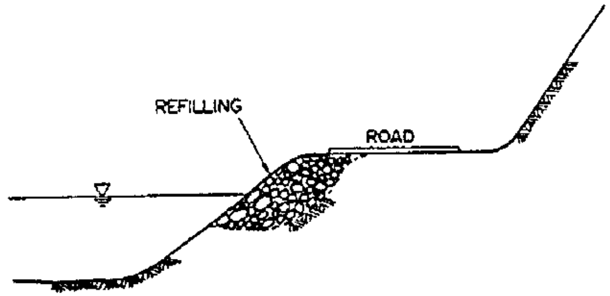
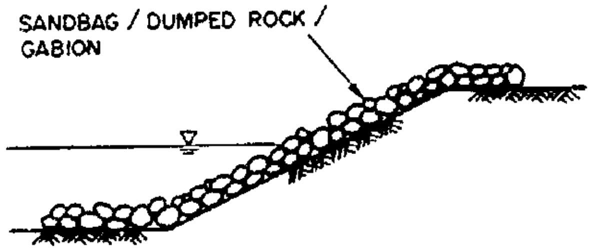
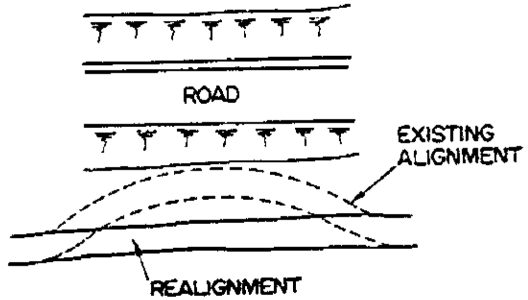
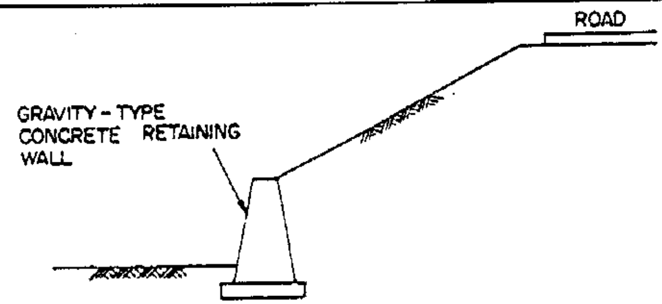
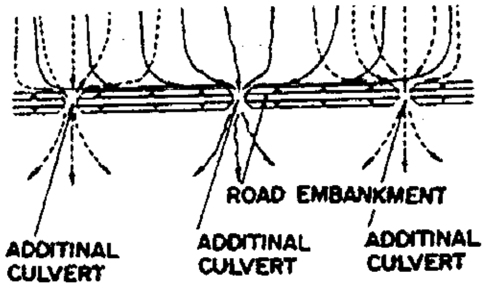
Damage Type	Repair Method	Purpose	Application	Sketch
Collapse	Refill	- to achieve an embankment capable of supporting design loadings	- in all situations and prior to other treatments being applied.	
	Rock protection	- to protect the toe of the slope from scour	- apply to slopes adjacent to water courses	
	Realign river channel	- to prevent erosion and scour of the toe of the embankment	- meandering river adjacent to embankment	

Table 5.4.4 - Repair Methods for Embankment Damage

Damage Type	Repair Method	Purpose	Application	Sketch
Collapse	Toe retaining wall	- to give extra support in resisting earth pressure	- low height wall, 2m max.	
	Additional drainage measures	- to maintain acceptable sub grade condition - to provide additional flood flow capacity	- where the subgrade is saturated by high ground water levels - where saturation is due to regular flooding of the embankment	

5.5 Selection of Repair Method

5.5.1 The Selection Process

For Embankments, consideration must be given to the need for emergency measures to keep the road open to traffic and in a safe condition. In selecting a repair method the cost and implications on traffic flow must be considered very carefully with simple methods being considered first as a quick solution and the methods requiring more major works being considered as part of a longer term solution.

Submerge (flooding)

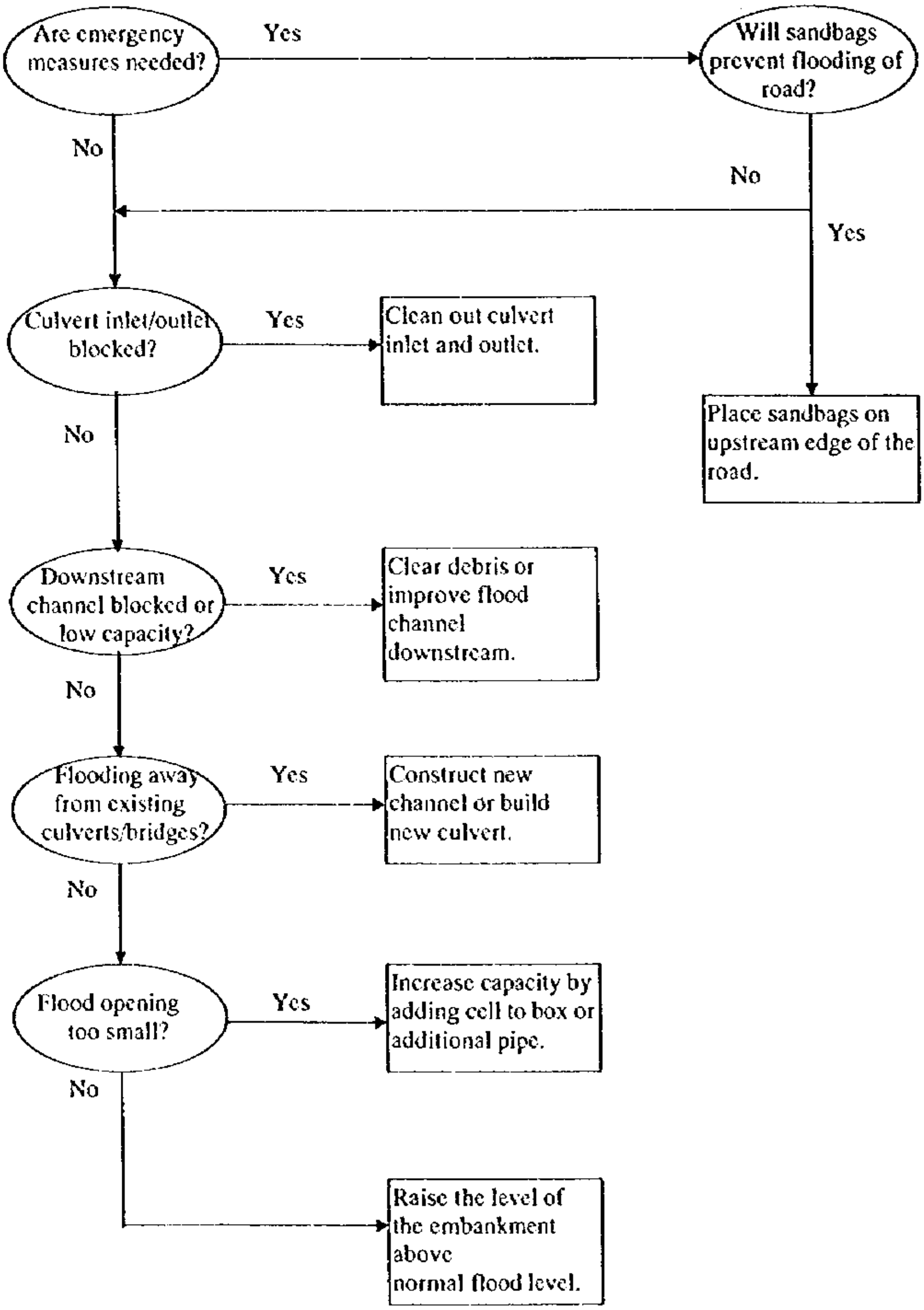


Fig. 5.5.1 Flow Chart for the Selection of Repair Method for Submerged (flooded) Embankment

Collapse of Embankment

There are a number of causes of collapsed embankments and in all cases the damaged section will require to be refilled with suitable material and should be adequately compacted to achieve the design requirements.

Where the collapse has been caused by river scouring, the cost of the permanent solution to realigning the river should be compared with the other alternatives to decide on the optimum solution. This will depend on the budget availability.

Drainage options may be considered both to avoid flooding, preventing saturation of the embankment and also to lower the ground water level to maintain a dry subgrade under the embankment.

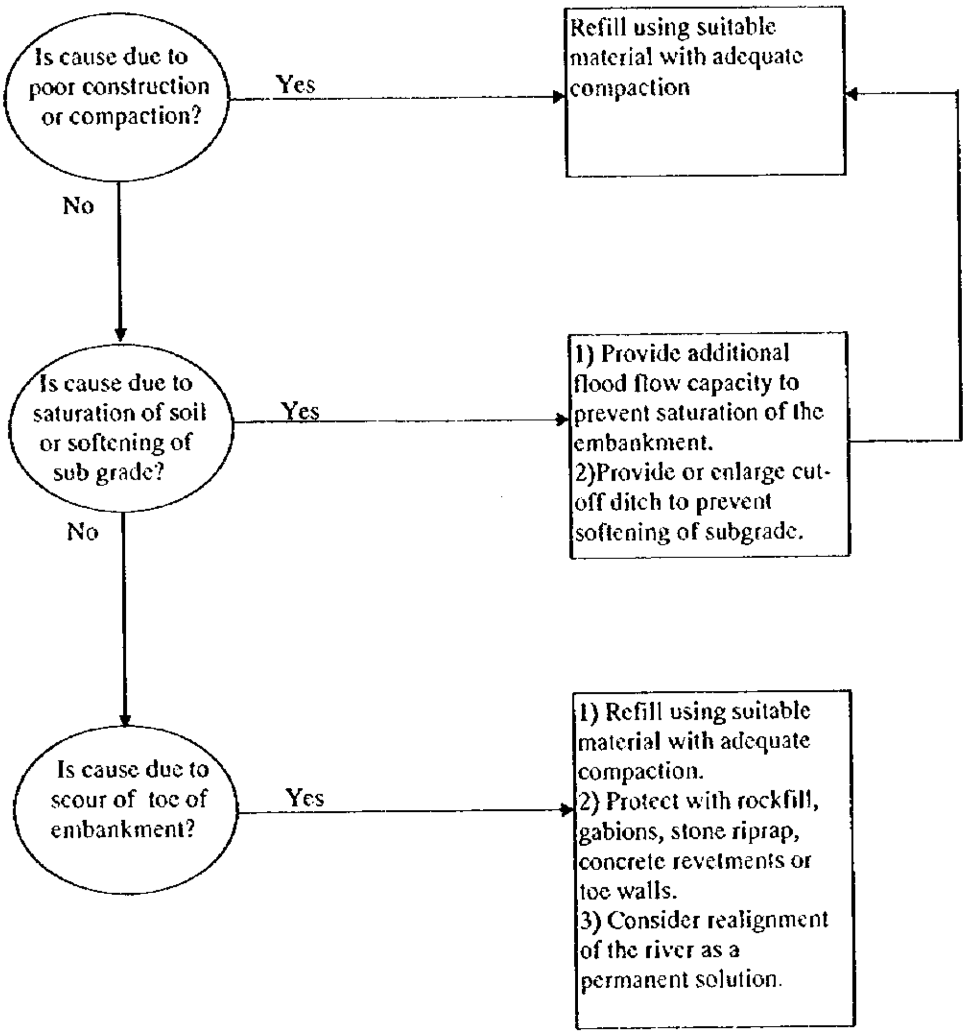


Fig. 5.5.2 Flow Chart for the Selection of Repair method for Collapsed Embankment

5.6 Design and Construction Matters

Downstream Improvements

This can be used to increase the downstream capacity. The river, stream or flood channel can be widened or regraded to provide additional flow capacity. Where regrading is considered, the design should ensure that adequate gradients can be achieved without extending the regrading to unreasonable lengths and so creating excessive construction costs.

The new works should be designed to prevent excessive scour and suitable scour protection works should be included where necessary.

Additional Culverts

Additional culverts are expensive to construct and may cause traffic disruption and so this method should only be used after careful consideration of all other options.

In general it will be suited where flooding occurs on a regular basis in a location where there is no existing culvert. Alternatives such as creating a flood channel parallel to the road to the nearest discharge point should be considered first.

Where it is decided that an additional culvert is the only solution, then a catchment area calculation should be carried out to confirm the required culvert size.

Increase Cross Section Area

This method is also expensive to construct and may cause traffic disruption and so this method should only be used after careful consideration of the situation.

The method is appropriate where flooding occurs at existing culverts and it has been identified as a lack of flow capacity. A catchment area calculation should be carried out to determine the required flood flow capacity taking account of the existing culvert size.

In some situations it may be possible to thrust bore a pipe or box through the embankment. This requires adequate land for construction of the culvert sections and for the thrust pits for jacks. It also needs a certain depth of cover to avoid major disruption to traffic.

In most circumstances, an additional pipe will be laid in an open trench or new box culvert cell in open excavation. In both cases the construction programme should be phased to minimise the disruption to traffic.

CHAPTER 6 SHOULDER

6.1 Evaluation of Data

It is important to establish whether this damage occurs on a regular basis or if it was a single occurrence. If it occurs on a regular basis, the road drainage should be checked and the path of the road surface water should be checked during heavy rainfall to see whether preventive measures such as an edge drain will solve the problem. In other situations, the verge and shoulder materials should be examined to see whether they are well compacted and of the right type of material. CBR tests may be used if necessary to assist in deciding on the material strength. As the shoulder provides support to the pavement, it is important to evaluate the situation quickly and at least carry out temporary repairs to prevent damage to the pavement.

6.2 Effects of Damage

Table 6.2.1 defines the damage type and states the major effects of the damage.

Table 6.2.1 Damage Types for Shoulder- Definitions and Effects

Item	Damage Type	Effects of Damage
Shoulder	Washing Out	. loss of edge support to pavement. Further deterioration likely. . exposes lower pavement layers to possible softening due to water action. . if damage encroaches inside the safety fence, this becomes a safety hazard for motorists.

6.3 Causes of Damage

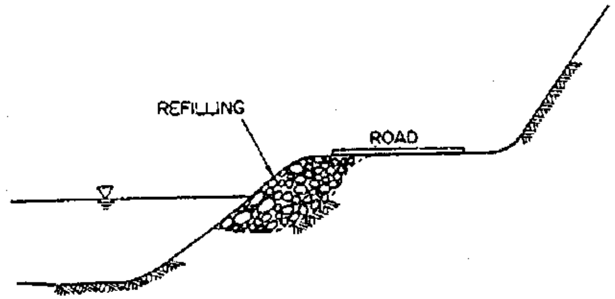
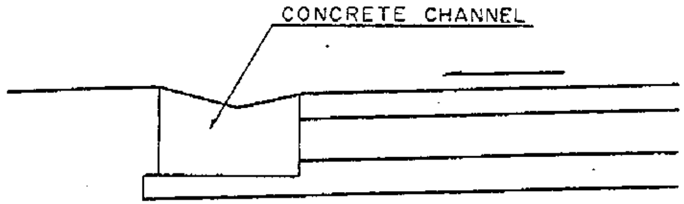
The major causes of damage for the damage type shown in Section 6.2 are summarised in Table 6.3.1.

Table 6.3.1 Major Causes of Damage for each Damage Type

Item	Damage Type	Major Causes of Damage
Shoulder	Washing Out	. lack of positive edge drainage . poor edge compaction

6.4 Repair Methods

Table 6.4.1 - Repair Work for Shoulder

Damage Type	Repair Method	Purpose	Application	Sketch
Washing Out	Refill	- to reopen the road by filling the cavity with suitable material, sandbags, rock or gabions	- cavity in shoulder	
	Edge Drain with kerb shute or pipe drain	- to collect road surface water in edge drain preventing scour of shoulder	- low side of road	
	Kerb with kerb shute or gullies and pipe drain	- to collect road surface water at kerb preventing scour of shoulder	- low side of road	

6.5 Selection of Repair Method

6.5.1 The Selection Process

Urgent repairs may be considered when the road has been closed to traffic because of the damage. The only rapid repair method is to refill the void with suitable material ensuring proper compaction during the refilling.

If the problem is one that occurs on a regular basis, it may be possible to use positive drainage such as an edge drain or kerb to prevent the surface water from running over the edge of the carriageway and washing out the shoulder.

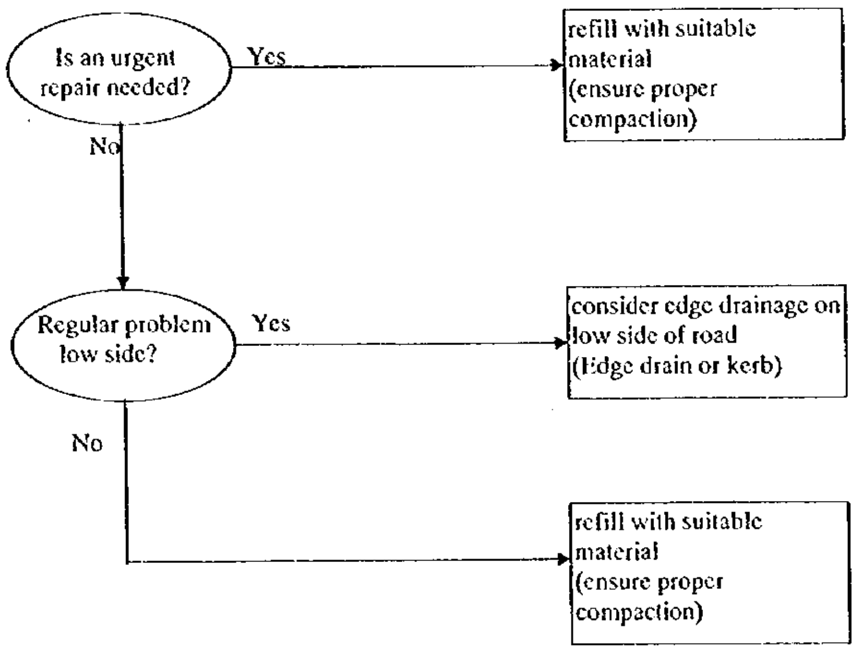


Fig. 6.5.1 Flow Chart for the Selection of Repair Method for Shoulder

6.6 Design and Construction Matters

Kerb or edge drain

This method should only be used where the damage occurs on a regular basis on the low side of the road. The positive drainage should be introduced over an adequate length to protect the length of shoulder at risk. The design should allow for discharging the water collected to a suitable river, stream or ditch via a pipe or shute system.

Kerbs may be either precast concrete laid on a mortar bed or an extruded asphalt kerb. The extruded kerb requires good preparation and quality control of materials but is easy to install on an existing pavement provided the equipment is available. The more traditional precast concrete kerb involves more work in a repair situation.

With kerbs, the surface water is carried on the carriageway adjacent to the kerb until it reaches a gully or outfall pipe or gully shute. With a channel, the surface water is carried in the channel adjacent to the edge of the road. The choice of kerb or channel needs to be examined for each situation as it will depend on the capacity requirements which are dependent on the local situation in terms of rainfall, road gradient and crossfall.

CHAPTER 7 DRAINAGE (SIDE DITCHES, GULLIES AND CULVERTS)

7.1 Evaluation of Data

For drainage works, the most useful information is that gained from past experience of the operation of the drainage system in the region. Knowledge of areas prone to flooding or silting up can greatly assist in the judgement as to the correct repair or preventative works.

When design checks are required, the data from cross section measurements may be of assistance but in general a catchment area calculation may be required to determine the required capacity of the culvert or opening.

7.2 Effects of Damage

Table 7.2.1 defines each of the damage types and states the major effects of the damage.

Table 7.2.1 Damage Types for Drainage - Definitions and Effects

Item	Damage Type	Effects of Damage
Side Ditch	Accumulation of debris	. decreases the section area and reduces drainage capacity . overflow water occurs weakening road bed, and causes reduction in bearing capacity . causes washing out of shoulder and slope
	Settlement	. causes accumulation of debris and collapse . reduced drainage capacity
	Collapse	. reduced drainage capacity . allows water to enter cracks and causes weakening of the road bed, shoulder and slope . may cause traffic accident
Gully	Accumulation of debris	. overflow water may cause traffic accident . overflow water may cause landslide . reduces drainage capacity
	Settlement	. cause of collapse . may cause traffic accidents
	Collapse	. may cause traffic accidents . allows water to enter cracks and causes weakening of the road bed . runoff water causes landslide . reduces drainage capacity
Culvert	Accumulation of debris	. disturbs the flow of water in culvert . lack of cross section area for overflow water may cause landslide . reduces drainage capacity
	Settlement	. cause of accumulation of debris . may cause traffic accidents
	Collapse	. may cause traffic accidents . allows water to enter cracks and causes weakening of the road bed . runoff water may cause landslide . reduces drainage capacity

7.3 Causes of Damage

The major causes of damage for each of the damage types listed in table 7.2.1 are summarised in Table 7.3.1.

Table 7.3.1 Major Causes of Damage for each Damage Type

Item	Damage Type	Major Causes of Damage
Side Ditch Gully Culvert	Accumulation of debris	. lack of regular maintenance to clean away the debris . additional inspections required where traffic numbers increase at holiday season, where windy or swampy area creates quick earth movement.
	Settlement	. lack of bearing capacity
	Collapse	.excessive load by heavy traffic .damaged by rockfall .poor materials .weak foundation

7.4 Repair Methods

Table 7.4.1 shows the repair methods for each of the damage types in Table 7.2.1.

Table - 7.4.1 Repair Methods

Damage Type	Damage items		Repair Method
Accumulation of debris	Side ditch Slope ditch Drain pipe Gully		■ Removal of debris by jet washer and sucker vehicle ■ Removal of debris by workman
	Culvert		■ Removal of debris by back-hoe and belt-conveyer ■ Removal of debris by jet washer ■ Removal of debris by workman ■ Dam or screen collects debris
Settlement			■ Relining of drainage base concrete ■ Cement mortar grouting works ■ Partial reconstruction works
Collapse	Crack	Small scale affect on the structure	■ Coating (Cement Paste, Synthetic Resin)
		Middle scale affect on the structure	■ V shape cutting into crack and sealing / filling
		Large scale affect on the structure	■ Partial concrete works required ■ Reinforcement works help to increase the strength
	Gap Collapse		■ Filling by use of synthetic resin or cement mortar to prevent water leakage ■ Cement mortar grouting and chemical grouting
	Overall Collapse		■ Reinforcement works helps to increase the strength ■ Relining by reinforced concrete ■ Construction of alternative culvert

Table 7.4.2 Types Repair Work for Drainage Damage

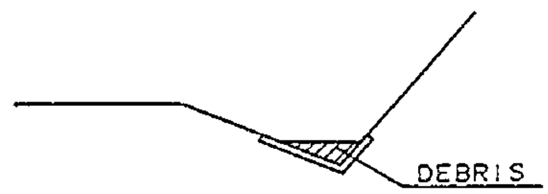
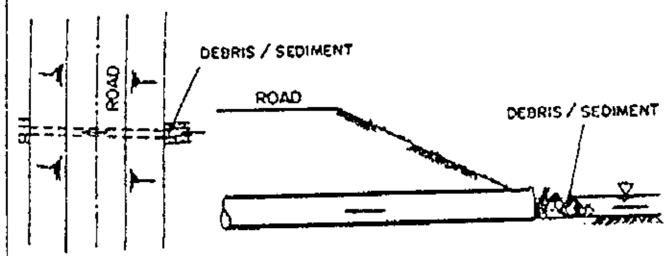
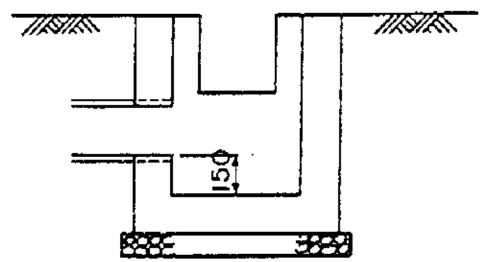
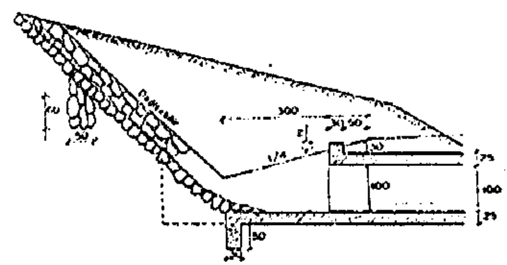
Damage Type	Repair Method	Purpose	Application	Sketch
Accumulation of Debris	Removal of debris	-To increase discharge capacity by the removal of debris from side ditch or gully	-Applicable to side ditch or gully	
	Removal of debris	-To increase discharge capacity by the removal of debris from culvert	-Applicable to pipe or box culverts.	
	Mud filtration	- To prevent accumulation of debris stops mud flowing into culvert or drainage.	-Gully -Inlet of Culvert	
	Prevention measure for scouring	-To prevent for running water scours surrounding of inlet of culvert, puts the stone on surface of slope.	-Applicable to pipe or box culvert -Soil	

Table 7.4.3 Types Repair Work for Drainage Damage

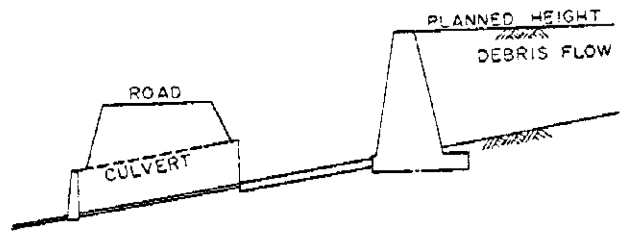
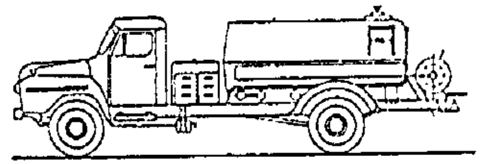
Damage Type	Repair Method	Purpose	Application	Sketch
Accumulation of Debris	Prevention Measure for Accumulation of Debris	- To prevent the debris going into culvert, set net at upper stream.	Mud flow area	
	High pressurised water washer	-Efficient disposal of the debris by machinery.	-Pipe or box culverts -Side ditch, Gully	

Table 7.4.4 Types Repair Work for Drainage Damage

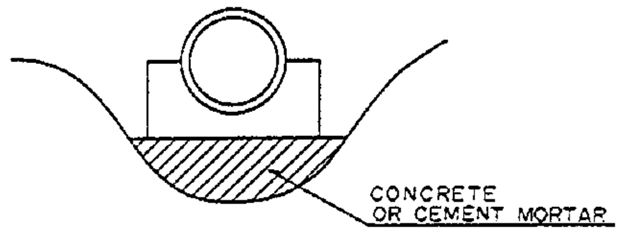
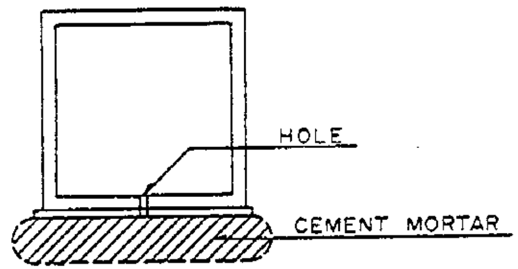
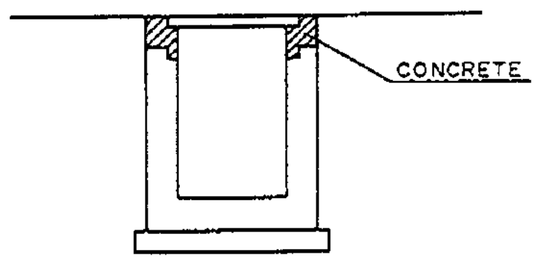
Damage Type	Repair Method	Purpose	Application	Sketch
Settlement	Filling	-To prevent settlement of pipe culvert as filling concrete into gap scoured by water.	-Side ditch, culvert	
	Grouting	-To prevent settlement of culvert as improving the bearing capacity of the ground.	-Side ditch, Culvert -Construction Gap	
	Relining	-To recover the settlement by relining.	-Gully, Side ditch	

Table 7.4.5 Types Repair Work for Drainage Damage

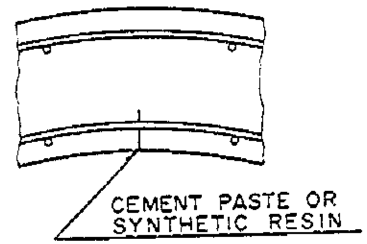
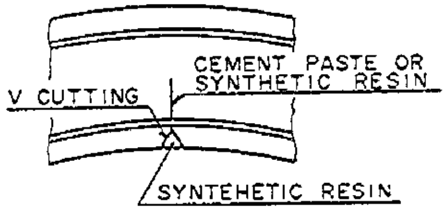
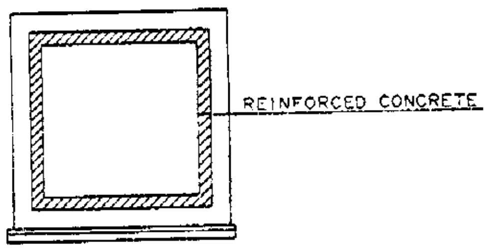
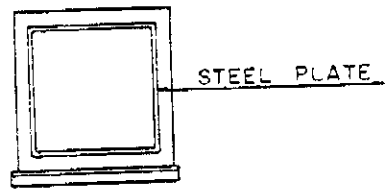
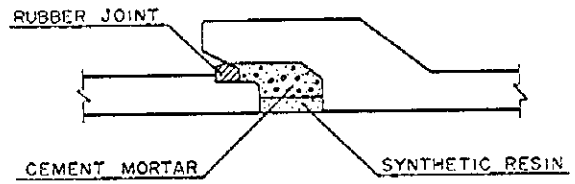
Damage Type	Repair Method	Purpose	Application	Sketch
Collapse	Coating	- Filling synthetic resin or cement paste into crack is to prevent water leakage.	-Side ditch, Gully, Pipe or Box Culvert (In case crack is smaller)	
	V shape cut	-Cutting with V shape onto crack and fill synthetic resin or cement paste into crack -To prevent water leakage.	- Side ditch, Gully, Pipe or Box Culvert (In case crack is bigger)	
	Relining	- To increase the strength of main structure to reinforce by relining reinforced concrete.	-Weakening part which requires to be repaired. -The cross section area which shrinks the flow area -Box culvert	
	Relining	- To increase the strength of structure with relining inside of culvert box.	- Damaged part required to reinforce. - In the case of impossible to reduce the water flow area - Box culvert	

Table 7.4.6 Types Repair Work for Drainage Damage

Damage Type	Repair Method	Purpose	Application	Sketch
Collapse	Filling	-To prevent the water leakage, cement mortar or synthetic resin filled into crack.	-Pipe or box culvert	

7.5 Selection of Repair Method

7.5.1 The Selection Process

(a) Accumulation of Debris

Fig. 7.5.1 shows the flow chart for the selection of repair method for accumulation of debris.

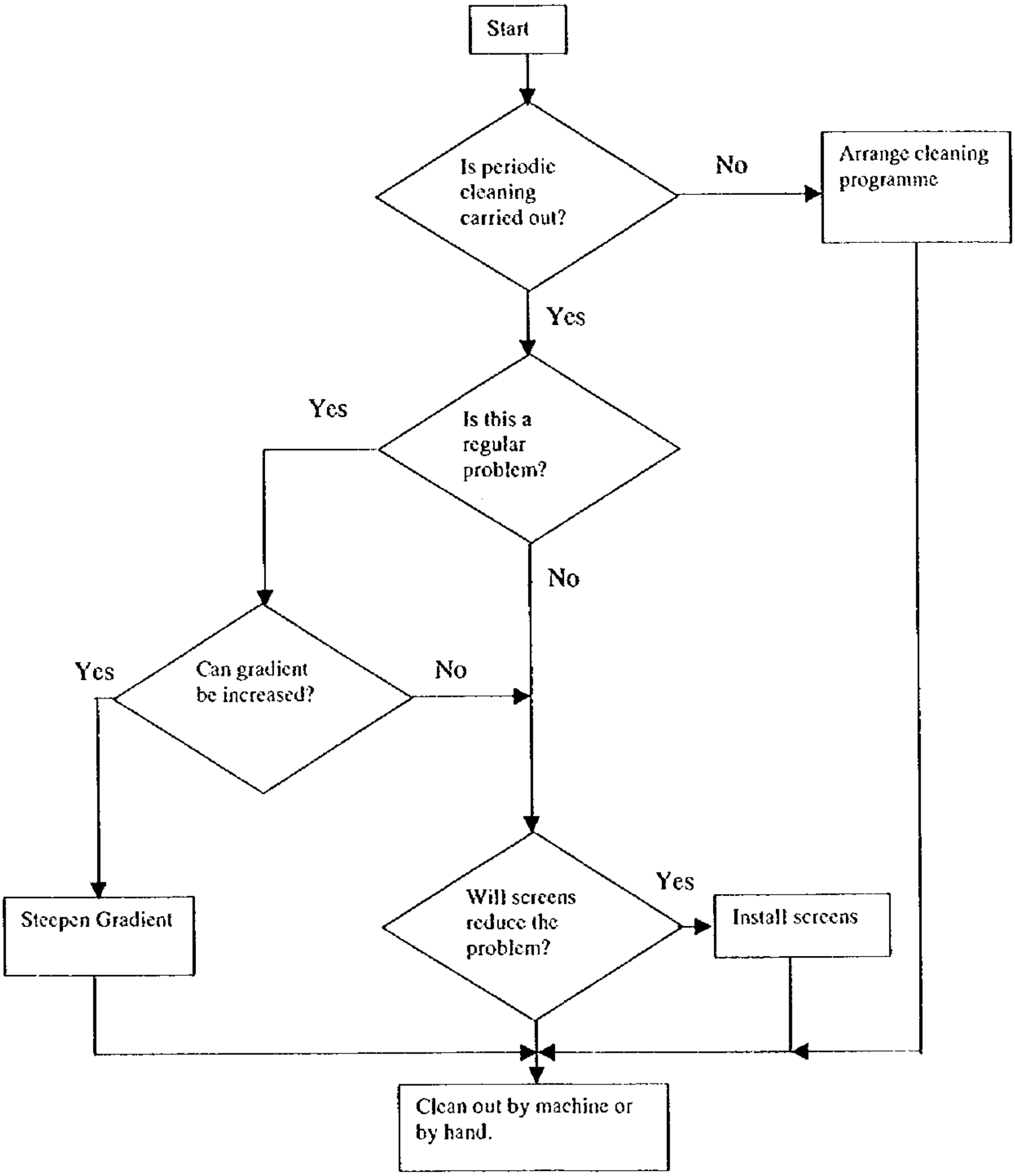


Fig. 7.5.1 Selection of Repair Method for Accumulation of Debris

(b) Cracking

Fig. 7.5.2 shows the flow chart for the selection of a repair method for cracking.

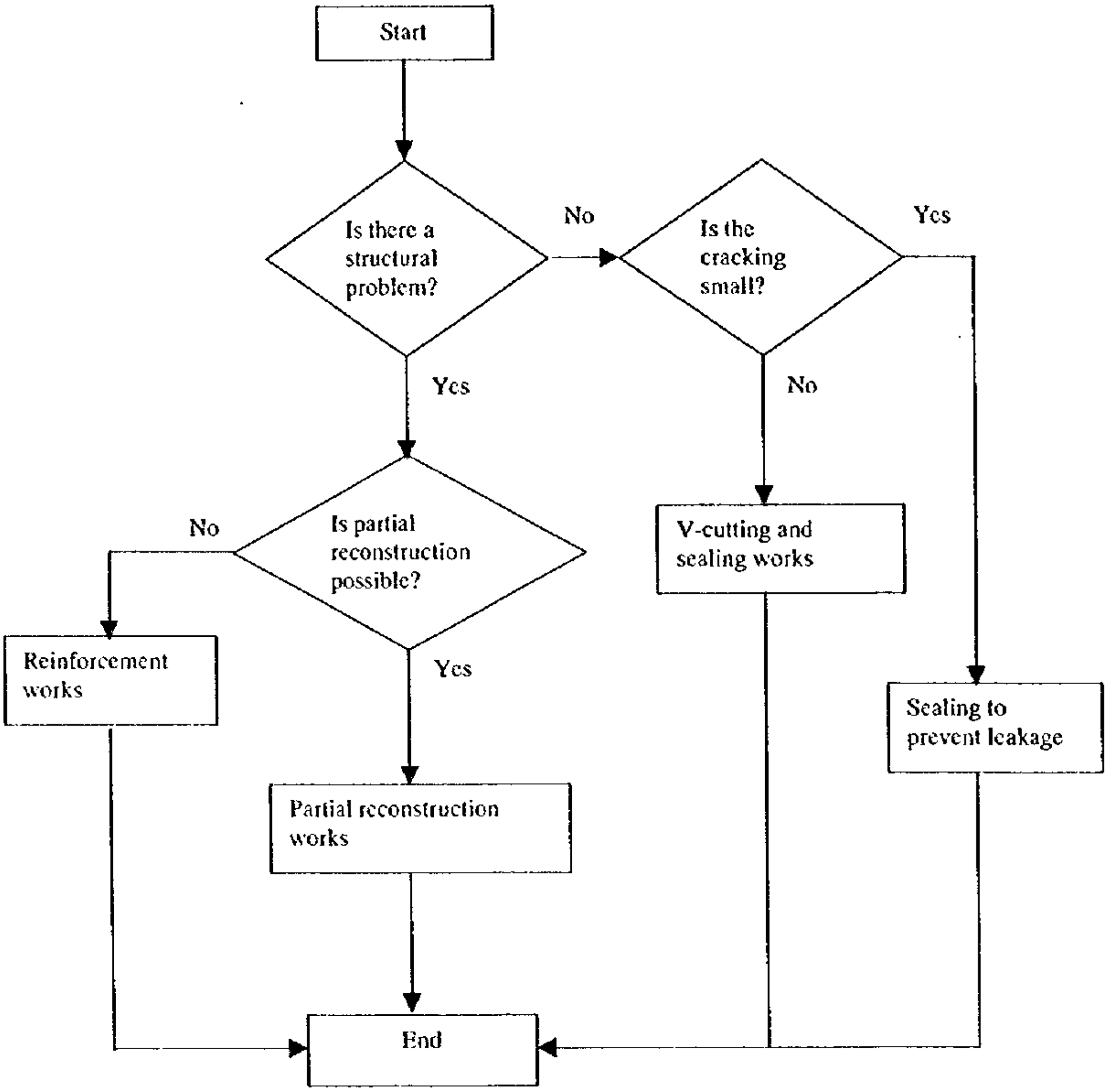


Fig. 7.5.2 Flow Chart for Selection of Repair methods for Cracking

(c) Settlement and Collapse

Fig. 7.5.3 shows the flow chart for the selection of repair methods for settlement and collapse.

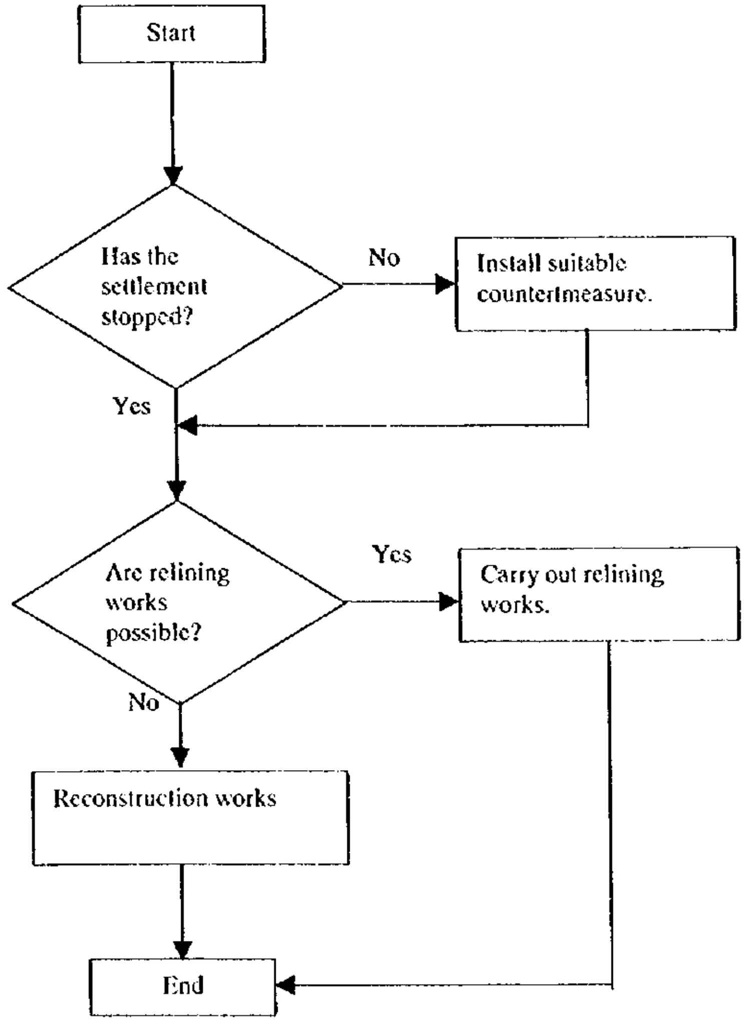


Fig. 7.5.3 Flow Chart for the Selection of a Repair Method for Settlement and Collapse

7.6 Design and Construction Matters

1) Repair Method for Accumulation of Debris

- It is important to remove the accumulation of debris periodically to suit the regional weather conditions and seasons of the year.

In some dry areas, dust will accumulate such that when it does rain, the capacity of the drainage system is inadequate. In other areas, the rainfall is sufficient to allow the drainage to be self cleaning, provided the sizing and gradient were correctly designed and constructed. The frequency of cleaning needs to be adjusted to suit these climatic variations.

- A sediment trap shall be set at the entrance of drainage works to prevent the flow of sediment into the permanent works.

Alternative ways of removing the mud and debris are as follows:-

- Manual Labour

Where labour is available, the amount of debris is not too great and the size of the pipe or culvert is accessible, this can be an effective way of clearing debris.

- Small Machine

Where the amount of debris is large and the size of the pipe or culvert will allow access, a small machine such as a back hoe will be more efficient than manual labour.

- Gully Sucker and Jet Spray

This machine is ideally suited to cleaning gullies, ditches, small pipes and kerb channels. It is clean, fast and efficient. Independent jet spraying equipment may also be used where the combined vehicle cannot gain access to ditches and small pipes.

The above points are summarised in Table 7.6.1.

Table 7.6.1 Methods for Cleaning the Accumulation of Debris

Item	Shape of Cross Section (w x h)	Manual Labour	Combined Gully Sucker and Jet Spray	Jet Spray	Small Machine
Side Ditch		♦	♦	♦	♦
Gully		♦	♦	♦	
Culvert	<1.0m x 1.0m		♦	♦	
	1.0m x 1.0m - 3m x 2.5m	♦		♦	♦
	>3m x 2.5m			♦	♦

♦ Suitable　　Not Suitable

- Cleaning Programme

The frequency and timing of the cleaning of drainage facilities shall be based on the following conditions:

- The climatic conditions in the region can greatly affect the amount of debris collecting at the drainage facilities. Local knowledge of the seasonal variations, the rainfall, snow and dry conditions shall be used to determine the frequency of the cleaning programme. Areas where high rainfall or high surface run off from snow is expected, should be cleaned out before the wet season to prevent the risk of flooding or scour. On occasions, they may need cleaning out during the wet season as well.

- The road conditions and traffic flow volume should also be taken into account, particularly where the traffic volume increases seasonally.

- Areas where severe winds are known to blow sediment and exposed coastal areas need to be monitored carefully.

The recommended minimum frequency for cleaning the drainage facilities is shown in Table 7.6.2.

Table 7.6.2 Minimum Frequency for Cleaning Drainage

Item	Frequency
Side ditch	More than once per year
Gully	2 times per year or as required because of climatic conditions
Culvert	1 time per year or as required by climatic conditions

Countermeasures against the Accumulation of Debris:-

- Scour Protection Works
  At the inlet area of a culvert, this will prevent the accumulation of the scoured material in the culvert or at the inlet and so avoid the risk of flooding. At the outlet areas for culverts or on bends in ditches, such works will prevent the channel from blockage and again will prevent the risk of flooding.

- Weirs and Screens
  Preventing the flow of debris by the construction of weirs or screens will keep the downstream sections clear. The locations of such works need to be carefully selected in relation to the topography and geology. This method requires careful monitoring of the amount of debris being collected at the weir or screen and regular cleaning out to maintain full flow capacity.

- Channel Works
  Channel improvements should always be considered to maintain or improve flow capacity or to increase the channel gradient to increase the water velocity and hence the self cleaning ability. These works can be expensive and should be considered very carefully in terms of the benefits they will bring in relation to the cost of the works.

(2) Repair Methods for Settlement

- Where the foundations of drainage facilities are washed away by water erosion, the cavity shall be filled with cement mortar or concrete.
- Where the bearing capacity of a footing is insufficient, the ground shall be strengthened using cement mortar or chemical grouting.

- Where the settled structure can be reinstated this should be done using materials in accordance with the original design.
- Where reinstatement is not possible, the structure shall be reconstructed.

(3) Repair Methods for Cracks and Spalling

- Where there are small cracks, the cracks shall be coated with cement paste or synthetic resin to prevent water leakage.
- Where there are large cracks, the cracks shall be cut into a V-shape and shall be filled with resin mortar.
- Where concrete is spalling from the structure, the spalled area should be cut back to sound concrete, and depending on the size of the works, resins or concrete will be applied to the surface and used to fill the void.

(4) Repair Method of Damaged Concrete Culvert

- Where the damaged concrete can be repaired and the cross section can be reduced without affecting the operation of the culvert, additional concrete is constructed inside the existing culvert to form a new lining and to give additional strength
- Where it is not possible to reduce the cross section and hence the flow capacity, the concrete may be strengthened by the addition of steel plates to the inside of the culvert.
- Where strengthening is not possible, the structure must be reconstructed.

(5) Repair Method at a Construction Joint

- Where a construction joint is open, the gap shall be filled with cement mortar, concrete, synthetic resin or cement mortar with synthetic resin.
- Where there is difference in level at the construction joint and the foundation needs to be improved, repairs are by mortar or chemical grouting.
- Reconstruction by jointing or water-proofing.

Table 7.6.3 Summary of Repair Methods for the Different Drainage Facilities

Repair Method / Drainage Item	Side Ditch	Gully	Culvert
Cracking			
- coating			
- cement paste	♦	♦	♦
- synthetic resin	♦	♦	♦
- v cut and synthetic resin and mortar	♦	♦	♦
Spalling			
- partial replacement with concrete	♦	♦	♦
Damaged Concrete			
- additional reinforced concrete			♦
- steel plate			♦
- reconstruction	♦	♦	♦
Filling			
- mortar	♦	♦	♦
- synthetic resin			♦
Difference in Level			
- mortar grouting			♦
- chemical grouting			♦

♦ Suitable Not Suitable

CHAPTER 8 RETAINING WALLS

8.1 Evaluation of Data

For retaining walls, it is important to establish the structural safety of the wall to prevent further collapse or movement of the retained material. It is also necessary to check that the wall as constructed is adequate in size weight and construction to retain the material it is supporting. Cross sections and measurements of the wall dimensions will help in any analysis of the wall stability against sliding or overturning. Data on the retained material, ground water levels and drainage facilities behind the wall and weepholes through the wall will also be needed for a proper assessment.

Where settlement has occurred, data on the soil under the foundations will be needed and also dimensions of the existing foundation to ensure an adequate design check can be carried out and appropriate remedial measures designed.

8.2 Effects of Damage

Table 8.2.1 defines each of the damage types and states the major effects of the damage.

Table 8.2.1 Damage Types for Retaining Wall - Definitions and Effects

Items	Damage Type	Effects of Damage
Retaining Wall	Cracking	. risk of collapse if left
	Settlement	. risk of collapse . risk of retained material spilling onto the road
	Collapse	. wall and retained material may block road . if material is left unsupported, risk to retained slope

8.3 Causes of Damage

The major causes of damage for each of the damage types shown in Section 8.2 are summarised in Table 8.3.1.

Table 8.3.1 Major Causes of Damage for each Damage Type

Item	Damage Type	Major Causes of Damage
Retaining Wall	Cracking	· vehicle impact · insufficient wall thickness · excessive build up of water behind wall due to lack of or blocked weep holes/drainage
	Settlement	· softening of sub grade due to ground water, flood or lack of drainage · lack of compaction below foundations
	Collapse	· vehicle impact · insufficient wall thickness · inadequate foundations · landslide, major slip or rockfall · excessive build up of water behind wall due to lack of or blocked weep holes/drainage

8.4 Repair Methods

Table 8.4.1 shows the major repair methods.

Table 8.4.1 Repair Methods for Retaining Walls

Damage Type	Repair Method	Purpose	Application
Cracking	Sealing/filling	- to prevent water penetration and regain structural integrity	- minor cracking with minimal displacement
	Demolish and rebuild	- to regain adequate wall strength to support the retained material	- where wall thickness is too thin - large cracking unsuitable for sealing/filling
	Clear/renew drainage	- to prevent the build up of water pressure behind the wall	- minor cracking caused by blocked or lack of weepholes/ drainage material behind the wall
	Strengthen wall with additional material	- to regain adequate wall strength to support the retained material	- where wall thickness is too thin
Settlement	Strengthen sub grade	- to provide a subgrade capable of supporting the wall	- localised problem where this method is the best economic option
	Demolish and rebuild	- to regain adequate wall strength to support the retained material	- long lengths effected; extensive ground treatment or drainage works may be necessary
Collapse	Demolish and rebuild	- to regain adequate wall strength to support the retained material	- collapsed sections where the wall can no longer support the retained material

8.5 Selection of Repair Method

8.5.1 The Selection Process

For retaining walls there are a limited number of repair methods and the choice is usually fairly clear having established the severity and cause of the defect.

Cracking

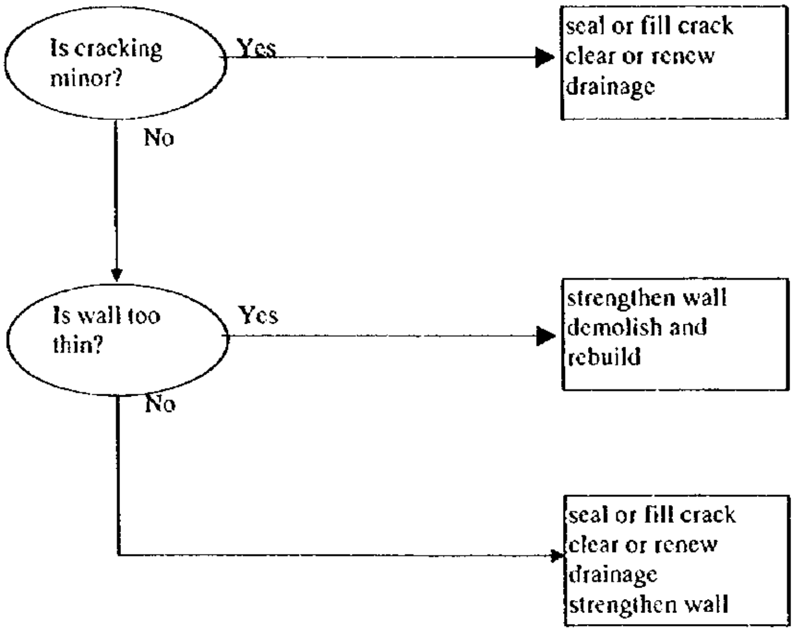


Fig. 8.5.1 Flow Chart for the Selection of Repair Method for a retaining wall with cracking

Settlement

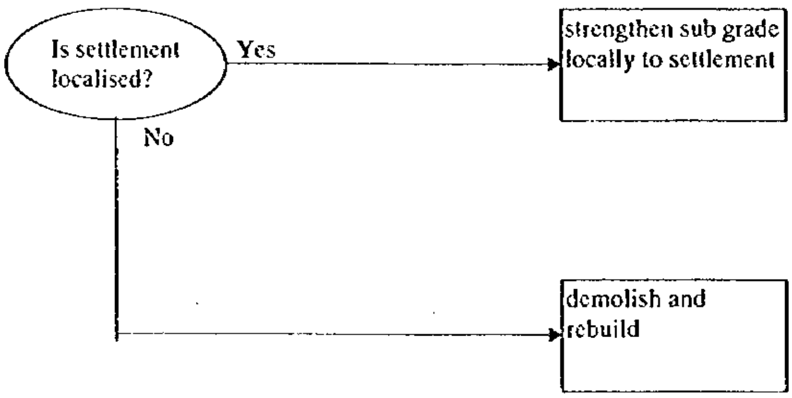


Fig. 8.5.2 Flow Chart for the Selection of Repair Method for a Retaining Wall with Settlement Problems

Collapse

For a wall that has collapsed, the only solution is to rebuild the collapsed section. Where the cause is other than vehicle impact, additional measures may be needed in addition to rebuilding to avoid another collapse e.g. additional drainage, stabilisation of the retained material.

8.6 Design and Construction Matters

Sealing and Filling

This is only suited to situations with minor cracking and minimal displacement. Cracks should be sealed or filled with material in keeping with the original construction materials. Cement mortars may be used in many situations.

Strengthen Subgrade

Before this method is used, any subgrade problems should be identified from supplementary surveys. Where water is softening the subgrade, suitable drainage measures should be introduced to prevent further deterioration.

The subgrade material should be removed in short sections (see Fig. 8.5.1) so as not to introduce excessive stress on the wall foundation. Suitable material should then be placed under the foundation and compacted in layers up to the underside of the foundation. Where compaction is unlikely to be achieved under the foundation, consideration should be given to replacing the softened subgrade with concrete which can be placed and vibrated to prevent voids forming under the foundation. The base of the excavated subgrade should be firm and free from loose material.

Where practical, pressure grouting may be considered as a quick method to improve the subgrade strength.

Demolish and rebuild

All loose material should be removed so that the remaining sections of wall are in a sound structural condition. It is important that the new section of wall is keyed into the old sections to provide structural continuity in the finished wall.

Wherever possible, identical materials should be used to rebuild the wall both from an aesthetic and a structural integrity point of view.

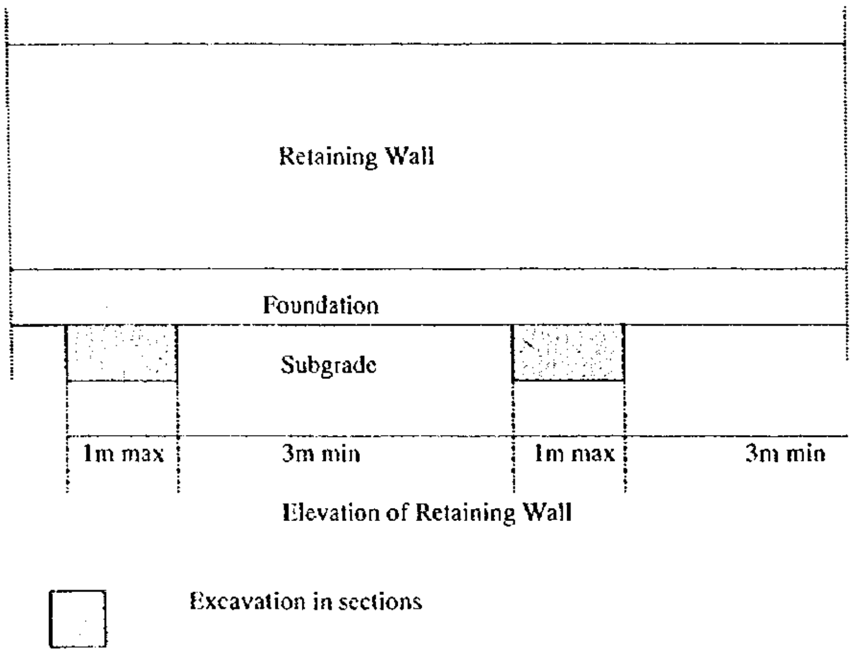


Fig. 8.6.1 Removal of Subgrade in Sections under Retaining Wall

CHAPTER 9 SNOW AND ICE CONTROL FACILITIES

9.1 Standards of Winter Road Maintenance

9.1.1 Service Level

Both state roads and provincial roads are classified into three categories of service level for winter road maintenance as shown below:-

1st level : Road which must always be kept passable
Open 1-lane for 2-lanes road, 2-lanes for 4-lanes road as the minimum requirement
2nd level : Road which is kept passable as much as possible
3rd level : Road which is excluded from winter maintenance

The classification of each road must be revised every year, taking a hard look at the influence of it being impassable when considering the seasonal variation of traffic density. In general, elements to be taken into account for the classification are as follows ;

Importance of road	Traffic density Alternative routes available Road networking Access to public facilities Bus route
Meteorological Conditions	Return periods of snow depth Return periods of daily snowfall amount Return periods of maximum/minimum temperatures
Disasters and Accidents	Frequency of snow drift, avalanche, surface freezing Frequency of car accidents and their causes
Road Structure	Carriageway width Width of sidewalk Width of snow removal Roadside conditions Line forms, traverse slope
Capacity of maintenance	Snow Removal Ice Control

9.1.2 Performance

Performance has two key aspects as follows:-

Target surface condition to be achieved through winter road maintenance
Time needed to perform the target surface condition

The required performance of winter road maintenance depends greatly on the preparation that drivers have made to drive in the winter road conditions. It has, therefore, a strong link with the information systems, through which drivers obtain the weather and road surface conditions so that they can prepare as necessary for their journey. Currently, information systems such as weather warnings through a bulletin board are not used enough. As a result, the surface condition to be achieved should be determined on the basis that drivers neither know the weather and road surface conditions, nor adequately prepare for journey. The target surface condition to be achieved through winter road maintenance should be defined as the condition that enables vehicles to drive at a safe speed whilst keeping the traffic moving.

The regulations requiring the use of snow chains for certain road conditions during winter season results in considerable damage to the pavement. It is recommended that KGM conducts a nationwide campaign to encourage the use of studless snow tires with special tread patterns which are designed to provide improved traction.

The time needed to achieve the target surface condition could be zero for the 1st level road. It is desirable that the operation is carried out without hindering the traffic flow. The winter maintenance operation for the 2nd level roads takes 2nd priority after the 1st level roads. However, it must be carried out whenever possible and the impassable hours should be as short as possible.

9.2 Snow Removal Operation

9.2.1 Principal Procedure

The purpose of snow removal for winter road maintenance is to ensure that the road is safe, that is, to eliminate slippery and hazardous winter conditions and to allow an acceptable flow of uninterrupted traffic under inclement weather conditions

The Principal procedure for the snow removal operation is shown in Fig. 9.2.1. The basic operation is "Removal of New Snow Deposits" and "Removal of Packed Snow". It is desirable that new snow is displaced before it is packed. When there is a heavy snowfall, a quick start and rapid displacement or removal is important.

1. Removal of New Snow Deposits(Snowplowing)
↓
2.Removal of Packed Snow (Snowplowing)
↓
3.Widening
↓
4.Transportation and Disposal
↓
5.Snow Removal of Special Sites

Fig. 9.2.1 Principal Procedure of Snow Removal

9.2.2 Snow Removal Equipment

Various types of snow removal equipment and their roles are summarized in Table 9.2.1.

Table 9.2.1 Snow Removal Equipment and its Role

Equipment	Removal of New Snow Deposits	Removal of Packed Snow	Widening	Transportation and Disposal	Snow Removal at Special Sites
Blade Plow	O		O		
Blade Plow with Side Wing	O		O		
Truck Grader	O	O			
Motor Grader		O			
Rotary Plow (Snow-blower)			O	O	O
Loader				O	O

The majority of snow removal devices fall into two categories, Blade plow (displacement plow), and rotary plow (snow blower). The relationships between various types of equipment design of those categories are shown in Fig. 9.2.1. The blade plow of front-mounted one-way fixed type is the most commonly used snow removal device. Rotary plow of drum type is also commonly used to displace deep and hard snow.

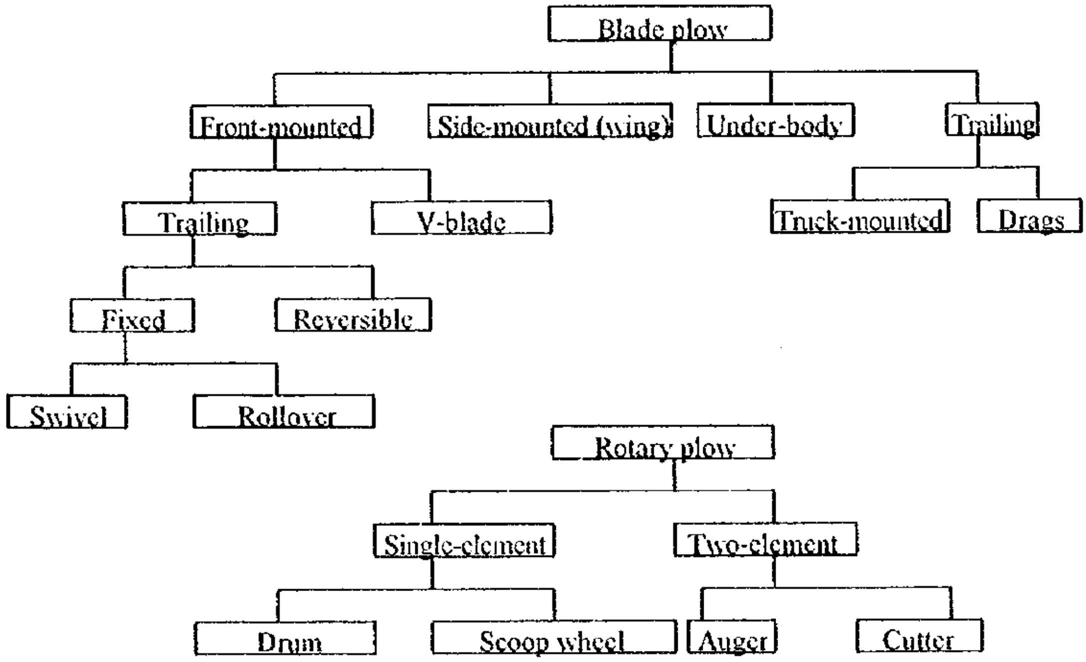


Fig. 9.2.2 Relationships between Various Types of Equipment Design

9.2.3 Snowplowing

It is important to have a clear policy that is easily understood; the technique used for multi-lane roads should be clearance by lane.

Due to the differences in local weather conditions, snow depth, snow wetness and road topography, it is difficult to be precise on the order of lane clearance. Also, local traffic densities and movements vary from day to day and even within in a day, and may affect lane clearance priorities.

In prolonged, heavy snowfall the priority will be to maintain a single lane open. In the majority of cases this will be the more heavily trafficked right lane (lane 1) and the first operation will be to plow snow from lane 1 to the shoulder, with clearance of outer lanes continuing as conditions improve.

Irregular windrows caused by plowing passes, especially those that weave from one lane to another, are dangerous, as they may tempt drivers to overtake by squeezing into the partly cleared lane. Lanes should be completely cleared, and the windrows of snow remaining should form a smooth and continuous lane without sudden encroachments into the cleared path

Speeds of plowing vehicles should be regulated, particularly at features such as under-bridges where snow could be thrown over the bridge parapet and adjacent to a central reserve where snow could be pushed into the opposing carriageway.

The aim is to clear all lanes as soon as conditions permit. Clearance work shall therefore proceed continuously, since a pause during a snowfall could lead to a build-up, which would take a disproportionately long time to clear. Packed snow, glazed by the wind, can be particularly difficult to remove.

Care must be taken to avoid damage to road surfaces, road studs, roadside furniture and structures. At road works, traffic management equipment must not be disrupted. An accumulation of plowed snow creating a ramp adjacent to safety fences and concrete barriers should be avoided.

9.2.4 Snow-blowing

Heavy snowfall, drifting and plowing operations may result in a build up of snow on the road and shoulders. Snow blowers are particularly suited to the clearance of blockages and to remove of accumulations from the shoulder and road where snow may be safely directed onto the verge (or possibly a wide central reservation).

9.3 Ice Control Operation

9.3.1 Purpose of Ice Control

The purpose of ice control for winter road maintenance is to ensure that the road is safe, that is, to eliminate slippery and hazardous winter conditions and to allow an acceptable flow of uninterrupted traffic under inclement weather conditions.

Ice control aims to improve the co-efficient of sliding friction.

9.3.2 Measures and Effects

The most widely adopted measure for ice control is the application of salt and other chemicals, which makes snow and ice melt. To be more exact, it makes the freezing point lower. The application of salt and other chemicals produces the following effects:-

Anti-icing to prevent water on road surface from freezing
Anti-snowpacking to prevent snow on road surface from being packed by tires by weakening the bond between the snow particles and also between the pavement surface and the snow on it
De-icing to make ice on the road surface melt
De-snowpacking to soften snow on the road surface packed by tires by weakening the bond between the snow particles

Fig. 9.3.1 shows the increase with time in the coefficient of sliding friction of a road surface initially covered with 0.6cm of packed snow, following the application of sodium chloride and a 3 : 1 mixture of sodium chloride and calcium chloride.

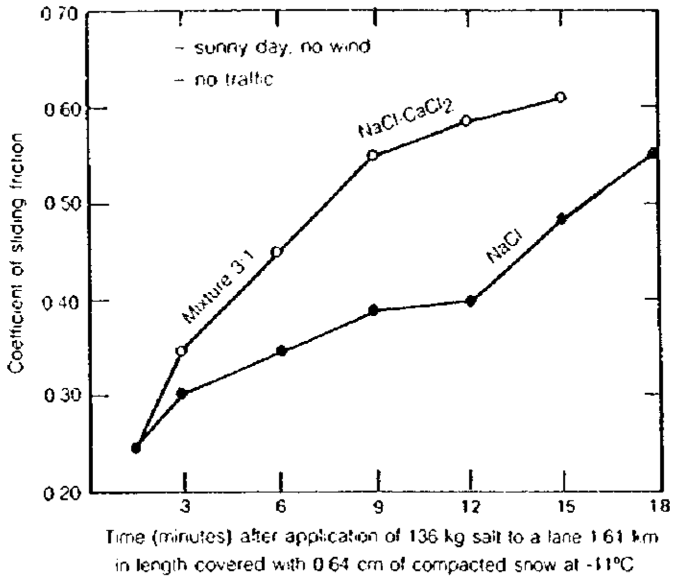


Fig. 9.3.1 Increase with Time in the Coefficient of Sliding Friction of Road Surface

The coefficient increases with time because of the increase in the amount of snowmelt, and as the result the traction increases.

Another measure is the application of abrasives, which increase the coefficient of sliding friction between tires and the road surface. This produces the effect of Physical improvement of the traction of tires running on a slippery road surface.

As the traction increases, the stopping distances of a vehicle decreases. Table 9.3.1 illustrates the decrease in stopping distances if an icy surface is sanded or the ice or snow surface is melted by salt to provide a wet surface.

Table 9.3.1 Effect of Sanding and Salting on the Stopping Distances

Road Condition	Stopping Distance	%
Icy Road at −1°C	143 m	100
Sanded Surface at −1°C	55 m	38
Bare Wet Surface after Salting	20 m	14

The mixture of salt and abrasives is also commonly used on a slippery road, expecting the combined effect of de-icing and physical improvement of tire traction.

9.3.3 Precautionary Treatment

Anti-icing and anti-snowpacking are effective with less spread rate (amount of chemicals per area) than de-icing and de-snowpacking. To be most effective, chemicals should be spread before ice forms, or after snowfall has started, but before snow starts settling on the road. Anticipating these conditions, and reacting correctly, depends on a mixture of local knowledge and experience, good weather forecasts, and the awareness of the current condition of the road (i.e. Is it wet or dry ; is previous treatment sufficient?). It is recommended that KGM makes effective use of the weather forecasting service in near future.

The success or otherwise of the operation depends greatly on the good judgement of those who decide whether or not to treat. Good weather forecasts are essential, but local topographical features or other factors may have to be considered in reaching a decision. It does however take time to acquire this kind of local knowledge, and therefore the continuity of staff is important. The decision will depend on many factors but if the road surface temperature is predicted to fall below plus 1°C, a precautionary treatment should normally take place unless :

No moisture is on or is expected to be on the road ; or

There is sufficient residual chemical on the road to deal with the expected conditions.

Road inspections should confirm residual treatment levels and other information about the road surface condition.

Elevated section of roads, including bridges, and sections lying in low ground or where the topography channels wind-borne cold air, are more prone to freezing and may need special attention.

Spread rates for a precautionary treatment should be 10-20 g/m^2 for salt except in the following circumstances :

If freezing conditions are expected after rain, salt should be spread at 20-40 g/m^2 according to the amount of moisture present and temperature expected. Unless freezing conditions coincide with rainfall, treatment should be delayed as long as possible to reduce loss of salt by run off.

If continuous snowfall is forecast, salt should be spread at 20-40 g/m^2 according to the anticipated severity of the snowfall. It is essential that enough treatment is applied before the snow starts to stick to the road as the treatment will melt the initial snowfall and provide a wet surface beneath subsequent snow making the work of snowplows much easier.

9.3.4 Treatment of Settled Snow and Ice

If ice has formed, salt for de-icing should be spread at up to 40 g/m^2, depending on the amount of ice present and the temperature, to ensure a rapid melt. Particular attention should be paid to lengths of road, which are known to be susceptible to 'run-off' water from verges or central reserves. Although the road itself may be dry, accumulation of snow may melt, run onto the road and then re-freeze.

Snow accumulations exceeding 30mm in depth are best removed by plowing. Each pass of the plow should be supplemented by salt spread at 20 g/m^2 to prevent the remaining snow from compacting and to aid disposal by traffic and subsequent plowing.

It is important to monitor air temperature and if the temperature drops, the spreading rates should be increased to 40 g/m^2 if necessary. Vehicle mounted thermometers can be misleading. Proprietary ice sensors placed at roadside sites, or thermometers at suitable open sites in compounds, or similar systems are a great help for such decisions.

Even light snowfalls may call for plowing where local drifting has occurred, or to remove snow not dispersed by traffic. This may occur where the traffic is reluctant to use lane 2 or at night when traffic light.

During prolonged falls of snow, plowing should be continuous to prevent build-up and be supplemented by simultaneous salting at a rate of 20-40 g/m^2.

If snow reaches 120 mm in depth, or when tackling drifts, or working on gradients, it may be better to plow without spreading, as the weight of the treatment load will aid vehicle traction. As soon as the situation is under control, spreading should be resumed. Use of a snowblower may also be considered for removal of deep snow.

Plowing or snowblowing is not practical in built up areas. Repeated applications of chemicals for de-icing can remove heavy accumulations, but this type of treatment is not otherwise recommended, as it is likely to provide as unacceptable surface for traffic. In this case consideration shall be given to the use of a snowblower with the snow being directed into an accompanying lorry, followed as soon as possible by salt spreading at 20 g/m^2. The formation of packed snow and ice should be rare if other recommendations are followed. If it does occur, provided it is no more than 20 mm thick and the air temperature is above minus 5°C, removal is possible by using successive treatment of salt at 20-40 g/m^2.

Great care must be taken as the use of chemicals for de-icing or de-snowpacking on the snow/ice can result in an uneven and slippery surface. If there is any danger that the surface will be unacceptably slippery, then the addition of abrasives should be considered.

Reversion to be the initial treatment technique shall be made as soon as possible since abrasives don't contribute to the removal of snow/ice and may block drains and gullies on thawing in the sections where they exist. Abrasives shall not be used on structures where is any danger of blockage to drains.

9.3.5 Treatment in Sustained Low Temperatures

For each degree drop below minus 5°C, the amount of salt needed to maintain the equivalent melting effect increases by about 14g/m^2. Where traffic is reasonably heavy, little or no increase is needed until sustained temperatures fall below minus 10°C. When sustained temperatures do fall below minus 10°C , one method that has proved to be effective is the addition of calcium chloride mixed with 4 parts of salt. Calcium chloride is expensive and difficult to store as it absorbs moisture freely.

9.3.6 Summary of Spread Rate

The spread rates of salt described above are summarized in Table 9.3.2.

Table 9.3.2 Summary of Principal Treatment for Settled Snow/Ice

Road surface Conditions	Treatment		
	Effect	Salt spreading	Plowing
Wet	Anti-icing	10-20 g/m^2	Not possible
Continuous snowfall forecasted	Anti-snowpacking	20-40 g/m^2	Not possible
Ice formed	Anti -icing	20-40 g/m^2 for rapid melting	Not possible
Moderate snow	Anti-snowpacking	20 g/m^2 to supplement plowing up to, 40 g/m^2 if temperature falling	Required (depth must exceed 30mm)
Prolonged snowfall	Anti-snowpacking	20-40 g/m^2 to supplement plowing	Continuous (without salting if necessary to aid traction)
Hard packed snow/ice	De-packed snow/ice	Successive treatments 20-40 g/m^2 (supplemented by abrasives if necessary)	Not possible

9.3.7 Spreading Techniques

Purpose built winter maintenance vehicles offer the opportunity to achieve a substantial saving in labor costs. In particular, the use of powered systems to control spreading eliminates the need for a second man in the cab during precautionary treatment. The use of driver and mate shall be restricted to snowplowing and to other occasions when conditions are hazardous, (e.g. when precautionary or emergency treatment is required on particularly isolated stretches of road, when difficult maneuvers are unavoidable or when visibility is poor). In compounds and depots where hoppers are provided, the drivers can load vehicles.

To be effective, salt should be spread evenly and at rates that suit the prevailing or expected conditions. Care should be taken to ensure that spread widths are neither too wide nor too narrow. The treatment should be spread by automatic machines, the controls of which shall be calibrated and clearly marked for distinct rates of spread, up to a maximum of 40 g/m^2.

Higher spread rates are unnecessary, wasteful, and environmentally harmful and shall be avoided.

Crosswinds can affect the distance that treatment is spread and to compensate it may be necessary to spread from a lane upwind from that normally chosen. In exceptionally strong winds it may be necessary to undertake a second treatment run with the spreader set asymmetrically into the wind.

Due consideration should be given to traffic conditions and the timing of winter maintenance operations. Wherever possible without detriment to the effectiveness of the treatment, precautionary salting should be undertaken in off-peak periods when disruption to traffic will be minimized and the proper distribution of the salt will be achieved. If precautionary treatment in heavy traffic is unavoidable it may be necessary to seek Police assistance or to consider treatment in two runs to ensure proper distribution of the salt.

Care should be taken at roadworks that in addition to areas currently being trafficked, all other areas likely to be opened to traffic are treated. Traffic management equipment, including cones and cylinders, may disrupt the distribution of salt; contraflow systems should be treated in both directions.

9.3.8 Routes

However well vehicle operational routes are planned, a certain amount of wasteful duplication (dead mileage) is inevitable because of network complexities and the siting of compounds and depots. Dead mileage should be kept to a minimum, but first condition shall always be given to the need to achieve the required treatment time.

Routes should be reconsidered whenever major roadworks may affect the winter maintenance operation.

9.4 Snow Drift Control Facilities

9.4.1 Basic Principles of Snow Drifting

There are three major factors governing the formation of drifts:-

Snowfall Amount and Snow Properties
Wind Speed and Wind Direction
Terrain (including obstacles) over which the windblown snow is carried

As each factor is extremely variable, it is difficult to predict the amount of drifting that will occur at a given site without the aid of field observations taken over a number of years.

The physical properties of snow, particularly the cohesion of its surface, determines the ease of drifting. If thawing and subsequent refreezing of the surface forms a hard crust, the individual snow grains will be firmly cemented. Wind action itself is a compacting mechanism, creating, after some hours, a surface capable of withstanding velocities that would ordinarily cause drifting in loose, fresh snow. This implies that most drifting occurs when snow is falling or during the first day or so immediately following the end of the snowfall. Once snow accumulates into drifts it tends to remain until it melts.

Snow accumulation depends on the shape of the obstructions, their number and the wind speed and direction. The general patterns shown in Fig. 9.4.1 are at best approximate guides to what can be expected in nature. The effect of embankment slope on the amount of drifting is well exhibited in Fig. 9.4.2.

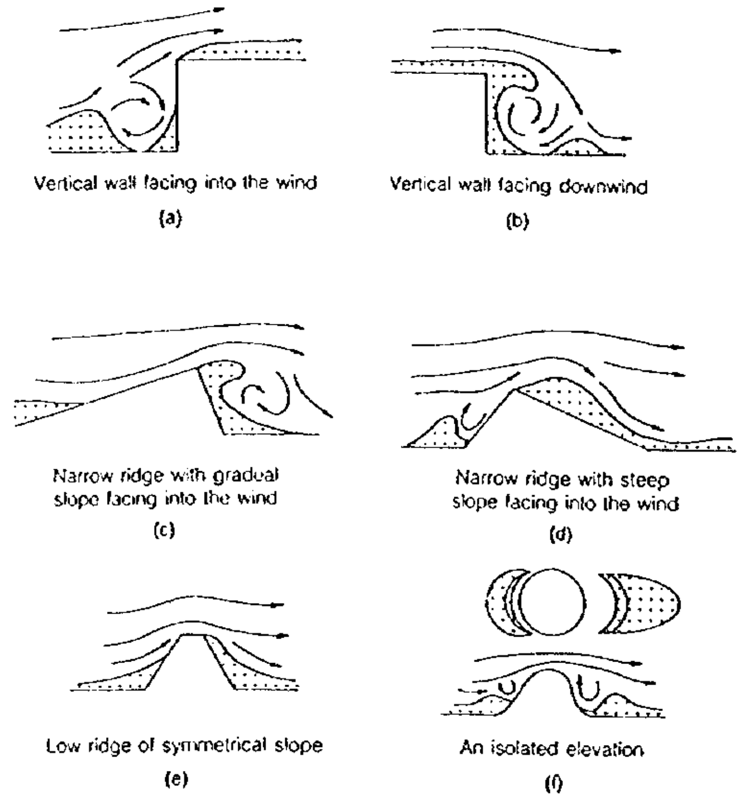


Fig. 9.4.1 Accumulation of Drifting Snow caused by some Typical Obstacles

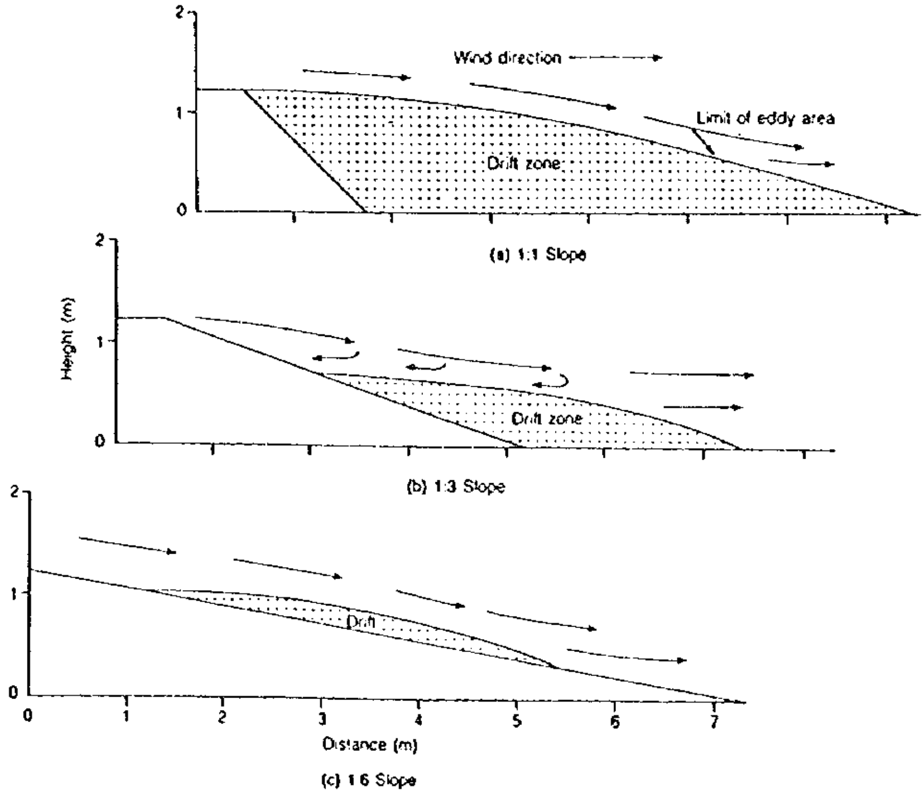


Fig. 9.4.2 Effect of Embankment Slope on the Amount of Drifting

9.4.2 Types of Snow Drift Control Facilities

Facilities to control snow drifting widely adopted at present are:-

Living Tree Fence
Snow Fence
Snow Shelter

9.4.3 Living Tree Fence

The objective in planting living trees is to cause the snow to be deposited before reaching the area to be protected (the road). Hedges and rows of trees provide effective protection and help to beautify the landscape.

Species should be low growing, dense near the ground, frost resistant and adapted to a wide range of soil and climatic conditions. By the end of winter the hedges may be covered with deep snow, therefore the individual trees and shrubs must be able to carry the load

The main disadvantages in using trees and hedges are that they require several years to grow and once planted are not easily moved to correct for any errors made in the initial site selection and orientation. Hedges need not be higher 2.5m.

9.4.4 Snow Fence

The most common method of snow drift control is with snow fences. Because the snow-carrying capacity of the wind is approximately proportional to the cube of its speed, even small reductions in speed will produce substantial deposits of snow. A snow fence is designed to reduce the wind speed, therefore causing snow to deposit. Normally, places where drifting occur are known from experience, or in the case of new installations, have been observed during the first few years. Without this information the effectiveness of a snow fence will be uncertain. It is placed upwind of the area to be protected and oriented perpendicular to the direction of the snow-carrying wind so that snow deposited in front of and behind it.

Various types of snow fences and configurations of snow deposits are shown in Fig. 9.4.3. The sloping type of fence is rarely used because it reduces the effective height.

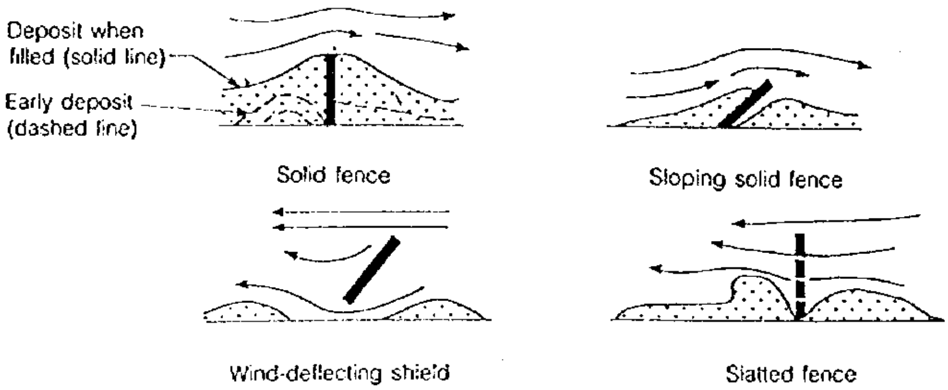


Fig. 9.4.3 Accumulation of Snow at Various Types of Snow Fences (Rickhter, 1945)

Economics, availability and space limitations determine the type of materials and arrangement used for fences. The wind pressure is less on the slatted fence and so it can be fabricated from lighter material. Vertically slatted fences are the most common. Since a solid fence or wall produces a shorter deposit on its leeward side than on its windward side, it is most suitable when space is limited. The major disadvantages of solid fences are the high cost of materials and the need for a strong foundation.

The expected depth of snowfall and the quantity of drifting snow associated with the snowfall are decisive factors in selection. Observations of the conditions under which drifting occur must be made. If drifting occurs when the snow is shallow the required fence height will be substantially less than that if drifting only occurs during and after heavy snowfalls. For areas with light to moderate snowfalls fence heights between 1.2 and 1.8m are usually sufficient. Even in places of heavy drifting two parallel rows of relatively low, inexpensive slatted snow fence may be more economical than one high fence that is more expensive to construct.

The base of the fence should lie above ground level. A ground gap tends to produce vortices immediately in front of and behind the fence, preventing filling in or choking at least until the deposit reaches the bottom of the fence; the gap also reduces the potential for the fence to rot due to moisture. The size of the gap will vary with the type of fence and amount of snow. Some authors recommended a gap about one-seventh the height of the fence, i.e., ~17cm for a 1.2m fence may be recommended.

The smaller the density ratio (the ratio between the solid area and the total area of the fence), the longer and shallower the drift. The maximum collecting capacity of an open fence occurs for a density ratio between 40 and 60 percent. The density of an open fence might be the most important factor in determining the volume of snow deposited. Tests in the field and in wind tunnels have demonstrated that the slat arrangement (vertical or horizontal, slightly inclined) or material (wood, metal or other) is not important.

The optimum distance of the fence from the object or area to be protected will vary with wind and snow conditions. In practice, unless better information is available, open fences should be placed upwind at a distance from the object of fifteen to twenty times their height.

Fig. 9.4.4 shows the relationship between fence density and distance of the fence from the protected area e.g. a fence with a height of 2m and a density of 50% should be approximately 26m from the protected area. In practice, other factors such as land ownership or building location often determine the siting of a fence.

Since the length of the deposit formed behind a solid fence is about ten times the height of the fence, this distance should be maintained between the fence and road. When a solid fence is longer than the width of the road to be protected and closer than five times its height, a strong eddy occurs between the fence and the road so that this space is usually snow free. It could be easily filled, however, if the wind direction was oblique rather than perpendicular.

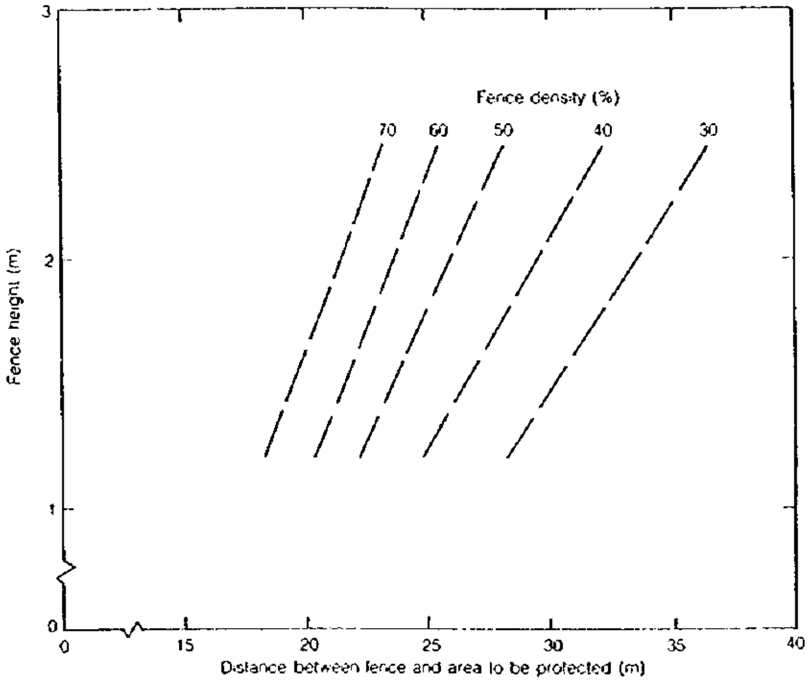


Fig. 9.4.4 Relationship between Fence Height, Fence Density and Distance between Fence and Area to be Protected

As a general rule if the wind-blown snow originates from more than one direction, which is frequently true, several protective fences may have to be installed. In regions where large quantities of drifting snow can be expected, snow fences are arranged in rows, at a recommended separation of about 10 times their height. Some basic row arrangements are presented in Fig. 9.4.5. The arrangement selected depends on the prevailing wind direction and its expected variation. Other factors such as the available space, soil condition, and the depth of snow must also be considered. The first arrangement will rarely give satisfactory results and field observations of the shapes of the deposits are necessary before the best locations can be selected.

Tall fences are more efficient than short ones in trapping snow. The reduction in wind speed behind the fence increases with it height. Since most of the blown snow is transported in a shallow layer adjacent to the ground or snow surface, the reduction of wind speed in this layer is responsible for the increase in catch rather than the capture of additional snow in the higher layers.

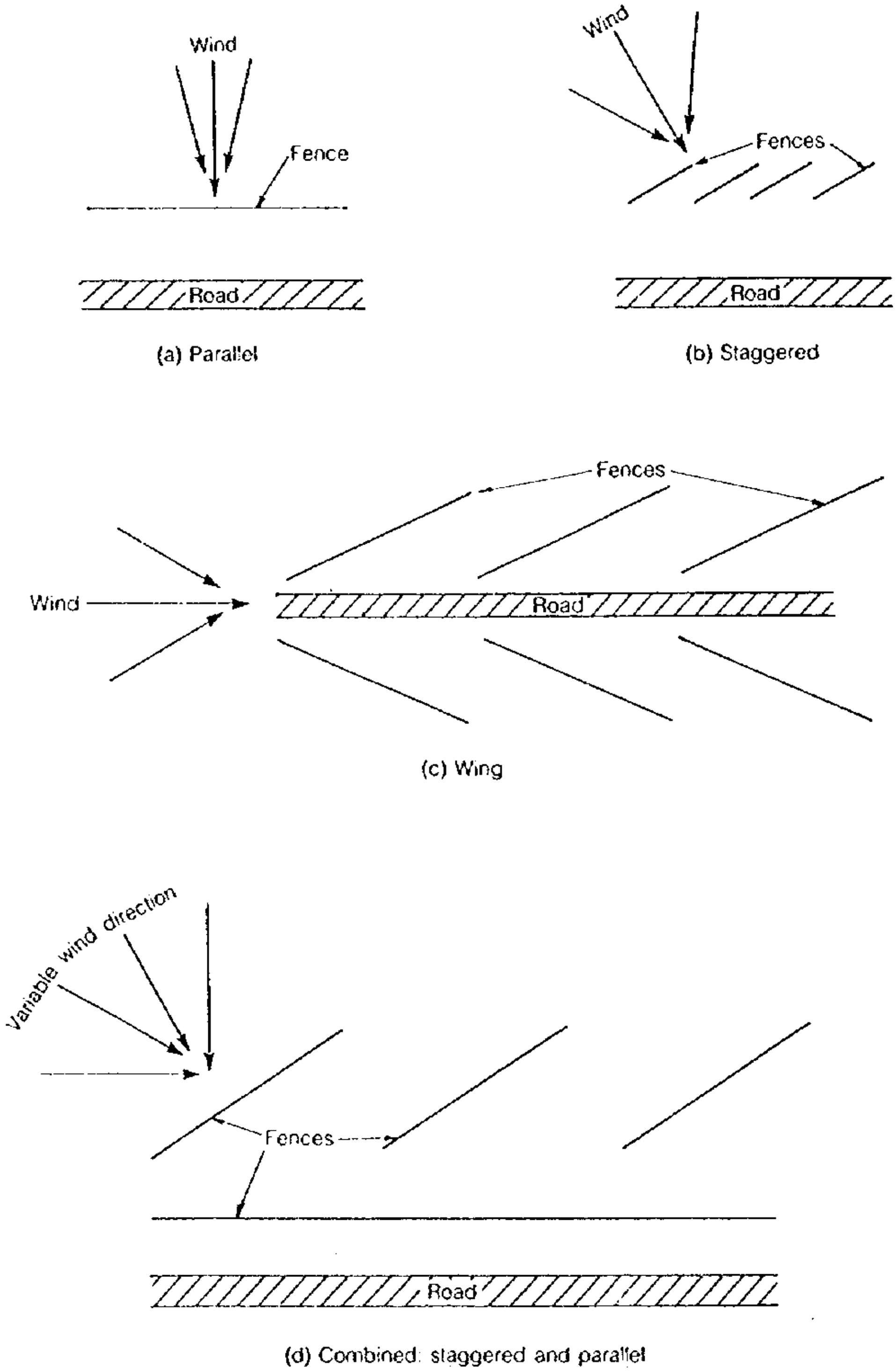


Fig. 9.4.5 Basic Arrangements of Snow Fences (Pugh, 1950)

9.5 Avalanche Control Facilities

9.5.1 Basic Principles of Snow Avalanches

The snow deforms readily under its own weight resulting in settlement, creep, and glide. Additional tensile and compressive stresses appear at anchor points such as rocks, trees, and flat parts of the terrain. Failure occurs when the stress exceeds the strength at some point. Stresses in a snowpack are increased by the weight of additional snowfall or the accumulation of drifting snow, but a decrease of strength most frequently results from a rise in temperature. After the snow has failed at one point, this causes a rupture to propagate over a wide area.

The variation in creep velocity along a slope produces different tensile and compressive stresses in the snow as shown in Fig. 9.5.1. It is important to identify zones of high stress because snow fractures and starts an avalanche at places of high tensile stress.

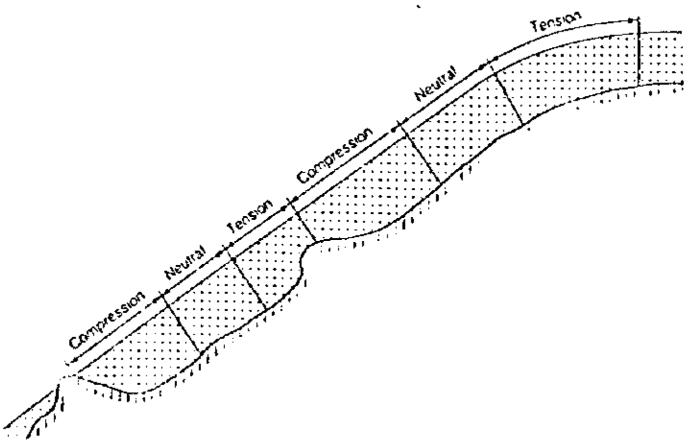


Fig. 9.5.1 Stress Distributions Developed under Creep and Glide Deformation

The dislodged snow usually accelerates rapidly on a steep slope and, as it moves downhill, breaking delicately balanced snow and the loose terrain. During the initial state of movement the snow has a gliding and rolling motion which becomes turbulent and the material is pulverized.

If the snow is dry, the fine particles mix with the air to form a powder. The component that follows the ground is known as a flowing avalanche; that carried by the turbulent air motion, a powder avalanche. Often both forms are present. A drop in the terrain may cause all the snow to mix with air producing a pure powder avalanche.

On a steep slope an avalanche may attain a high speed and exert great pressures on obstacles in its path, thereby becoming destructive. As the slope of the terrain decreases the avalanche decelerates and finally stops.

An avalanche path is the specific locality in which a snow mass moves. It is generally divided into the starting zone at the top where the snow initially breaks away, the runout zone at the bottom where the snow decelerates and stops, and the track that connects the starting zone with the runout zone. On the track, the speed of the avalanche may increase, remain steady, or decrease, while its mass remains more or less constant. Often there is no clear separation between each stage.

Minimum inclines of around 25° are required to initiate avalanches and maintain their motion. The runout zone begins where the angle of the slope drops below this minimum value and can usually be recognized by a break in the terrain.

9.5.2 Avalanche Control Measures

The choice of a particular avalanche protection measure depends on the level of protection required, the terrain, type of avalanche prevalent in the area and cost. Avalanche control measures influence the start or course of avalanches and can be divided into the two categories shown below:-

Modification of the terrain
Modification and stabilization of the snowpack.

The implementation of control measures which would completely eliminate the avalanche hazard, and damage is impractical and uneconomical. The more common practice is to accept those measures that reduce the hazard to some acceptable level.

9.5.3 Modification of Terrain

In avalanche control and protection work, terrain modifications include those structures and earthworks that are constructed either to prevent the release of avalanches or deflect the sliding snow away from the facilities to be protected.

9.5.4 Supporting Structures

Supporting structures or retaining barriers are used in the starting zones of avalanches. The functions are:-

To provide external support to the snowcover, thereby reducing the internal stresses within the snow,
To produce a discontinuity in the snowcover, thereby limiting the propagation of a fracture and the resultant size of the avalanche, and
To stop small avalanches before they gain sufficient momentum to cause major damage.

Supporting structures are earth terraces, posts and masonry walls. Today the structures are made out of wood, steel, aluminum, concrete, and various combinations of these materials. Supporting structures are expensive because of their large physical size. They must be at least as high as the deepest snow, usually between 3 and 5m, capable of resisting the forces produced by creeping snow and small avalanches, and of covering the full width and length of the starting zone. Because of their high cost, supporting structures can only be justified for the protection of inhabited areas or for installation at sites where the starting zone is small.

Temporary low cost structures of wood are often used on reforestation projects to protect young trees from snow creep and avalanches. These temporary structures weather and decay.

However, they generally last sufficiently long for the trees to grow large enough to provide natural avalanche protection.

9.5.5 Snow Fences and Wind Baffles

Collector fences and baffles control drifting snow that would contribute to avalanche formation. The structures have proven effective in reducing avalanches but do not eliminate them. They are generally used in combination with supporting structures for the control of avalanches as well as cornices. Cornices can be a hazard when they break and roll on a road; occasionally they may start an avalanche. The function of collector fences, which are usually 4 to 6m high and located on the windward side of ridges is to decelerate the wind velocity and to retain blowing snow. Conversely, wind baffles are either vertical walls about 4m high and 2m wide or jet roofs (blower fences) made of inclined boards 4m long.

9.5.6 Deflectors

Deflecting structures are used as protection devices in the track and runout zones of avalanches. Three major types are commonly used: dykes and walls, splitting wedges and galleries. Deflecting dams or walls intercept avalanches and direct the flow to an area where they can run out harmlessly as shown in Fig. 9.5.2.

Action of a deflecting wall.

P_f = friction stress which acts parallel to the wall.

P_v = pressure normal to the deflecting wall produced by impact of the avalanche

V_a = average "design" velocity of the avalanche, and

α = angle of incidence of the avalanche to the wall.

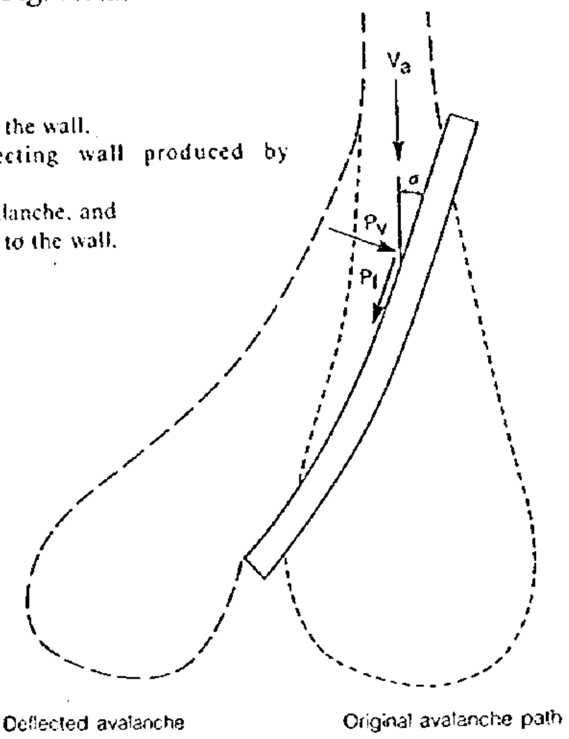


Fig. 9.5.2 Action of Deflecting Wall

Guiding dams or walls are constructed parallel to the direction of the avalanches and confine it in a narrow channel; they are often used in combination with galleries. Most are built as earth banks but may be concrete or steel walls, gabion walls and cribs.

Dykes and walls are effective against flowing avalanches, but do not control powder avalanches. Deflecting dykes for avalanche control can essentially only be used in areas having enough space for the deflected avalanche to run out harmlessly, but this often limits their application.

9.5.7 Retarding Works

Retarding works, also called breakers or arresters, are obstacles located in the path of avalanches, whose function is to slow down or stop the avalanche. These works are effective in controlling wet flow avalanches but they are ineffective against powder avalanches. The most common type, which has proven both economical and efficient, is massive earth mounds, which are usually from 4 to 10m high arranged in two or more rows. Other types are wall and earth and snow dykes. Dykes stop very slow avalanches but are easily flooded by rapidly moving large avalanches.

The best location of a retarding structure is on flat terrain near the end of the runout zone. As a general rule, retarding structures should not be built on slopes steeper than 20 degrees.

9.5.8 Protection by Forests

The cause of many early avalanche disasters can be traced to the extensive deforestation accompanying habitation. As the population in the mountains regions increased, forests were often removed to obtain more grazing land. Avalanches began to run on denuded mountains where there had been no history of occurrence. A forest with high trees in the starting zone inhibits the formation of avalanches because:-

The tree trunks support the snowcover and anchor a potential slab avalanche,
There is little snow drifting,
The crowns of the trees retain snow and release it gradually to form a stable cover on the ground,
The forest canopy moderates variability in the net energy exchange with the snow surface which tends to produce a uniform snow temperature distribution and stable snow.

To be effective for avalanche control, the forest must be dense, i. e. the spacing between young trees should not exceed 3m. An open forest offers no protection against avalanches. A forest in the track and runout zone would probably stop small and slow avalanches but would not inhibit the progress of large avalanches. When avalanches break trees, the trees are carried in the flow, thereby increasing its mass destructive power.

In potential avalanche zones the forest must be protected from fire. Also logging projects on steep terrain should be investigated as to their potential impact on the avalanche hazard. The most important consideration is the preservation of the trees in potential avalanche starting zones and at ridge tops.

A large avalanche denudes the slopes of trees. The areas can only be reforested with great difficulty. In the meantime, temporary supporting structures should be made large enough to provide natural control.

9.5.9 Use of Explosives

The prevention and control of avalanches by snowcover modification is a more versatile and usually a much cheaper procedure than terrain modification. However, it is only a temporary measure that must be undertaken every winter.

The artificial release of avalanches by explosives is the most widespread protective method. Explosives are most effective in inducing avalanches if they are placed in the starting zone at the time when the stress-strain relationship of the snow is critical, yet before the unstable snow is deep enough to produce large avalanches.

9.5.10 Safety Measures

Several safety measures are employed in an attempt to reduce the possibility of disaster from avalanches, such as closures, avalanche detection, warning systems and warning signs. The simplest means of preventing disaster is to impose restrictions on the use of roads during high hazard periods.

The effectiveness of these measures depends on the reliable evaluation of the daily hazard by a person capable of recognizing when a dangerous condition may begin and end. Preventive closures of roads with low traffic volume may be frequent but for major traffic routes are accepted only when they are short and infrequent.

A major problem in effecting closures as a safety measure is enforcement. Traffic can usually be controlled by warning notices posted on low volume private roads, such as forest and mine roads, but only by strong, physical barriers and police patrols on public highways.

9.6 General Procedure for the Selection of Optimum Snow/Ice Measures

General procedure to select the optimum measures against snow/ice hazards is shown in Fig 9.6.1.

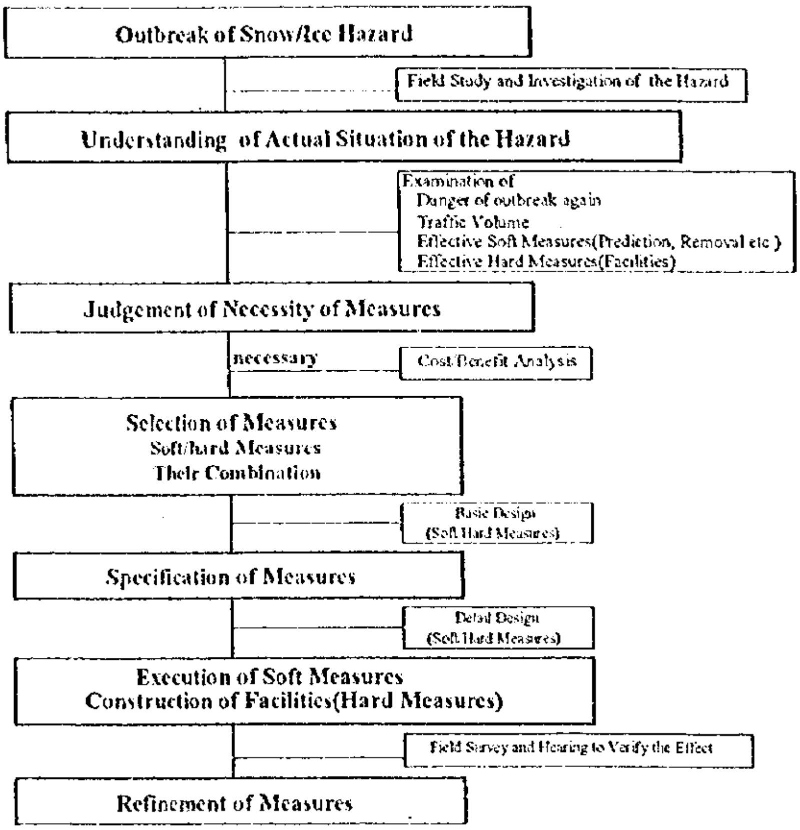


Fig. 9.6.1 General Procedure to Select the Optimum Measures against Snow/Ice Hazards

Appendix A

Sample Calculations for Overlay Design

Overlay Design using CBR equivalent thickness method

Section Reference	
Section	100-10
km	40-41
Sub Div.	17
Surface	AC
Lanes	4

1. Equivalent Thickness of the Existing Pavement

Core Sample			
Material	Depth (cm)	Layer Coefficient	T_{AO}
Asphalt Concrete	5	0.5	3
Binder Course	7	0.5	4
Bituminous Base	10	0.5	5
Base	20	0.3	6
Sub Base	20	0.2	4
Total equivalent depth (cm)			21

2. Required thickness of pavement

Traffic Volume				
Vehicle class	AADT 1996	Growth Rate	Average Traffic	One way Traffic
Truck	2917	5%	3918	1959
Trailer	149	2%	171	86
Bus	678	4%	929	465
Total				2509
Total after applying lane factor				2509
Traffic Classification				C

Overlay Life (years)
5

Overlay year
1999

Lane Factor
1

3. CBR Value from site: 10

4. Target value of T_A (cm) for the design CBR value of the Subgrade and Traffic Volume

Design CBR value of subgrade	Traffic Volume Classification				
	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

Target T_A value =	-	13.5	18	24.5	32

Overlay depth required	=	24.5	-	21
	=		3.5 cm	
Recommended overlay depth			**4 cm**	

Date of calculation
23/03/98

Overlay Design using CBR equivalent thickness method

Section Reference	
Section	650-12
km	(36-37)
Sub Div.	134
Surface	ST
Lanes	2

1. Equivalent Thickness of the Existing Pavement

Core Sample			
Material	Depth (cm)	Layer Coefficient	T_{AO}
Surface Course	5	0.5	3
Base Course	20	0.2	4
Sub Base	25	0.2	5
Total equivalent depth (cm)			12

2. Required thickness of pavement

Traffic Volume				
Vehicle class	AADT 1996	Growth Rate	Average Traffic	One way Traffic
Truck	1587	5%	2426	1213
Trailer	49	3%	61	31
Bus	309	6%	514	257
Total				1501
Total after applying lane factor				1501
Traffic Classification				C

Overlay Life (years)
10

Overlay year
1999

Lane Factor
1

3. CBR Value from site 10

4. Target value of T_A (cm) for the design CBR value of the Subgrade and Traffic Volume

Design CBR value of subgrade	Traffic Volume Classification				
	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

Target T_A value =	-	13.5	18	24.5	32

Overlay depth required	=	24.5	-	11.5
	=			13 cm
Recommended overlay depth				**13 cm**

Date of calculation
23/03/98

JICA