



**Indian Roads Congress
Special Publication 42**

**GUIDELINES ON
ROAD DRAINAGE**

New Delhi 1994

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GUIDELINES ON ROAD DRAINAGE

National Highways Authority of India
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GUIDELINES ON ROAD DRAINAGE

1. INTRODUCTION

1.1. Adequate drainage is a primary requirement for maintaining the structural soundness and functional efficiency of a road. Pavement structure including subgrade must be protected from any ingress of water, otherwise over a period of time it may weaken the subgrade by saturating it and cause distress in the pavement structure. That is why rapid dispersal of water from pavement and subgrade is a basic consideration in road design. Also, quick drainage takes away the water from pavement's surface and reduces chances of skidding of vehicles. Because of inadequate surface drainage, the structural stability of pavement is undermined by :

- (i) weakening of pavement structure and subgrade through infiltration of water from the top, and
- (ii) erosion of shoulders, verges and embankment slopes caused by water running off the pavement.

1.2. The role of proper drainage to ensure longevity of pavement has been emphasised in IRC:37-1984 "Guidelines for the Design of Flexible Pavements". Among the measures mentioned therein to guard against poorly drained conditions are maintenance of transverse sections in good shape to reasonable cross fall so as to facilitate quick run-off of surface water and provision of appropriate surface and sub-surface drains, where necessary. Some other measures, such as, extension of granular sub-base over the entire formation width, provision of drainage layer, adequate height of formation level above HFL/ground level etc. are also mentioned. Infiltration of water under the pavement through adjoining earth shoulders (verges) is also a major cause of weakening of the pavement. Road design must take this into account.

1.3. Despite measures for quick drainage of pavement surface as well as provision of a fairly watertight surface, water enters from top and travels through various pavement layers and gets accumulated at

the interface of sub-base/base course and subgrade specially in a boxed type pavement section causing considerable functional problems. While in new road construction, this aspect could be taken care of by providing a drainage layer at this level, in the existing boxed type pavement construction, this is an acute problem and special measures need to be thought of and taken as per actual site requirements for draining out the locked water.

1.4. A clear idea about internal drainage of a pavement structure including permeability reversal conditions obtaining where an impervious/less pervious course is overlaid by a pervious/more pervious course, for example, a stabilized soil layer overlaid by water bound macadam, is essential because many pavement structures malfunction on account of inadequate drainage provisions. Mechanism of failure on account of inadequate drainage facilities in a pavement system should be understood and suitable remedial measures taken against it to ensure desired performance during the service life of the pavement.

1.5. Considering the importance of drainage, the Drainage Committee of IRC in one of its meetings decided that separate guidelines covering specific requirements for different situations such as rural (plain and rolling), hilly and urban sections of roads and airfield pavements should be prepared. These guidelines on road drainage are the first such guidelines on this subject in this country. They are applicable in non-urban (rural) road sections in plain and rolling terrain.

1.6. Initial draft of these guidelines was prepared by S/Shri Rajendra Kumar Saxena, Convenor and Indu Prakash, Member-Secretary, as per the decision of the Drainage Committee at its meeting on 28.10.1988. Earlier S/Shri R.P. Sikka and J.B. Mathur had prepared two chapters on Design of Surface Drains for the draft document on Drainage for the consideration of the Drainage Committee. The material of these two chapters have been appropriately utilized in the preparation of the initial draft of the present guidelines. Contribution was also made by Shri R.D. Mehta in preparation of the final draft which was discussed by the Drainage Committee (personnel given below) at its meeting on 28.7.1989 and was approved subject to some modifications. The Committee also authorised S/Shri Rajendra

Kumar Saxena, Convenor and Indu Prakash, Member-Secretary to bring out the final draft version incorporating the approved modifications.

Rajendra Kumar Saxena
Indu Prakash

... Convenor
... Member-Secretary

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1.7. The Highways Specifications & Standards Committee discussed the guidelines in their meeting held on 30.10.90 and a group consisting of Convenor, S/Shri R.K. Saxena & J.B. Mathur was constituted to finalise the document based on the comments of members. The Member-Secretary, Highways Specifications & Standards Committee has forwarded modified guidelines to IRC Sectt. on 19.5.93. The approval of Executive Committee on the modified draft was obtained through circulation. Thereafter modified guidelines were approved by Council in their meeting held on 19th June, 1993 at Pondicherry, subject to certain modifications to be carried out by the Convenor, Highways S & S Committee on the basis of comments of members. Accordingly, the Convenor, HS&S Committee had forwarded modified

guidelines on 2-2-1994 for printing as one of the publications of IRC.

2. SCOPE

These guidelines deal with drainage of non-urban (rural section) roads running through plain and rolling areas. The aspects covered are influence of alignment and geometrics of the road drainage of shoulders, verges and median (central verge), internal drainage of pavement structure, drainage of subgrade, drainage of high embankment and surface and subsurface drains. Examples of estimation of peak run off and hydraulic design of surface drain are also given. However, it may be noted that drainage of urban roads, hill roads, air-field pavements and cross drainage structures have not been covered under these guidelines since separate guidelines on these subjects are proposed to be brought out later on.

3. GENERAL CRITERIA

3.1. Alignment of the road can have a vital bearing on the problem of drainage. Therefore, in case of new roads surface drainage should be one of the criteria in fixing proper alignment. For example, locations parallel to large streams and running close to them are likely to give rise to constant trouble besides several converging tributaries would be needed to be crossed. An ideal alignment should avoid steep and heavy cuts/fills as these situations have the potential of throwing up piquant problem of drainage and erosion control. Problems of these types are often prominent in rolling terrain since alternate cuts and fills, unless designed with an eye on the smooth dispersal of surface water, could play havoc with the natural drainage of the area and give rise among other difficulties to subterranean flow under and across the road. In each case where cutting is involved meticulous care is needed right at start to anticipate the strength of the drainage courses so that necessary design measures to avoid instability of the road can be taken. No doubt surface drainage is just one among many other considerations in road location but it warrants careful attention which should be given.

3.2. Normally in plain areas road subgrade elevation in fill sections

is so fixed that the difference between formation level (top of sub-grade) and highest water table/high flood level is not less than 0.6 to 1 metre and between formation level and ground level not less than 1 metre. However, in sandy areas and deserts it will be preferable that the road is taken on natural ground surface or in slight cutting or filling, if that is necessary to satisfy the ruling gradient of the road. In such a terrain, high embankment is likely to be eroded easily, while cuts are likely to be blocked by sand storms. In cut and fill sections and hill roads where it may be difficult to satisfy the said 0.6 to 1.0 m criteria, drains may be provided to lower down the water table.

3.3. If a consolidated view is taken, there are three aspects of surface drainage design in which the road engineer is particularly interested. First of all he is concerned with fast dispersal of precipitation on the road surface so as to minimise danger to moving vehicles. This is achieved by proper geometric design of the road, e.g., by crowning the carriageway or one side cross fall, giving proper cross slope to the shoulders and verges, providing requisite longitudinal gradient etc. Second requirement is that water from road and the surrounding area shall be successfully intercepted and led away to natural outfalls. This is accomplished by a system of suitable surface drains, shallow ditches by the side of the road or deep catch water drains on the hill slopes. Thirdly the engineer must build adequate cross drainage structures at river crossings and minor streams.

3.4. Survey and investigations is a basic necessity for designing a system fulfilling the above objectives. The work may involve :

- (i) preparation of alignment plan, longitudinal and cross sections and contour map;
- (ii) hydrological survey such as rainfall analysis and run off estimation;
- (iii) hydrographical survey and
- (iv) geotechnical investigation.

Recourse to remote sensing methods such as aerial photography and satellite remote sensing can be made if necessary facilities are available. The factors which may have bearing on road drainage such as rainfall, topography and natural drainage of the area, crossfall and longitudinal profile, existing drains and internal drainage of pavement layers etc. should be recorded.

4. ROAD GEOMETRICS

4.1. Longitudinal Gradient

4.1.1. Wide roadways increase the surface area to be drained and consequently the quantities of rain water that must be removed. Flatter slopes both longitudinal & transverse slow down the flow of rain water over the roadway and decrease the draining capacity. This throws emphasis on careful selection of grades. Generally longitudinal gradient is governed by factors like the cost of construction, type of vehicle and transverse slope by the quality of pavement surface. However, minimum gradients are governed by drainage consideration. On uncurbed pavements near level longitudinal gradients may not be objectionable, when the pavement has sufficient crossfall/camber to drain rain water laterally. But for better internal drainage of pavement layers, especially of granular material, a slight longitudinal gradient is preferable. Also, in cut sections and medians a slight gradient is desirable to facilitate the removal of water. A minimum longitudinal gradient of 0.3 per cent is considered adequate in most conditions to secure satisfactory drainage.

4.1.2. Due to gradients the drainage problems usually get accentuated at vertical curves. This happens because of the various low slopes of pavement close to the level point of the curve. In some instances the length of the curve may have to be adjusted to satisfy the drainage requirements. In general, difficulties of drainage are more acute on valley curves, especially if these are situated in cut sections. Prudence will lie in valley curve being avoided at such locations, as far as practicable.

4.2. Pavement Cross Slope/Camber

4.2.1. Pavement cross slope/camber is often a compromise between the requirements of drainage and those of vehicular traffic. From consideration of comfort to the traffic steep cross slopes are objectionable but from drainage stand point of view a reasonably steep cross slope/camber will be helpful in minimising ponding of water on flat grades. Flat slopes are major contributors to the condition which produces

hydroplaning (condition where one or more tyres of a moving vehicle are separated by a thin film of water) and accidents on high speed roads. And therefore, higher than minimum crossfall/camber value can be adopted where feasible and/or necessary. Moreover, it should be borne in mind that the crossfall/camber for a particular pavement course should match to its draining requirement otherwise flatter one would result in sluggish drainage conditions in that course.

4.2.2. In geometric design pavement crossfall/camber could be made to slope either on one side or on both sides with a crown in the middle of the road pavement. Unidirectional cross slope is to be favoured where the roads are provided with carriageways which are separated by a narrow median without the central drainage or the road is in hilly section with curvilinear alignment so that it is impracticable to provide two sides crossfall/camber, though if the straight length is more than 130 metre a crowned section could still be resorted to. On divided roads crossfall/camber is usually made to slope away from median except at super elevated sections where that would not be possible. On hill roads preference generally is to drain the carriageway water towards the hill side particularly where the road banking is susceptible to erosion so that the drain on the roadway could carry away the discharge safely to proper outfall.

4.2.3. When the road is on gradient, the water travels on a path perpendicular to contour on the road surface and takes longer time to reach shoulder from the crown. In these cases the camber should not be less than one half the gradient, e.g., if gradient is 1 in 20, camber should not be less than 1 in 40. Thus, it is seen that in the case of steep gradients on long length of the road, there is need to increase camber.

4.2.4. IRC:73-1980 "Geometric Design Standards for Rural (non-urban) Highways" recommends the camber or cross slope on straight section of roads as given in Table 1.

For a given surface type the steeper values may be adopted in the areas having high intensity of rainfall and lower values where intensity of rainfall is low.

Table 1

Crossfall/Camber Values for Different Road Surface Types

Surface Type	Crossfall/Camber
High type bituminous surfacing or cement concrete	1.7-2.0% (1 in 60 to 1 in 50)
Thin bituminous surfacing	2.0 to 2.5% (1 in 50 to 1 in 40)
Water bound macadam, gravel	2.5 to 3% (1 in 40 to 1 in 33)
Earth	3.0 to 4.0% (1 in 33 to 1 in 25)

4.2.5. The Indian practice for National Highways is 2.5 and 2.0 per cent for bituminous construction for annual rainfall above and below 100 cm respectively, 2 per cent for plain and reinforced cement concrete, 2.75 and 2.5 per cent for thin premix carpet and surface dressing for the said rainfall categories respectively, 4.0 and 3.0 per cent for water bound macadam and gravel similarly, 4 per cent for unturfed earth shoulder (verge) and 5 per cent for turfed earth shoulder (verge).

5. SHOULDER DRAINAGE

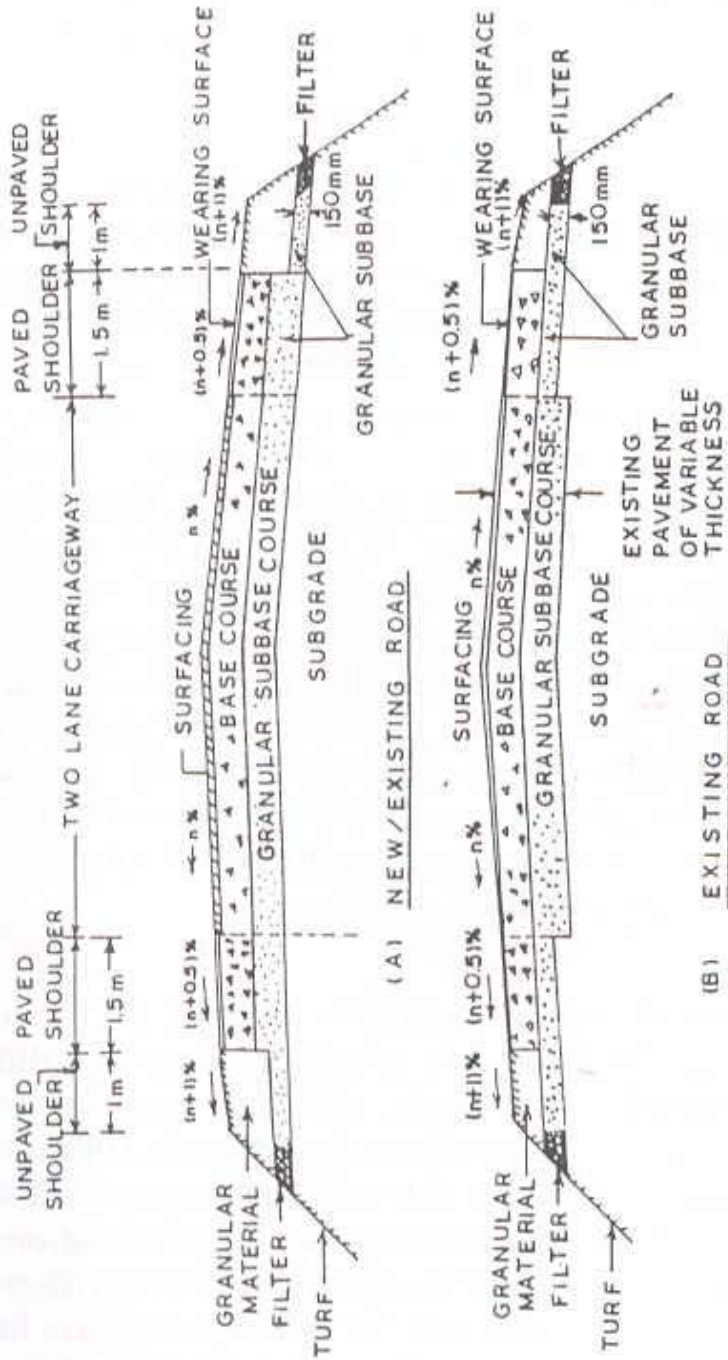
5.1. Quick drainage from road shoulders is generally ensured by keeping the surface of the shoulder properly sloped and smoothed. The rain water trapped in the depression on shoulders caused by the movements of traffic penetrates into the road sub-grade and weakens it. Progressively this results in premature failure of various pavement layers. Therefore, proper maintenance of shoulders is very desirable. Shoulders should be shaped regularly, specially before and during the monsoons in order to avoid damage to the road pavement and its surface. Keeping in view the increased intensities of traffic the only effective and sure method of maintaining the shoulders is to have paved and/or hard shoulders instead of earth shoulders (verges).

5.2. A common defect in some of the road is occurrence of shoulders

at levels higher than pavement surface. In such situations, during rain the water on road surface does not find a free outlet and accumulates on top of it. Apart from finding its way through cracks and voids in pavement surface the pavement edge at its shoulder provides a possible entry point to the water. Therefore, such defect where shoulder blocks the drainage shall be rectified.

5.3. Drainage of pavement layers across the earth shoulders (verges) has an important bearing on the performance of the pavement. This point has been stressed to some length in IRC:37-1984. Ideal treatment particularly when shoulders are of impervious type would be to extend the subbase/base course with drainage material across the side shoulders upto the side drains and give a generous cross slope to permit rapid flow. Alternatively, a continuous drainage layer, 75mm to 100 mm, might be laid under the shoulder at the bottom level of subbase or bottom most granular subbase layer 15 cm in thickness may be extended in the entire formation width upto the edge of the formation as shown in Fig. 1 where extension of base or subbase is too expensive, buried drainage ditches filled with permeable material could be cut across the shoulders to a depth of 50 mm below the subbase at 3 to 5 metres intervals. Width of such trenches could be from 0.5 to 0.7 metres. Where the road is on a gradient such shoulder drains may be arranged in-herring-bone pattern to intercept the water quickly and their spacing may not exceed width of pavement.

5.4. The crossfall of the shoulder should be as per IRC:73-1980 which stipulates that on earth shoulders (verges) the crossfall should be at least 0.5 per cent steeper than the slope of the pavement subject to minimum of 3 per cent. For paved shoulders the crossfall appropriate to the type of surface should be as per Table 1. When both paved and/or hard shoulders are provided in combination the paved shoulder may be at least 0.5 per cent steeper than the cross slopes in carriageway and hard shoulder may be at least further 0.5 per cent steeper. Earth shoulders (verges) where provided will have 4 per cent slope. Illustrative diagrams of paved and hard earth shoulders are shown in Fig. 1. The width of shoulders could vary. Hard (granular/treated soil i.e. stabilized) is preferable to earth shoulders (verges) from overall considerations of improved pavement performance.



NOTATIONS :-

- n = CROSS FALL (CAMBER) OF PAVEMENT.
- WBM= WATER BOUND MACADAM.
- WMM= WET MIX MACADAM.

NOTES:-

1. $(n+1)\%$ CROSSFALL SHALL NOT BE LESS THAN 2.5 TO 3% ON GRANULAR SHOULDER - STEAPER VALUES SHALL BE USED FOR RAINFALL EXCEEDING 150 Cm PER YEAR.
2. WHEN FEASIBLE, HARD SHOULDERS SHOULD BE PREFERRED.

Fig. 1. Typical cross section of paved shoulders (not to scale)

5.5. Superelevation creates certain problems for the shoulder slope on horizontal curves. In such reaches, shoulder on the inner side of the curve should have a somewhat steeper slope than the pavement. Shoulder on the outer side should be made to drain away from the pavement with low rates of superelevation and low rates of shoulder slope. With higher rates of superelevation, the outside shoulder should be kept level or rounded appropriately so that part of the shoulder drains on to the pavement and part away from the pavement.

6. MEDIAN DRAINAGE

6.1. Generally it is undesirable to drain the median (central verge) area towards the pavement surface but where the medians are narrow (less than 5 metres in width) these could be crowned for drainage across the pavement. Very narrow medians 1.2 to 1.8 m wide are usually provided with kerbs and are necessarily paved. Medians 1.8 to 5.0 metre wide are usually turfed and crowned so that the surface water could run towards the road pavement. These medians may be with or without kerbs. On the other hand medians wider than 5 metre are generally not built with any kerb at the edge. In their case and specially if the carriageway is also sloping towards the median provision of a central swale becomes a must for satisfactory drainage of median area. The swale should not be deeper than just necessary to carry the run off. Usually the side slopes should not be steeper than 6:1 to reduce hazard to the out of control vehicles. For the median drain, flat prefabricated concrete gutter sections could be used to advantage. At intervals the rain water could be removed from the median by inlets and carried through a drain to an outlet channel. Inlet spacing is determined by the design discharge, longitudinal slope, capacity of the median channel and allowable velocity in the median channel.

6.2. Earth surfaced median should not be crowned or cross sloped to drain on the road pavement because washed away soil may deposit on road pavement making it slippery and accident prone.

7. DRAINAGE OF HIGH EMBANKMENT

7.1. The problem of erosion of slopes and shoulders is most severe in high embankments (usually more than 8m) having steep slope in

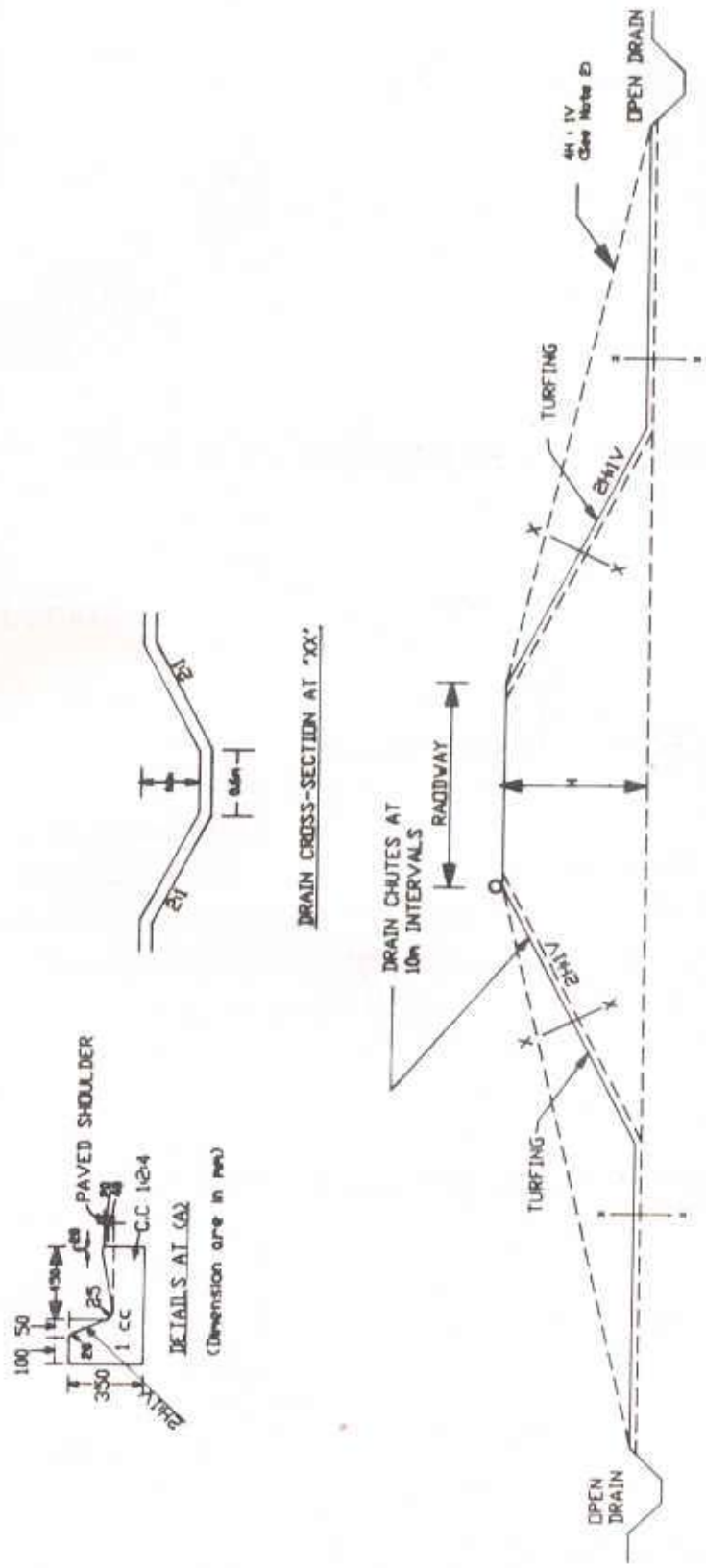
longitudinal direction such as in approaches to bridges, when the embankment has been built with an erodible soil without longitudinal and cross drains and it has no vegetation worth the name or pitching on its slopes and earth shoulders (verges) In these cases the water gains velocity and eventually when it leaves the roadway at an undefined spot it may cause serious erosion of slopes manifesting sometime in the form of deep gulleys extending right upto carriageway and at time undermining the pavement courses. Therefore in such cases where high embankments are on longitudinal slopes, longitudinal and cross drains may be provided. The longitudinal drains may be at the edges of roadway. Once water is channelised in these side drains it is led down the slopes by means of stepped outfalls or lined chutes at about 10 metre interval ultimately discharging into side channel at the bottom. Fig. 2 shows a typical drainage arrangement in such a situation. Fig. 3 gives typical chute sections.

7.2. There are various methods such as vegetative turfing by seeding, transportation of turfs, saw dust mulching, asphalt mulching, jute and coir netting which could be deployed to protect embankment slopes and are covered in IRC:56-1974 and are not the detail subject matter of these guidelines. Geogrids/geocells can also be used to support the growth of vegetation.

7.3. Longitudinal and cross drains together with treated slopes provide better answer to the erosion problem of high embankment slopes than common method of stone/brick pitching which may be costly as well as not very effective in many situations.

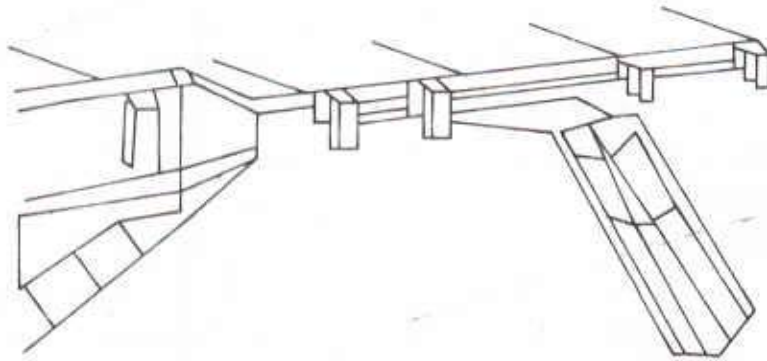
8. DRAINAGE AT CULVERTS AND BRIDGES

For culverts and bridges provision of suitable cross slope/camber and pipes near the kerbs at regular intervals, covered with gratings at the inlet points, are necessary aids for achieving efficient drainage. Drainage is especially important in the case of earth-filled arch spans, as inadequate drainage would saturate the earth filling and decrease the load bearing capacity of the structure. Special drains will also be necessary at natural low spots of piers of arch bridges to tap accumulated water and allow it to flow out. Other general

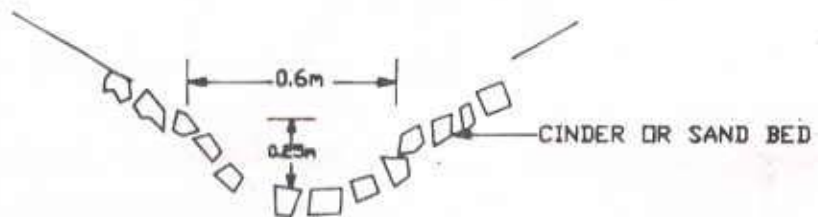
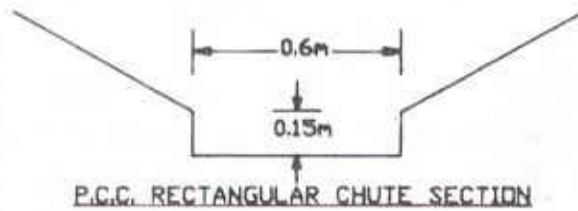


1. THE FINAL SIZE AND SPACING OF DRAINS SHOULD BE DECIDED ON THE BASIS OF ACTUAL RAINFALL SURFACE AREA ETC.
2. IF OPEN DRAIN IS PROVIDED WITHIN 4H : 1V LINE THE OPEN DRAIN SHOULD BE LINED WITH STONE/BRICK MASONRY OR CONCRETE.
3. THE OPEN DRAIN AT GROUND LEVEL SHOULD BE CONNECTED TO A NATURAL WATERCOURSE.
4. INSTEAD OF CONCRETE CHANNEL PIPE CAN ALSO BE PROVIDED ON SLOPE.

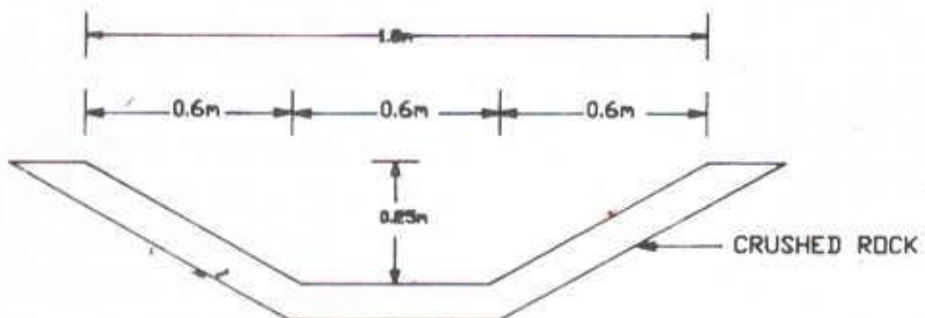
Fig. 2. Typical cross section of approach embankment



(i) ISOMETRIC VIEW OF EMBANKMENT SIDE SLOPE CHUTE.



(iii) CHUTE IN GROUTED RUBBLE STONE



(iv) P.C.C. TRAPEZOIDAL CHUTE SECTION

Fig. 3. Typical chute sections

requirements are laid down in Clause 117 of IRC:5-1985 "Standard Specifications and Code of Practice for Road Bridges - Section I.

9. OPEN DRAINS

9.1. Depending on their location and function open drains are known as side drains, catch water drains, intercepting drains or gutters. The catch water drains and intercepting drains are not being discussed in these guidelines. Open side drains are normally provided on one or both the sides of the roadway in order to intercept surface water run off from the carriageway and shoulders/verges. In the cut sections these may be located on the roadway itself. Where the road is in embankment, side drain could be at ground level as indicated in subsequent para 9.5. Sometimes in the case of high embankment these are also provided on the edges of roadway in order to protect the embankment.

9.2. Type of road traffic and rainfall intensity are some of the main factors which influence the shape, location and capacity of open drains. Width and depth of drains should be adequate for the water draining into them. That is to say that drain should have sufficient capacity to carry natural peak run-off without water overflowing the road surface. Some of the hydraulic design aspects of the open drains are discussed in the subsequent para 9.7.

9.3. The choice of cross section of open drains is generally limited to 3 types - triangular, trapezoidal and rectangular. Each of the cross section type has its own advantages and disadvantages, for example the triangular section may be most suitable from traffic consideration. Its gentle slope in continuation of the road shoulder allows greater usable road width. But this form of cross section has the disadvantage of lesser flow capacity. Rectangular section is well suited for roadside drains when larger discharge is required. But unless these are covered or kept sufficiently away from the traffic, they may prove to be greater traffic hazard. Trapezoidal section is a compromise between triangular and rectangular section.

9.4. Base earth surface in the drain can withstand only a limited amount of flow without erosion problem. The problem will be severe

in silt and sand where permissible flow velocity is between 0.3 to 1.0 m/sec. In stiff clay the said velocity may be 1.5 m/sec. but in all the cases the tolerable flow velocity can be increased significantly by lining the channel. Also, by lining the drain, the side slopes can be steepened. For example, the unlined section may require 4:1 to 2:1 side slope but sections with brick lining can even be vertical. The following linings are feasible on the drain surface:

(a) **Turfing**

Turfing is useful and cheap method in humid areas for preventing erosion but it requires proper maintenance so that undesired growth of vegetation may not reduce the flow capacity of drain. The turfed surface has good resistance and flexibility and assumes the shape of drain bed without breaking or cracking. Also if it is properly maintained it has unlimited life and any minor damage to the turf will be repaired by itself. From the consideration of maintenance turfing is more suitable for triangular drains having 4:1 to 3:1 slopes otherwise trimming the grass may be difficult. This method is less suited for rectangular and trapezoidal drains since maintenance will be difficult.

(b) **Stone/Brick Masonry**

It provides stronger surface capable of taking wear and tear as compared to turfing. The method is particularly useful where the drain is required to carry a large amount of debris or where the water velocity due to either quantum of discharge or slope will be high. In such cases turfing will be easily uprooted. It is also useful for paving the roadside drains of rectangular section where turfing can not be carried out. The stones/bricks can be either laid dry or bedded in concrete with joints filled in cement mortar. In areas with annual rainfall of over 150 mm specially if the intensity of rainfall exceeds 50 mm per hour, the masonry should be bedded on concrete to prevent ingress of water under the road structure and to prevent the stones/bricks from being pulled out or washed away. This method has the defect that cracks in the masonry cannot be prevented nor can they be effectively repaired, thus certain amount of percolation will take place. This method is not suitable in known unstable areas particularly slide faces where once disturbed, it will not be possible to repair the masonry effectively.

(c) **Concreting**

The advantages and disadvantages are the same as for stone/brick masonry.

(d) **Stone Slab Lining**

This method is useful in triangular section drains and can be used in other sections in combination with masonry/concreting. The technique has no special

advantage over masonry and concrete except that it is cheaper in certain areas where flat stone slabs are easily available.

(e) **Boulder pitching**

Boulder pitching can be used to prevent erosion.

(f) **Bituminous Treatment**

Its use is primarily limited to quick sealing of the surface. When used in conjunction with boulder pitching, bituminous treatment can be very handy. 10 to 15 cm impregnation with bitumen cutbacks or emulsion on the sides and base of a catch water drain is a quick method of ensuring prevention of seepage water.

(g) **Polyethylene Lining**

This type of lining is very flexible and totally impervious though the lining can be easily punched by boulder or debris. Nevertheless it is the only material that can be effectively used on unstable surfaces. The damage to polyethylene sheeting can be reduced by laying filter material layers as cushioning to stone boulder pitching.

9.5. The open drains if provided at ground level should be kept sufficiently away from the toe of embankment. When the drain is unlined, it should be beyond 4H:IV imaginary line drawn from the edge of shoulder as shown in IRC:10-1961. When due to lack of space the drains are located near the toe, they should be provided with erosion restraint lining such as concrete, stone slab etc., so that erosion does not cause any instability of the embankment.

9.6. The drains should be connected to some natural water course.

10. HYDROLOGIC DESIGN

10.1. Hydrologic analysis is a very important step prior to the hydraulic design of road drainage system. Such analysis is necessary to determine the magnitude of flow and the duration for which it would last. Hydrological data required for design include drainage area map, water shed delineation, arrow indicating direction of flow, outfalls, ditches, other surface drainage facilities, ground surface conditions, rainfall and flood frequencies. Factors which affect run-off are size and shape of drainage area, slope of ground, load use characteristics, geology, soil types, surface infiltration and storage.

10.2. Highway drainage facilities range from very small roadside channels and culverts to large drain systems and bridges. The extent and depth of hydrological analysis required depend on the importance and value of structures in terms of initial cost as well as its life cycle cost. The most important factor in selecting the design value are cost and safety. The optimum design return period can be determined by simple economic analysis, if the probability of a hydrological event and the damage that will result, if it occurs, are both known. As the design return period increases the capital cost of structure increases, but the expected damage decreases because of better protection effected. Fig. 4 illustrates the method of selecting the optimum return period.

10.3. To estimate the amount of run-off requiring disposal at a given instant, the engineer must have information regarding rainfall intensities within the catchment area and the frequency with which this precipitation would bring peak run-off. However, all the methods in vogue for estimating their peak run-off are based on laws of probability and predict future run-off on the basis of accumulated records. Therefore, knowledge must be coupled with experience, if data are to be correctly interpreted. One method widely used due to its simplicity is the "Rational Method". Other methods include unit hydrograph, empirical formulae and run-off from stream flow records.

10.4. The rational method is an universally accepted empirical formulae relating rainfall to run-off and is applicable to small catchment areas not exceeding 50 km². The formulae is :

$$Q = 0.028 PAI_c \quad \text{..... Eqn. 1}$$

Where

Q = Discharge (Peak run-off) in cum/sec.

P = Coefficient of run-off for the catchment characteristics

A = Area of catchment in hectares

I_c = Critical intensity of rainfall in cm per hour for the selected frequency and for duration equal to the time of concentration.

10.5. Coefficient of run-off (P) for a given area is not constant but

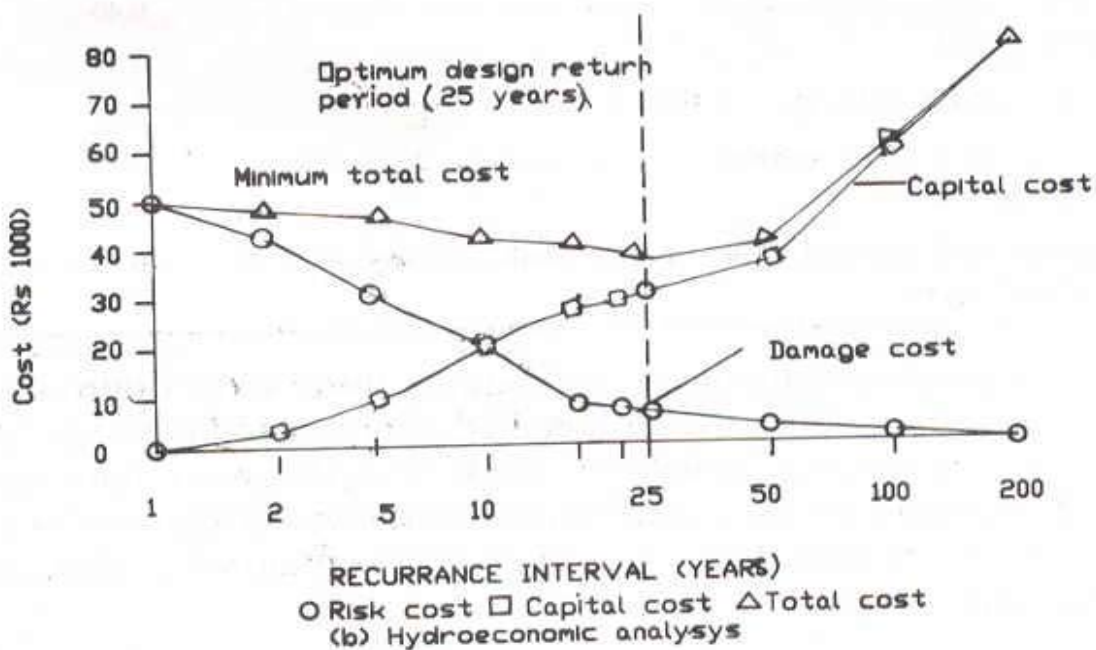
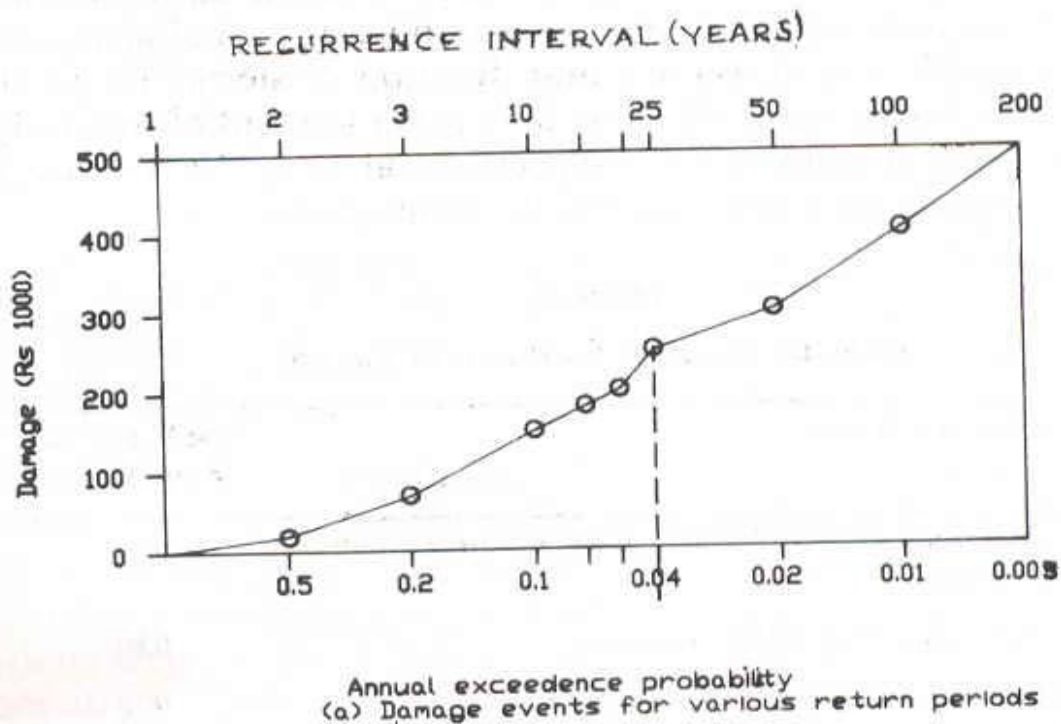


Fig. 4. Determination of the optimum design return period by hydro-economic analysis

depends on large number of factors even for a single storm. Factors affecting it are porosity of soil, type of ground cover, catchment area, slope and initial state of wetness and duration of storm. To get the maximum discharge, value of 'P' as it exists at the end of the design period of storm is chosen. The suggested values of 'P' for use in Rational Formulae are given below in Table 2.

Table 2
Suggested Values of Coefficient of Run-off

S.No. Description of Surface	Coefficient of Run-off (P)
1. Steep bare rock and watertight pavement surface (concrete or bitumen)	0.90
2. Steep rock with some vegetative cover	0.80
3. Plateau areas with light vegetative cover	0.70
4. Bare stiff clayey soils (impervious soils)	0.60
5. Stiff clayey soils (impervious soils) with vegetative cover and uneven paved road surfaces	0.50
6. Loam lightly cultivated or covered and macadam or gravel roads	0.40
7. Loam largely cultivated or turfed	0.30
8. Sandy soil, light growth, parks, gardens, lawns & meadows	0.20
9. Sandy soil covered with heavy bush or wooded/forested areas	0.10

10.6. The primary component in designing storm water drains is the design storm *viz.* rainfall value of specified duration and return period. As the extent of drainage system for roads is small, even intense rainfall of short durations may cause heavy outflows. Extreme values of rainfall of various short durations are, therefore, required in designing road drainage systems.

10.7. The storm duration chosen for design purposes is equal to "time of concentration" and is based on the assumption that the maximum discharge at any point in a drainage system occurs when the

entire catchment is contributing to the flow. The time of concentration for any watershed is the time required for a given drop of water from the most remote part of the watershed to reach the point of exist. They may have two components: (i) entry time; and (ii) time of flow. If the drainage point under consideration is at the entry of the drainage system, then the entry time is equal to the time of concentration. If, however, the drainage point is situated elsewhere, then the time of concentration is sum of the entry time and the time required by the raindrop to traverse the length of the drainage system to the point under study.

10.8. Time of concentration can be estimated with reasonable accuracy by anyone familiar with the laws of hydraulics and experienced in drainage design. All that it calls for is a reconnaissance of the watershed to trace the flow path and estimate the velocity of water in various sections. For urban areas, an entry time of 3 to 5 minutes is normally used, but in the case of grassy plots it may take 10 to 20 minutes for the water to flow over a distance of 30 m. Table 3 shows entry time values for typical agricultural catchment areas in rolling topography for guidance. These are meant to be applied to catchment areas possessing about 0.5 m of fall per 10 m and having length about two times the average width. Fig. 5 gives a graph for estimating time of concentration for catchment of different lengths, character and slope.

Table 3

Concentration Values for Typical Agricultural Catchment Areas in Rolling Country

Size of catchment area in Hectares	Minimum concentration time in minutes	Size of catchment area in Hectares	Minimum concentration time in minutes
0.4	1.4	40	17
1.2	3.0	80	23
2	3.5	120	29
4	4.0	160	35
8	4.0	240	47
12	8.0	320	60
20	12.0	400	75

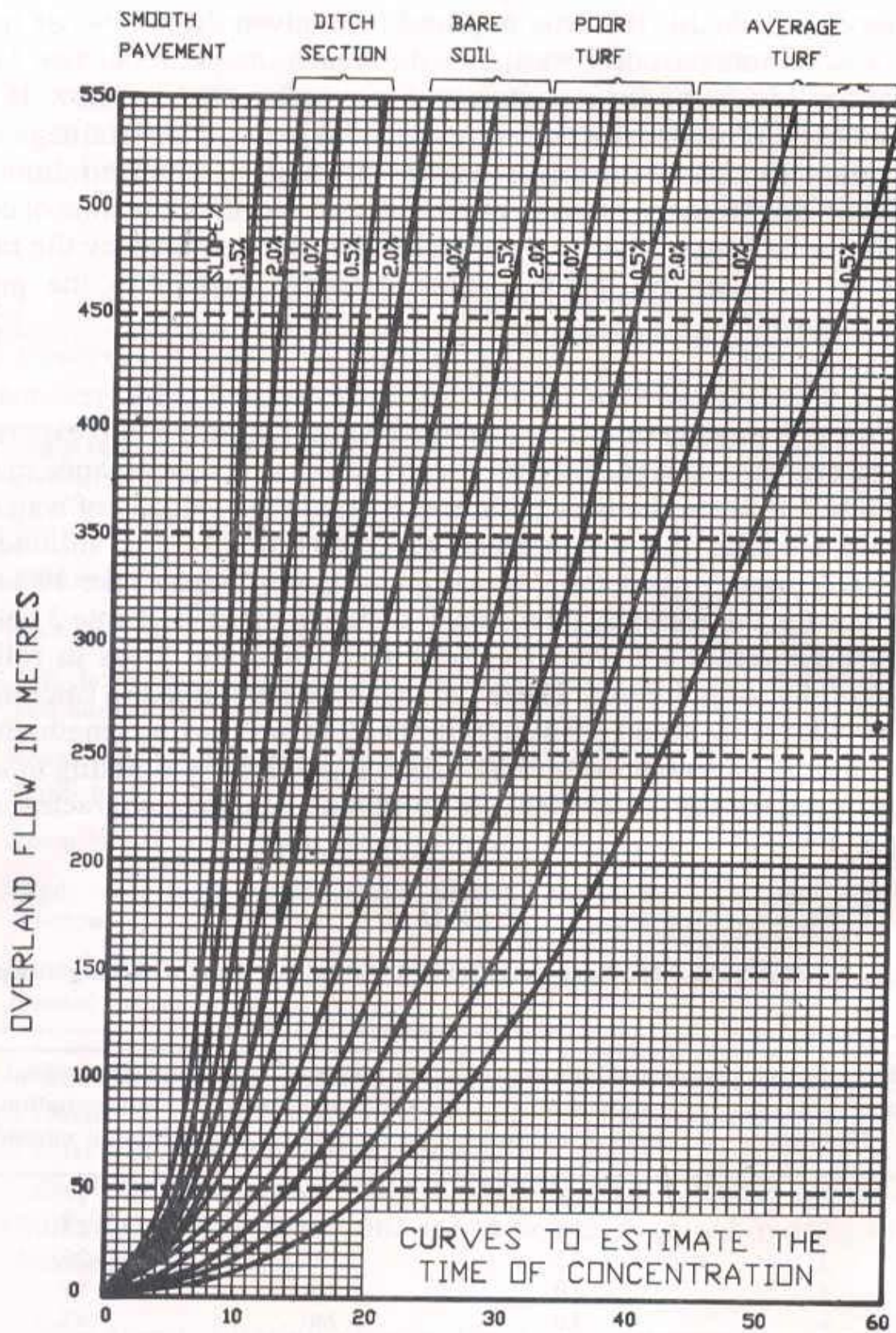


Fig. 5-Time of concentration in minutes

10.9. Once the time of concentration has been fixed, the next step consists in reading the intensity of rainfall from the appropriate rainfall map for a storm duration equal to the time of concentration and admitted design frequency. Unfortunately, rainfall maps of India for duration less than 1 hour are not yet available. Since on highway drainage problems, the time of concentration is generally of the order of 5, 10, 15, 20, 30 or 40 minutes, it would be necessary to apply certain conversion factors to 1 hour rainfall values in order to obtain the intensity of rainfall for the desired period. The conversion factors given in Tables 4 and 5 correlating the total rainfall with shorter durations were determined for lower Gangetic Basin (comprising of part of Bengal and Bihar). The values for other areas might be different.

Table 4

'n' Minutes Rainfall as Ratio of 60 Minutes Rainfall

Duration minutes	5	10	15	20	30	40	50	60	90	120
Ratio	3.7	2.85	2.4	2.08	1.67	1.33	1.17	1	0.834	0.661

Table 5

Relation Percentage of 24 hours Extreme Rainfall to Shorter Duration Extreme Rainfall

	Minutes				Hours			
Duration	15	30	45	1	3	6	24	
Percentage	16	25	31	39	55	65	100	

10.10 Because of lack of data relevant to Indian conditions, judgement could be exercised in choosing conversion factors based on the above information to convert 1 hour rainfall to shorter duration for rough estimation of the run off. A general equation given in IRC Special Publication No. 13, may also be used for deriving intensity for

shorter duration. The Eqn. is

$$i = \frac{F}{T} \left(\frac{T + 1}{t + 1} \right)$$

.....Eqn. 2

Where

i = Intensity of rainfall within a shorter period of 't' hrs. within a storm

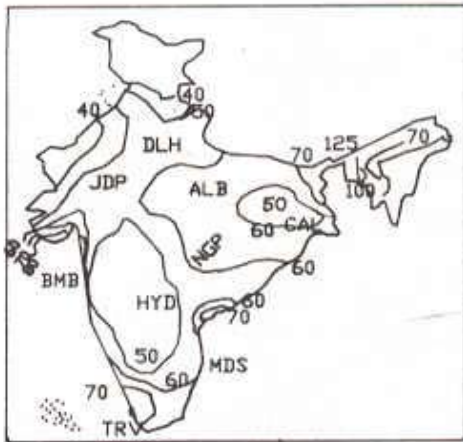
F = Total rainfall in a storm in cm falling in duration of storm of 'T' hours.

t = Smaller time interval in hrs. within the storm duration of 'T' hours.

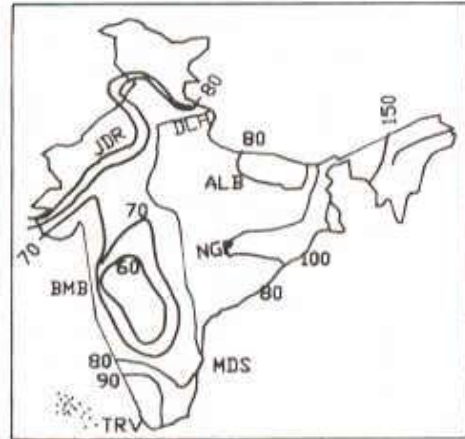
The one hour rainfall maps of India for return periods of 2, 5, 10, 25 and 50 years are given in Figs. 6 and 6A.

10.11. The type of highway and traffic carried are the principal factors to be considered in determining the design frequency. In highway sections where a drain is provided at the end of shoulders, it is more economical to select a design frequency that will keep the speed of water on the travelled way within tolerable limits and allow removal of water within 2 hours of the cessation of the storm. For important routes like National and State Highways, we could consider adopting 25 years frequency with the stipulation that for underpasses and depressed roadways it may be increased to 50 years. In the case of lower category roads, the design frequency selected could be 10 years. Ideally the choice of design storm should be based on cost-benefit analysis in which comparison could be made of the cost of constructing a high-quality drainage structure capable of handling the run-off from an infrequent storm, with the cost of damage, which would be caused by not doing so. If this approach is adopted it is quite possible that for roads such as motorways, storms of relatively rare frequency would be considered for design.

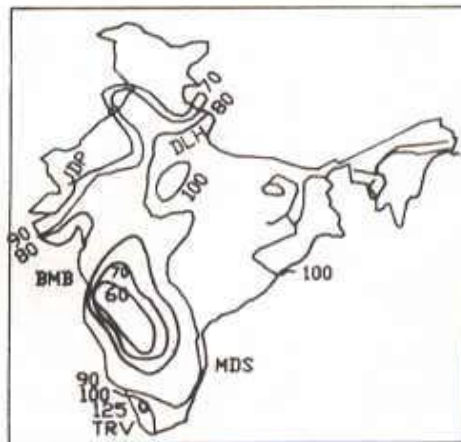
10.12. To highlight the different issues involved in roadside drainage design, typical design sections have been worked out & Tabulated at *Annexure-I*. The example illustrates the effect of change in design frequency on the section of the drain and of the effect of time of concentration on catchment area and design section. It will be observed that selection of a higher design frequency increases the drain section and hence the cost of the drainage scheme. However, the time of concentration and the catchment area are interdependent and are fixed for particular site conditions.



(A) 5 - YEAR 1 - HOUR MAXIMUM RAINFALL (mm)



(B) 25 - YEAR 1 - HOUR MAXIMUM RAINFALL (mm)



(C) 50 - YEAR, 1 - HOUR MAXIMUM RAINFALL (mm)

Fig. 6. One hour rainfall for different recurring intervals.

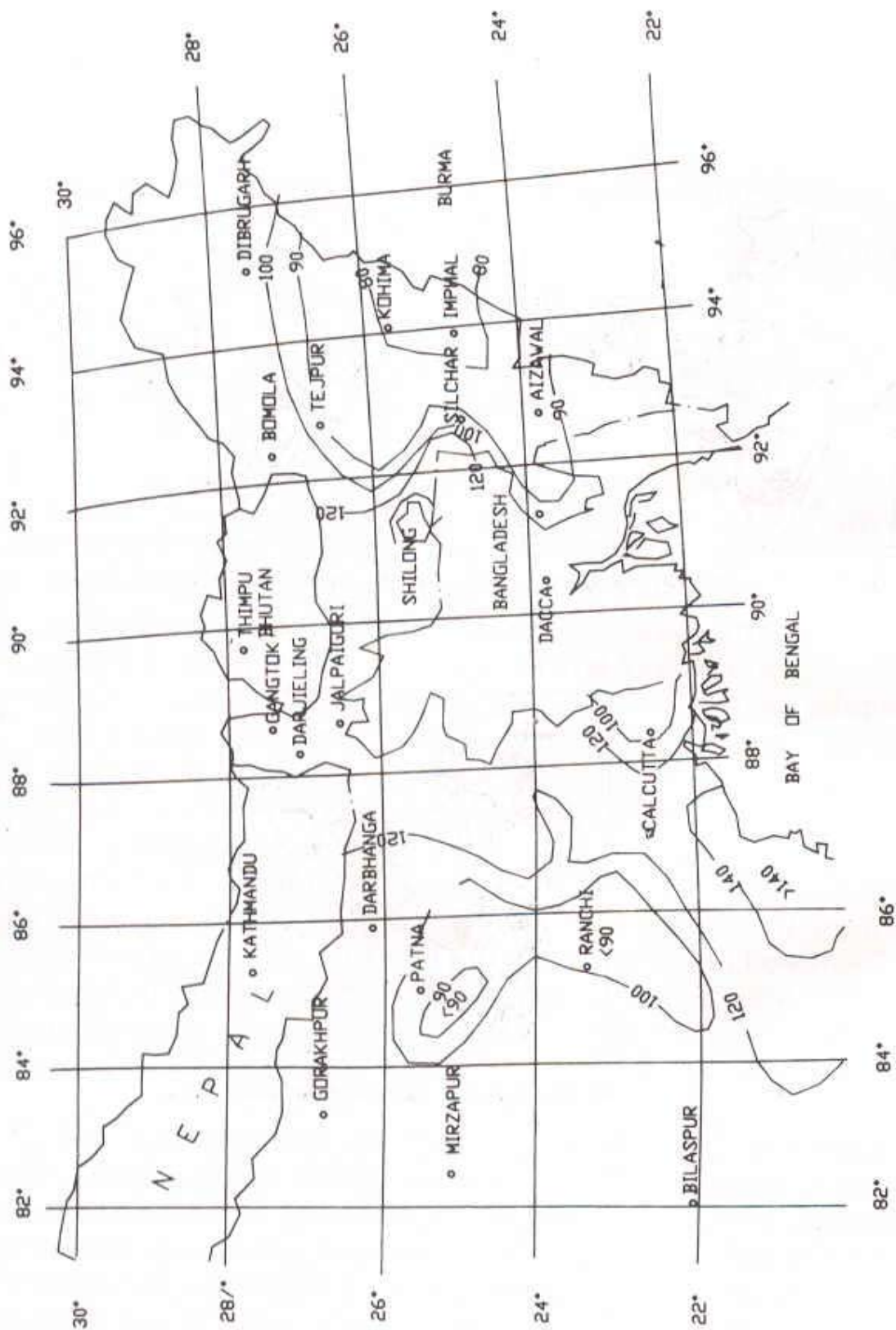


Fig. 6A. 50 year—one hour rainfall in lower gangetic and Brahmaputra Basin

10.13. More accurate 24 hour rainfall data for various parts of the country is now available from Directorate of Hydrology (small catchments), Central Water Commission, New Delhi. This data can be converted to shorter duration data using Table 5 or equation mentioned above. Fig. 7 gives a map of India showing the Zones for which rainfall maps are available. Conversion factors for converting to rainfall intensities for shorter periods in each area are also given in this publication.

11. HYDRAULIC DESIGN

11.1. General

Once the quantity of run-off has been determined, the stage is set for the next step of hydraulic design of the drain. It is convenient to discuss the design of side drains for urban and rural areas separately.

Side drain sections in urban areas are generally restricted to right triangular sections due to the provision of a vertical kerb at the end of the carriageway or the shoulder. The gutter section is normally 0.3 to 1 m wide having a cross slope steeper than that of the adjacent surfacing, usually 1:12 or the cross slope of the pavement might continue to the kerb. The kerb confines the storm run off to the gutter section. The overflow spills to the adjacent paved surface, when the gutter capacity is exceeded. At intervals the water is removed from the gutter section by inlets. The spacing of the inlets is determined by the design discharge, the carrying capacity of the gutter and the allowable spread of water on travelled way. A suggested assumption is that the flow should not encroach on the outside lane by more than 1.8 m for a storm of 20 minutes duration and one year return period. It is reasoned that storms of shorter duration have such high intensities that vehicles must travel slowly since vision is obscured by rain pelting on the windshields. The capacity of a gutter depends upon its cross-section, grade and roughness. Similar right triangle ditches are also sometimes used on rural highway where a kerb is placed on the outer edge of the surfaced shoulder on a fill section when water cannot be permitted to run down the embankment slope.



Fig. 7. Map of India showing main rivers sub-zones and state boundaries

In rural highways, side ditches are normally placed alongside the roadway in order to intercept surface water running off the carriageway and shoulders. In cut sections they also serve to prevent water running down the cut slopes and invading the roadway. Side ditches are usually V-shaped or trapezoidal in cross-section. On low-cost roads the V-ditch is very often favoured because it can be more economically formed. If equipment is available, the same is also amenable to quick and economic maintenance with the help of a motor grader. V-shaped drains are very popular in India in hill sections. On high type of roads, the trapezoidal section is generally preferred because of its greater carrying capacity. Normally, due to lack of economic justification small roadside ditches are not hydraulically designed. Instead the ditch side walls are simply cut to the natural angle of repose of the soil and to a depth usually 0.3 to 0.6 m or more. In the latter respect care should always be taken to ensure that the depth is such that sustained flow in the bottom of the ditch never rises above the subgrade level. On important roads, however, the hydraulic capacity of ditches should be checked to ensure that they are able to handle the expected flows without danger either to traffic, the embankment or the road structure. This is especially important of the ditches carrying water from adjacent back slopes as well as from the roadway. Vehicle safety considerations usually govern the ditch side-slopes on important roads, preference being given to the use of relatively flat slopes, especially on the side closest to the carriageway. Capacity of a ditch can better be increased by widening than by deepening the channel so that velocity and erosion are also reduced.

11.2. Open Channel Design

For uniform flow in open channels, the basic relationships are expressed by the Manning's Formula :

$$Q = \frac{1}{n} AR^{2/3} S^{1/2} \quad \dots\dots\dots \text{Eqn. 3}$$

$$\text{and } V = \frac{1}{n} R^{2/3} S^{1/2}$$

- where Q = discharge in cum/sec.
 V = mean velocity m/sec.
 n = Manning's roughness coefficient
 R = hydraulic radius in m which is area of flow cross section divided by wetted perimeter.
 S = energy slope of the channel, which is roughly taken as slope of drain bed.
 A = Area of the flow cross-section in m²

In design of roadside channels, the flow of water is assumed as sub-critical flow. The slope and velocity are kept below the critical level. Critical depth of flow 'dc' in open channel is that depth at which specific energy is minimum. On mild slope flow is sub-critical and normal depth of flow dn is more than critical depth. For rectangular channel $dc = (Q^2/b^2g)^{1/3}$ where 'g' is acceleration due to gravity and b is width of channel. If $dn < dc$, the slope and channel section should be redesigned so that $dn > dc$.

Values of "n" for various channel surfaces are given in Table 6. The soil classification used in the Table is the Extended Casagrande Classification. Also shown are the maximum permissible velocity values for various types of ditch lining. Velocity values in excess of these will cause erosion in the ditches, which will not only increase the maintenance cost, but also, in the case of side ditches may weaken the road structurally.

Open-channel design can be accomplished by solving the Manning's equation numerically. As this procedure is tedious and time consuming, chart solutions have been developed to solve the problems commonly occurring.

Table 6

Manning's 'n' and Maximum Permissible Velocity of Flow in Open Channels

S. No.	Ditch Lining	Manning's 'n'	Allowable velocity to prevent erosion m/sec.
(1)	(2)	(3)	(4)
1.	Natural Earth		
A.	Without Vegetation		
	(i) Rock		
	(a) Smooth & Uniform	0.035-0.040	6
	(b) Jagged & irregular	0.04 -0.045	4.5-5.5
	(ii) Soils (Extended Casagrande classification)		
	G.W.	0.022-0.024	1.8-2.1
	G.P.	0.023-0.026	2.1-2.4
	G.C.	0.020-0.026	1.5-2.1

(Contd. Table 6)

(1)	(2)	(3)	(4)
	G.F.	0.024-0.026	1.5-2.1
	S.W.	0.020-0.024	0.3-0.6
	S.P.	0.022-0.024	0.3-0.6
	S.C.	0.020-0.023	0.6-0.9
	S.F.	0.023-0.025	0.9-1.2
	CL and CT	0.022-0.024	0.6-0.9
	MI and ML	0.023-0.024	0.9-1.2
	OL and OI	0.022-0.024	0.6-0.9
	CH	0.022-0.023	0.6-0.9
	MH	0.023-0.024	0.9-1.5
	OH	0.022-0.024	0.6-0.9
	Pt	0.022-0.025	0.6-0.9
B.	With vegetation		
(i)	Average turf		
	(a) Erosion resistant soil	0.050-0.070	1.2-1.5
	(b) Easily eroded soil	0.030-0.050	0.9-1.2
(ii)	Dense turf		
	(a) Erosion resistant soil	0.070-0.090	1.0-2.4
	(b) Easily eroded soil	0.040-0.50	1.5-1.8
	(c) Clean bottom with bushes on sides	0.050-0.080	1.2-1.5
	(d) Channel with tree stumps		
	No. sprouts	0.040-0.050	1.5-2.1
	With sprouts	0.060-0.080	1.8-2.4
	(e) Dense weeds	0.080-0.012	1.5-1.8
	(f) Dense Brush	0.100-0.140	1.2-1.5
	(g) Dense willows	0.150-0.200	2.4-2.7
2.	Paved		
A.	Concrete with all surfaces, Good or Poor		
(i)	Trowel finished	0.012-0.014	6
(ii)	Float finished	0.013-0.015	6
(iii)	Formed, no finish	0.014-0.016	6
B.	Concrete bottom, float finished, with sides of		
(i)	Dressed stone in mortar	0.015-0.017	5.4-6
(ii)	Random stone in mortar	0.017-0.20	5.1-5.7
(iii)	Dressed stone or smooth concrete rubble (Rip-rap)	0.020-0.025	4.5
(iv)	Rubble or random stone (Rip-rap)	0.025-0.030	4.5

(1)	(2)	(3)	(4)
C.	Gravel bottom with sides of		
	(i) Formed concrete	0.017-0.020	3
	(ii) Random stone in mortar	0.020-0.0238	2.4-3
	(iii) Random stone or rubble (Rip-rap)	0.023-0.033	2.4-3
D.	Brick	0.014-0.017	3
E.	Bitumen (Asphalt)	0.013-0.016	5.4-6

The Manning equation cannot be used without modification to compute flow in right triangular sections as used in urban or hilly areas because the hydraulic radius does not adequately describe the drain section particularly when the top width of water surface may be more than 40 times the depth (d) of curb. To compute drain flow the Manning equation for an increment of width is integrated across the width Zd and the resulting formula is:

$$Q = \frac{0.315}{n} F_1(Z) d^{8/3} S^{1/2} \quad \text{.....Eqn. 4}$$

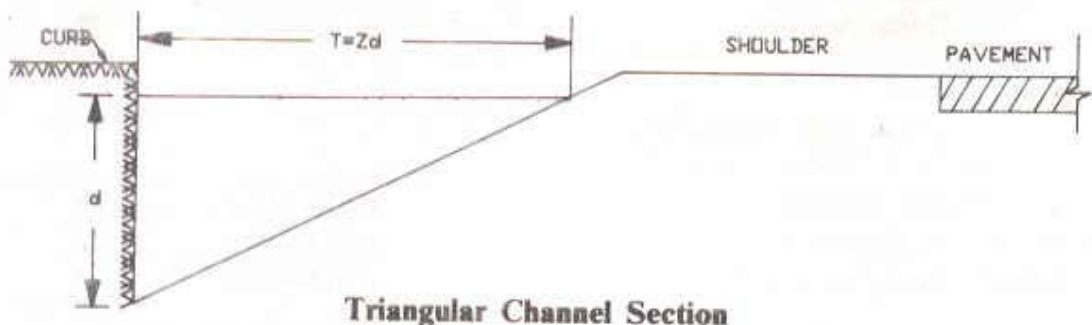
Where

Z = Reciprocal of cross slope

d = Depth of Channel in m

T = Spread of water in m

$$F_1(Z) = \frac{Z^{5/3}}{(1 + \sqrt{1 + Z^2})^{2/3}}$$



For V-shaped channel section, formula is

$$Q = \frac{1}{n} F_2(Z) d^{8/3} S^{1/2} \quad \text{..... Eqn. 5}$$

$$\text{Where } F_2(Z) = \frac{0.63 Z^{5/3}}{(Z^2 + 1)^{1/3}} \quad \text{..... Eqn. 6}$$

This equation could be corrected to give depth of flow 'd' as

$$d = 1.1892 \left[\frac{Q.n}{\sqrt{5}} \right]^{3/8} \left[\frac{Z^2 + 1}{Z^{5/3}} \right]^{3/8} \dots \dots \dots \text{Eqn. 7}$$

12. SUB-SURFACE DRAINS

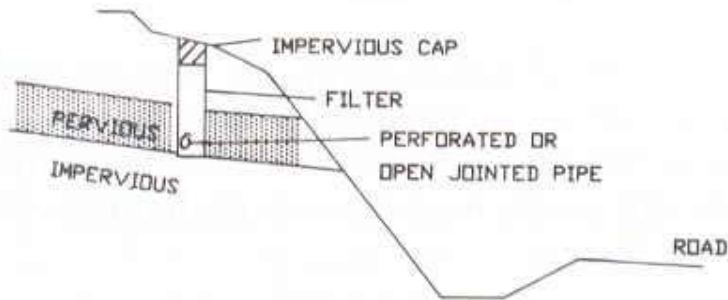
12.1. Two main objectives of subsurface drains are to lower level of water table and to intercept or drain out underground water. To be effective they should not be less than 0.5 m below the subgrade level. Also subsurface drains should not be used for surface drainage. Their normal applications are as follows :

The subsurface drain in cut slope as in Fig. 8(A) can carry away the underground water which otherwise would have caused sloughing of the slope. Horizontal drains drilled through cut slopes may be alternative in such situation.

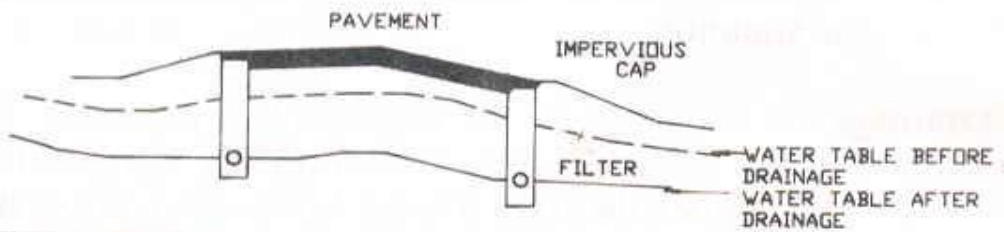
Drainage of subgrade is an important application. Subsurface drains placed on each side of the road as in Fig. 8(B) can lower down the water table under the road. It may however be noted that such a drain may not be effective if the subgrade consists of fine grained soils such as clay. In that case it may be more satisfactory to raise the road level.

Subsurface drains may be provided in pervious subbase or base course in situations where it may not be practical to carry them under the shoulder (Fig. 1). The drains carry off the water which permeates to the base or subbase through the surface. Such an application is shown in Fig. 8(C).

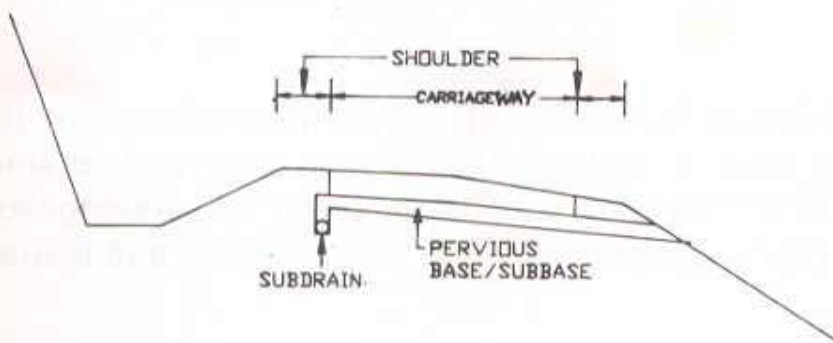
12.2. The subsurface drain may consist of perforated pipe or open jointed solid pipe in a trench with backfill around it or it may simply be free draining material in the trench without any pipe. The perforated pipes may be of metal/asbestos cement/cement concrete/PVC and unperforated pipes of vitrified clay/cement concrete/asbestos cement. The top of trench is sealed by providing impervious cap so that only subsurface water may enter the drain. In pipe drain the internal diameter of pipe should not be less than 150 mm. Holes in the per-



(A) INTERCEPTION OF FREE WATER IN CUT SLOPE



(B) LOWERING WATER TABLE



(C) BASE/SUBBASE DRAINAGE IN CUT AREA

Fig. 8. Examples of typical sub-surface drains

forated pipes may be in one half of the circumference only. Size of the holes may be close to D_{85} size of material surrounding the pipe subject to being minimum 3 mm and maximum 6 mm. D_{85} stands for size of the sieve that allows 85 per cent of the material to pass through it. The backfill may consist of sand-gravel material or crushed stone satisfying the grading of Table 7 in case where no specific design exercise based on filtration and permeability criteria has been carried out. The backfill should be free of organic material, clay balls and other deleterious material.

Table 7

Grading Requirement for Filter Material Per Cent by Weight Passing the Sieve

Sieve Designation	Class I	Class II	Class III
53 mm	—	—	100
45 mm	—	—	97-100
26.5 mm	—	100	—
22.4 mm	—	95-100	50-100
11.2 mm	100	48-100	20-60
5.6 mm	92-100	28-54	4-32
2.8 mm	83-100	20-35	0-10
1.4 mm	59-96	—	0-5
710 μm	35-80	6-18	—
355 μm	14-40	2-9	—
180 μm	3-15	—	—
90 μm	0-5	0-4	0-3

Note 1. When the soil around the trench is fine grained (fine silt or clay or their mixture) then Class I grading, when coarse silt to medium sand or sandy soil then Class II grading and when gravelly sand then Class III grading should be adopted.

Note 2. The thickness of backfill material around the pipe should not be less than 150 mm. Therefore considering that the minimum diameter of the pipe is 150 mm, the width of the trench should not be less than 450 mm.

12.3. When the subsurface consists of only free draining material, the drain may be constructed without any pipe. The trench may be filled with material such as gravel, slag or stone aggregate free from organic and deleterious substances. This drain is known as aggregate drain. Its grading may be as per Table 8.

Table 8

Grading Requirement for Aggregate Drain

Sieve designation	Per cent by weight passing the sieve
13.2 mm	100
11.2 mm	92-100
5.6 mm	27-46
2.8 mm	3-16
1.4 mm	0-6

12.4. The subsurface drain can be provided with geotextile either along the trench or around the pipe or both as shown in Fig. 9. The geotextile acts as both separation and filtration layer. When geotextile is provided, the filtration requirement in the grading is not important as far as material on both sides of it are concerned.

12.5. Outlet of pipes should be carefully positioned to avoid possible blockage and protected with grating or screen securely fastened in place. For a length of 500 mm from the outlet end the trench for pipe may not be provided with granular material but backfilled with excavated soil and thoroughly compacted so as to stop water directly percolating from backfill material around the pipe. The pipe in this section should have no perforation.

12.6. The designing of sub-surface drain on rational basis is not simple. It requires permeability estimation, usage of seepage principles to estimate inflow quantity and calculation of outflow conductivity of drainage system. The flownets are useful in determining inflow quantity. Based on Darcy's law:

$$Q = K i A$$

Where

- Q = discharge in m³/sec.
- A = Cross sectional area in m²
- i = Hydraulic gradient
- K = Coefficient of permeability in m/sec.

Some typical values of K are given in Table 9

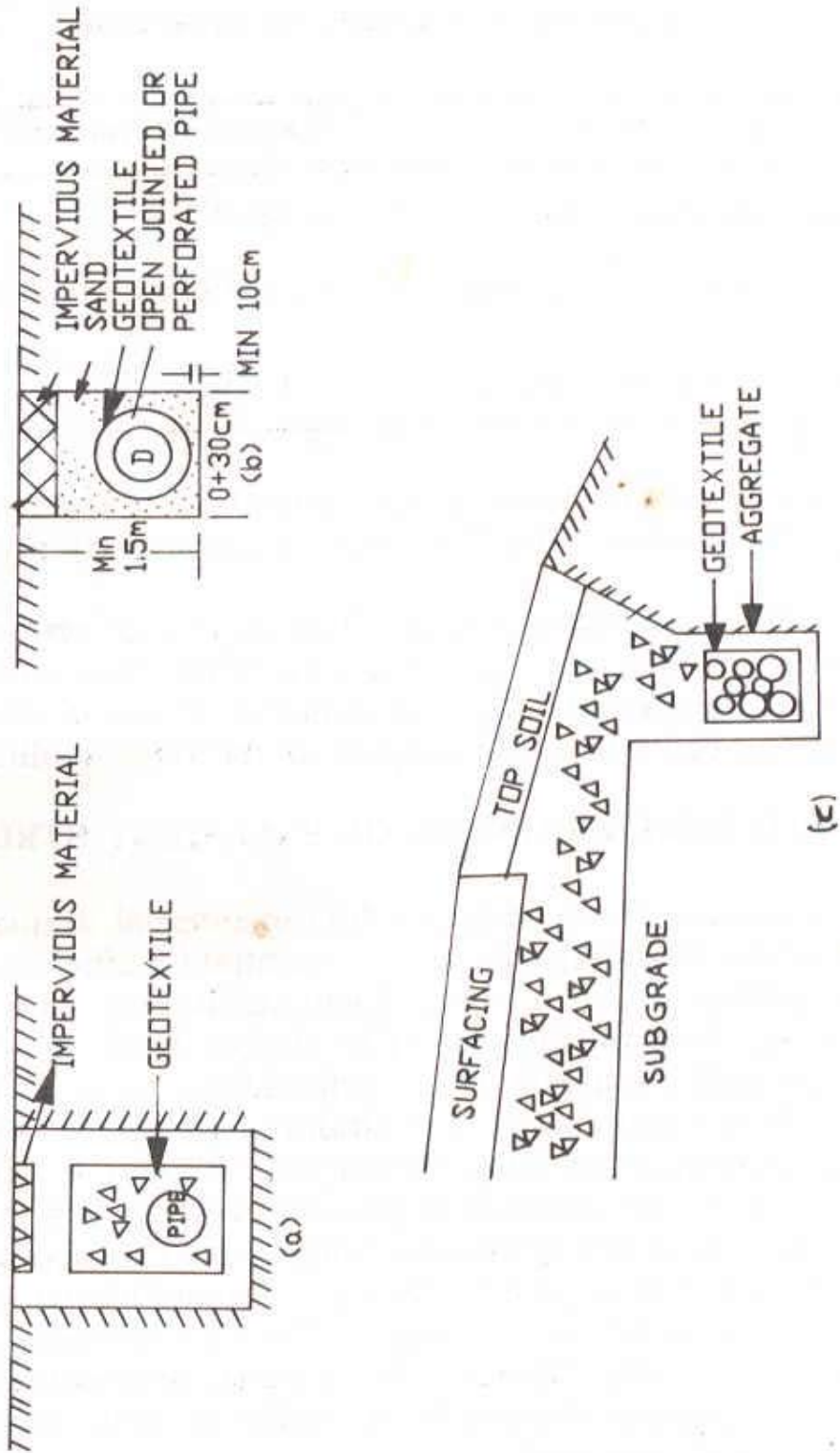


Fig. 9. Typical sub-surface drains with geotextile

Table 9

Coefficient of Permeability for Typical Soils

Type of Soil	Coefficient of permeability in m/sec.
Impervious soil such as stiff clay	$< 1 \times 10^{-8}$
Semipervious soil such as silty clay, sandy silt, silt	1×10^{-5} to 1×10^{-8}
Pervious soil such as sand, gravel	$> 1 \times 10^{-5}$

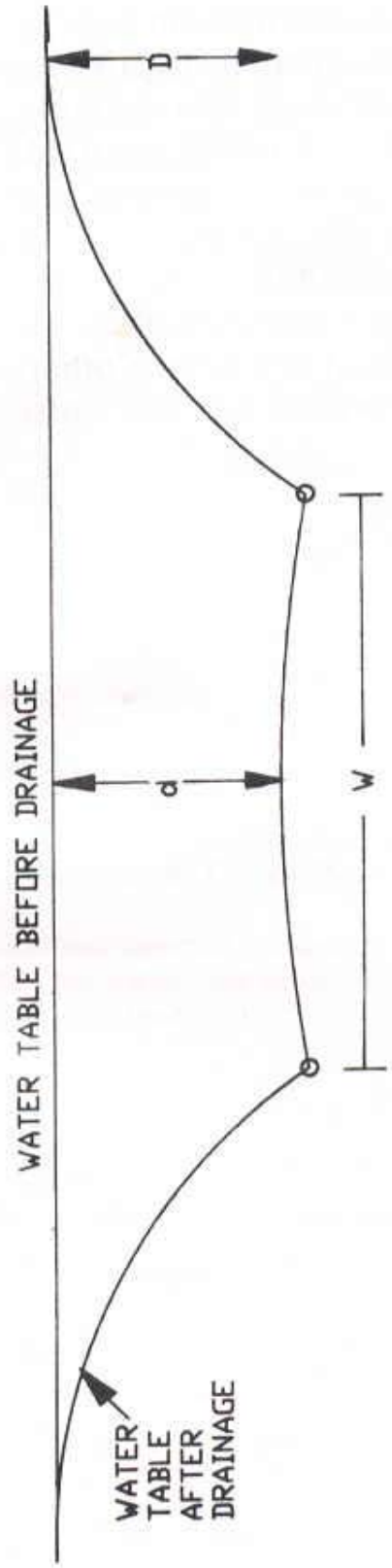
However, it may be noted that drawing flownet to get value of hydraulic gradient (c) in layered section is not an easy job.

In a simple case shown in Fig. 10 the discharge per unit length of pipe per unit time can be calculated from dimensionless ratios indicated therein. It may be noted from Fig. 10 that discharge is maximum in the beginning and reduces as the flow stabilizes.

13. INTERNAL DRAINAGE OF PAVEMENT STRUCTURE

13.1. Knowledge and understanding of internal drainage of pavement structure including subgrade is essential for efficient functioning of the road structure as a whole. Adequate drainage of the pavement structure should form the part of its design. Boxed type pavements housed in earth shoulders (verges) should not be constructed at all. Sub-base/base should have self draining provisions by extending granular drainage layer fully over the road formation width. In addition care should be exercised to provide crossfall appropriate to the draining layer to guard against any sluggish flow on account of inadequate crossfall than needed for the type of material used in that layer. Road subgrade must also be provided with a crossfall appropriate to the draining characteristics of the material with which it is built so that there is no accumulation of water at the top of the subgrade due to sluggish flow at that level.

13.2. System functioning of various pavement structures built with



- q = Discharge per unit length per unit time
- f = Time since beginning of drainage
- k = Coefficient of permeability
- v = volume of drainable water per unit volume of soil
- d = Minimum depth of water table
- D = Depth of drain
- W = Distance between pipes

Dimensionless Ratios	
$\frac{tkD}{vw^2}$	$\frac{q}{KD}$
0.001	0.80
0.01	0.47
0.1	0.25

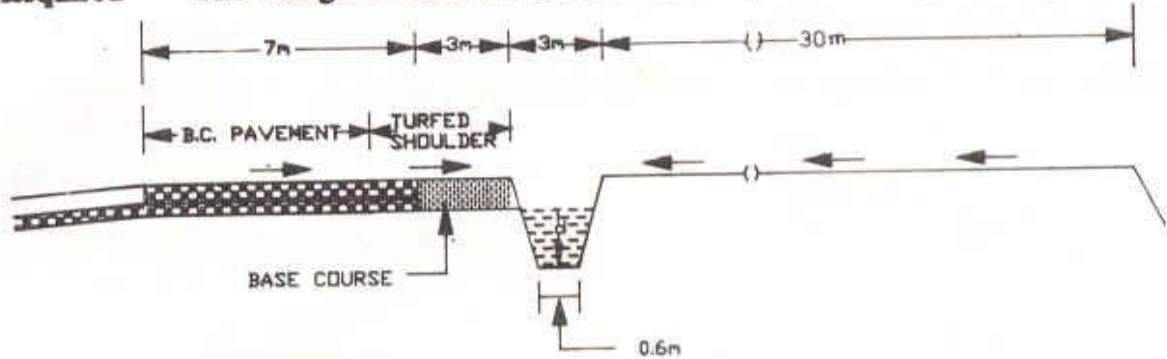
Fig. 10. Dimensionless ratios for drainage by two parallel pipes

pavement courses of different specifications should also be kept in mind while designing them in order to ensure that there is no problem of interfacial drainage between the two pavement layers. For example, a denser pavement layer i.e. with lesser voids should not be overlaid/covered with a pavement layer having more voids since it causes permeability reversal conditions detrimental to the survival of the overlaid course(s). In case of existing pavements where such a situation might become unavoidable from other considerations, then the overlaid layer having larger voids should be drained off laterally otherwise interfacial drainage problems would be created which will cause premature failure of the overlaid layer itself.

Typical Example of Roadside Drainage

Given Typical highway cross-section as shown in the figure, at New Delhi, with a continuous longitudinal grade of 1 in 100. The soil in the region is easily erodable soil with average turf.

Required The design of side drain for various points along the highway.



Typical highway cross-section

Discharge Calculations

(a) Coefficient of runoff

The drain is carrying runoff from half the roadway width and the adjoining agricultural land. The coefficient of runoff from the various surfaces are:

Bituminous concrete pavement	=	0.90
Turfed shoulders and drain slopes	=	0.30
Agricultural land	=	0.40

$$P_{av.} = \frac{0.90 \times 7 \times L + 0.3 \times 6 \times L + 0.4 \times 30 \times L}{(7L + 6L + 30L)}$$

$$= 0.46$$

Where L = Length of road under consideration.

(b) Time of concentration

The remotest point in the cross-section is the end point of agricultural land; the time required for water to reach drain from the remotest point = $30/v$.

Assuming $v = 0.06$ m/sec, over the agricultural land and 0.3 m/sec. in the drain

$$t = \frac{30}{0.06} \times \frac{1}{60} + \frac{L}{0.3 \times 60} \text{ Minutes}$$

$$= (8.33 + L/18) \text{ Minutes}$$

$$\text{and } L = (t - 8.33) \times 18$$

Time (mts)	10	15	20	30	40	50	60	90	120
L ft	30	120	210	390	570	750	930	1470	2010

(c) **Area**

Area contributing to flow at any point L m from start of grade of 1 in 100 is given by

$$A_t = \frac{43 \times L}{10,000} \text{ hectare}$$

$$= \frac{43 (t - 8.33)}{10,000} \times 18 \text{ hectare}$$

Time (mts)	10	15	20	30	40	50	60	90	120
A_t (hectare)	0.129	0.516	0.930	1.677	2.451	3.225	3.999	6.321	8.643

(d) **Rainfall Intensity 'i'**

From rainfall maps of India, 1 hour maximum rainfall near Delhi is given below :

Frequency	Rainfall in Cms for 1 hour	Conversion factor (From 2 year frequency)
2 Years	3.6 cm	1
5 years	5.5 cm	1.53
10 years	6.2 cm	1.72
25 years	8.0 cm	2.22
50 years	9.2 cm	2.56

Now conversion factors for converting 60 minutes rainfall intensity to intensity of other durations are as below for 2 year frequency.

Duration 't' (mts)	5	10	15	20	30	40	50	60	90	120
Conversion factor	3.7	2.85	2.4	2.08	1.67	1.33	1.17	1.0	0.834	0.667
Rainfall intensity in cm	13.32	10.26	8.64	7.488	6.012	4.788	4.212	3.6	3.0	2.4

- 2 year frequency

(e) Discharge is given by the relation

$$Q = 0.028 \times P_{av} \times I_t \times A_t$$

$$= 0.08 \times 0.46 \times i_t \times A_t$$

A_t 30 m from start of grade

$$L = 30 \text{ m, } t = 10 \text{ mts (from 'b' above)}$$

$$A_t = 0.129 \text{ hectare (from 'c' above)}$$

$$i_t = 10.26 \text{ cum (from 'd' above)}$$

$$Q \text{ 2 years frequency} = 0.028 \times 0.46 \times 10.26 \times 0.129 = 0.0170 \text{ cum/sec.}$$

$$Q \text{ 5 year frequency} = Q_2 \times 1.53 = 0.026 \text{ cum/sec.}$$

$$Q \text{ 10 year frequency} = Q_2 \times 1.72 = 0.029 \text{ cum/sec.}$$

$$Q \text{ 25 year frequency} = Q_2 \times 2.22 = 0.0378 \text{ cum/sec.}$$

$$Q \text{ 50 year frequency} = Q_2 \times 2.56 = 0.0435 \text{ cum/sec.}$$

Similarly discharge at various distances from start of the grade will be as shown in the Table A.

II. Channel Section Calculation

Flow in a trapezoidal channel with 0.6 m flat bottom and sides on 2:1 slopes are assumed for design calculations.

For easily eroded soil with average turf

$$n = 0.03$$

$$v \text{ max} = 0.9 - 1.02 \text{ m/sec.}$$

For ground slope of 1 in 100

$$S = 0.01$$

For 10 years frequency & $t = 10$ minutes

$$Q = 0.029 \text{ cum/sec.}$$

Let depth of channel be 'd' m, then

$$\begin{aligned} \text{Area of Channel } A &= \frac{0.6 + (0.6 + 4d)}{2} \times d \\ &= (0.6 + 2d) d \end{aligned}$$

$$\text{Wetted per metre of channel} = 0.6 + \sqrt{5} d \times 2$$

$$\text{Hydraulic radius} = \frac{(0.6 + 2d) \cdot d}{0.6 + \sqrt{5} d \times 2}$$

$$Q = \frac{1}{n} AR^{2/3} S^{1/2}$$

$$\& V = \frac{1}{n} R^{2/3} S^{1/2}$$

$$\therefore Q = \frac{1}{0.03} (0.6 + 2d) d \left[\frac{(0.6 + 2d) d}{0.6 + \sqrt{5} \times 2d} \right]^{2/3} \left[\frac{1}{100} \right]^{1/2}$$

Solving the above equation we find by trial & error that $d = 8$ cm and $V_n = 0.55$ m/sec which is within the permissible value and flow is not super critical.

Similarly

$Q = 0.098$ cum/sec	$dn = 0.15$ m,	$vn = 0.72$ m/sec
$Q = 0.17$ cum/sec	$dn = 0.185$ m,	$vn = 0.81$ m/sec
$Q = 0.223$ cum/sec	$dn = 0.225$ m,	$vn = 0.9$ m/sec.
$Q = 0.260$ cum/sec	$dn = 0.24$ m,	$vn = 0.9$ m/sec
$Q = 0.301$ cum/sec	$dn = 0.27$ m,	$vn = 0.99$ m/sec
$Q = 0.318$ cum/sec	$dn = 2.75$ m,	$v = 0.99$ m/sec
$Q = 0.419$ cum/sec	$dn = 0.3$ m,	$v = 1.05$ m/sec
$Q = 0.454$ cum/sec	$dn = 0.33$ m,	$v = 1.125$ m/sec

Similarly, the sections for other discharges have been worked out and presented in the Table A.

Example -2

A concrete triangular gutter is to be designed for 0.03 cum/sec. discharge with 1 in 40 cross slope when $n = 0.014$ and channel slope is 1 in 100.

Solution

From equation

$$Q = \frac{0.315}{n} F_1 (Z) d^{8/3} S^{1/2}$$

Where

Z = reciprocal of cross slope i.e. side slope of channel in Z horizontal :
1 Vertical

d = depth of channel in metres

and

$$F_1 (Z) = \frac{Z^{5/3}}{[1 + \sqrt{1 + Z^2}]^{2/3}}$$

And Q , n and S have the following meanings :

Q = discharge in cum/sec

n = manning's roughness coefficient

S = energy slope which is roughly taken as slope of the bed of road drainage

$$0.03 = \frac{0.315}{0.014} F_1 (Z) d^{8/3} \left(\frac{1}{100}\right)^{1/2}$$

$$\text{and } F_1 (Z) = \frac{40^{5/3}}{[1 + \sqrt{1 + 40^2}]^{2/3}} = 39.3$$

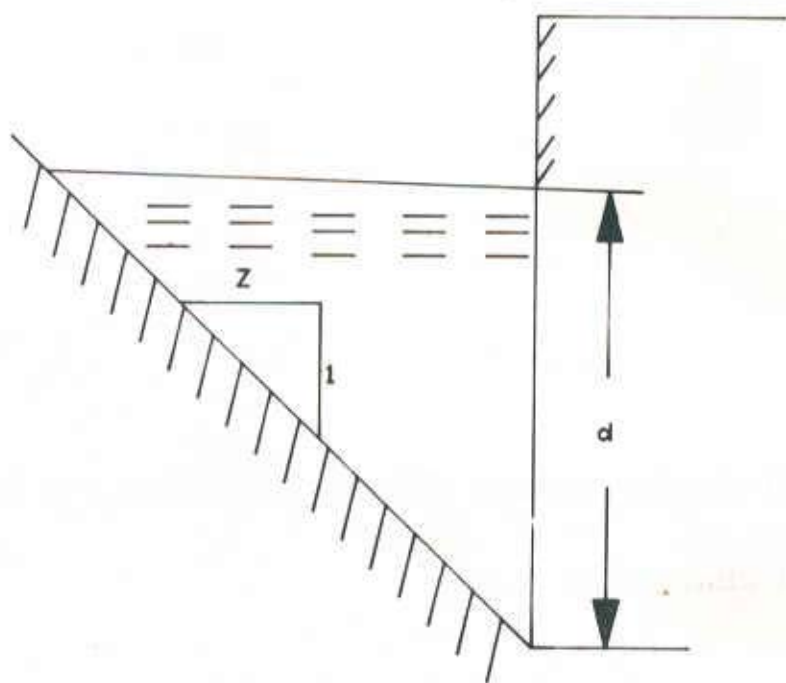
Solving the equation we get

$$d^{8/3} = 3.388 \times 10^{-4}$$

$$\text{or } d = 0.05 \text{ m}$$

The spread of water ($Z \times d$, figure below) is

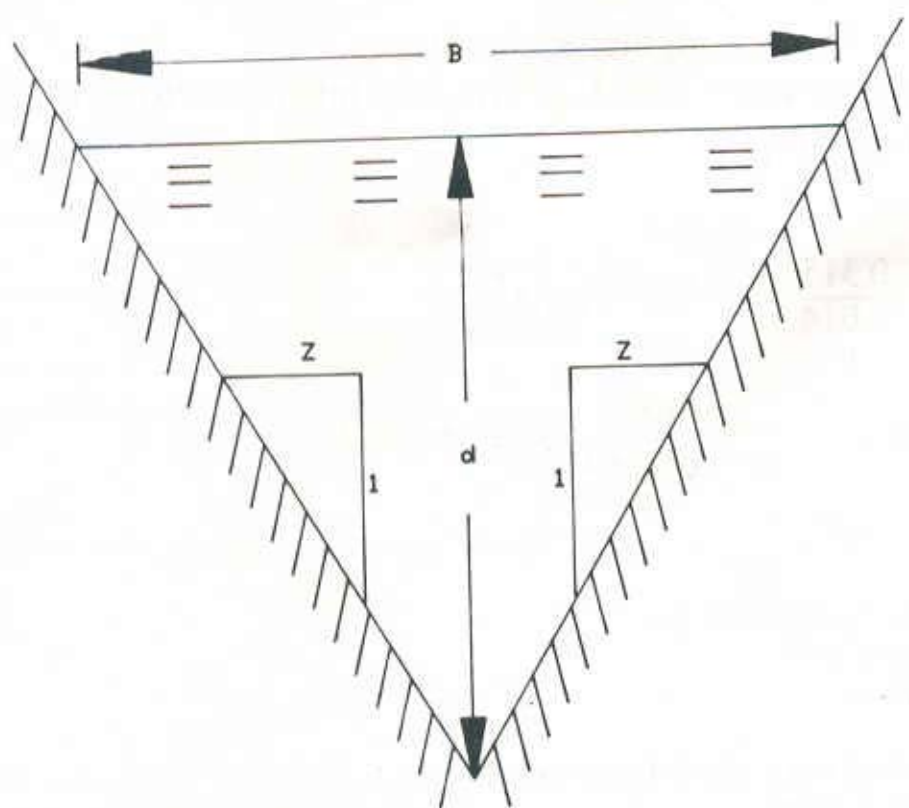
$$0.05 \times 40 = 2.00 \text{ m}$$



Shallow right triangular channel

Example -3

For designing a V-shaped channel section (figure below).



Shallow V-shaped channel

Table A : Discharge and Direction at various locations along the Highway

S. No. of the grade	Distance in m from the start of the grade	Time of concentration 'T' (Minutes)	Area tributary of the flow (Hectares)	Intensity of Rain fall for 2 years cms	Frequency 2 Years		Frequency 5 Years		Frequency 10 Years		Frequency 25 Years		Frequency 50 Years		
					Dis-charge cum/sec	Design depth (m)	Dis-charge cum/sec	Design depth (m)	Dis-charge cum/sec	Design depth (m)	Dis-charge cum/sec	Design depth (m)			
1.	30	10	0.129	10.26	0.017	0.09	-0.026	0.09	0.029	0.09	0.038	0.10	0.044	0.11	
2.	120	15	0.516	8.64	0.0574	0.11	0.088	0.19	0.098	0.15	0.127	0.17	0.146	0.18	
3.	210	20	1.032	7.488	0.099	0.14	0.151	0.17	0.170	0.19	0.220	0.21	0.253	0.23	
4.	390	30	1.677	6.012	0.1298	0.16	0.199	0.21	0.223	0.23	0.288	0.25	0.332	0.27	
5.	570	40	2.451	4.788	0.1512	0.18	0.233	0.23	0.260	0.24	0.535	0.28	0.387	0.3	
6.	750	50	3.225	4.212	0.175	0.21	0.267	0.25	0.301	0.27	0.388	0.3	0.448	0.31	
7.	930	60	3.999	3.6	0.185	0.22	0.283	0.23	0.318	0.27	0.411	0.3	0.474	0.32	
(From Map)															
8.	1470	90	6.381	3	0.244	0.23	0.373	0.3	0.419	0.3	0.542	0.36	0.625	0.38	
9.	2210	120	8.643	2.376	0.254	0.24	0.404	0.31	0.454	0.33	0.586	0.4	0.675	0.40	

Shallow V-shaped Channel

The following equations will be used

$$Q = 1/n F_2(Z) d^{8/3} S^{1/2}$$

$$\text{Where : } F_2(Z) = \frac{0.63 Z^{5/3}}{(Z^2 + 1)^{1/3}}$$

And other elements Q, n S, Z and d are as defined in Example 2.