SOME HYDROLOGIC & HYDRAULIC CONSIDERATIONS FOR DESIGN OF ROAD SIDE DRAINS

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Abstract
Adequate road drainage is essential for the safety of a road, increased life span and reduced maintenance cost. Essential requirements of a good drainage system have been stated. Different data to be collected from site for planning and design of road drainage system have been outlined. Hydrological and hydraulic considerations involved in proper drain design have been discussed. Some typical drainage drawings have been furnished.

Key Words: Drainage, data collection, hydrological and hydraulic considerations, drainage drawings

1 INTRODUCTION
Govt. of India has an ambitious plan of connecting different parts of our country for better communication through a network of national highways, state and village roads under the East –West Corridoor, Gram Sadak Yojna, NREGP, Bharat Nirman (2007) and many other such schemes launched by the Govt. of India from time to time. The enormous fund being invested in the road sector will be useful for our future development since road is one of the most important infrastructures which we should try to preserve and protect. Inadequate drainage invariably results in reduction of life span of a road and increased annual maintenance cost. Drainage congestion in the urban and rural areas leading to submergence of land and consequent loss of agricultural and other valuable properties arise often due to improper planning and design of the road drainage system. Although the cost of road drainage (excluding the cost of bridges and culverts) varies from 1 to 2 percent only (depending on rainfall) of the total cost of road, it is more often noticed that the planning, design and execution of road drainage are not given due importance unlike structural and foundation design / construction of a road. The main objective of road drainage is to remove the storm water from the road surface as rapidly as possible so that traffic may move safely and efficiently without loss of travel time and risk of road hazards. The purpose of writing this paper is to emphasize the various considerations involved in the proper hydrological and hydraulic design of efficient road drainage.

IRC: SP:42 (1994) and IRC:SP:13 (2004) give guidelines for design of road drainage and drainage culverts respectively. IRC:SP:50 (1999) and IRC: SP:48 (1998) are meant for design of urban road drainage and hill road drainage respectively. An earlier paper by the author on “Optimum Spacing and Design of Drainage Culverts in the Hilly Stretch of Buangpui –Lunglei State Road in Mizoram”(Mazumer,2009) is under consideration of publication by IRC. The main focus of that paper was on proper planning, spacing and design of culverts in a hilly road. This paper, however, deals with the planning and design aspects of storm water drains in rural and built-up areas through which our national and state highways run.

2 NECESSITY AND ESSENTTIAL REQUIREMENTS OF ROAD DRAINAGE SYSTEM

When rain falls on a sloped pavement surface, it forms a thin film of water thickness of which increases as it travels to the edge of the pavement. The flow concentrates in road side gutters and ditches running parallel to the road. Overflow from gutters and ditches may spread out in to the pavement and other adjoining areas in case the conveying capacity of the drainage system is insufficient. Factors that determine the thickness of water film on the road pavement and water spread in roadside gutters encroaching on the road surface are
(i) the length of the flow path (ii) texture and camber of the road surface and (iii) intensity of rainfall.

As the depth of water on the road pavement or the water spread from gutters increase, the potential for hydroplaning , disruption of transportation and risk of accident increase. Essential requirements of an ideal road drainage system are summarized below:

- Road must have adequate cross - slope or camber as per Clause 5 of IRC, SP-42(1994) for quick disposal of storm water run-off laterally to the road side gutters and ditches.
- A minimum longitudinal grade of ½% should be provided to the road wherever possible for facilitating both surface and sub - surface drainage
- Capacity of the longitudinal gutters and road side ditches, the size and spacing of inlets, chutes, diversion conduits etc. must be sufficient to dispose the incoming flow quickly.
- Adequate size and numbers of cross - drainage structures (bridges and culverts) should be provided to ensure safe and quick disposal of storm water.
- Run-off from the catchment area should be disposed as quickly as feasible. to avoid any drainage congestion and flooding.
- Run- off water from both sides of the terrain (road in valleys) or from upstream side (in terrains with one side sloping) should be intercepted in the roadside ditches so that the run-off water moves to the cross-drainage system quickly and a continuity of flow is maintained.
- In case the width of terrain contributing flow to the drain is very high, additional intercepting drains at higher elevation away from the road or detention basins (which also helps in recharging ground water) should be provided in order to ensure that the inflow rate into the road side drain does not exceed the carrying capacity of the drains.
- The drain should be connected to the cross - drainage structures so designed that the water moves out without any objectionable heading up / afflux and there is no overtopping of road and damage to the road and hydraulic structures.
- GSB /drainage layer should be provided for sub-surface drainage of percolating / seepage water as well as for intercepting capillary water

3DATA COLLECTION

Designer of road drainage system must be familiar with (i) the terrain through which the road is passing (ii)the natural drainage system prevailing before the road construction (iii) rivers and its tributaries draining the area (iv) ponds and other water bodies (v) topographic features like habitats, industries, marketing places, institutional buildings, existing roads, foot tracks, cable lines, gas ,electrical and telephone lines, railway lines etc. (vi) details of exiting drainage, canals , marshy land, waterlogged and flooded areas, forest areas, agricultural areas, rural and built up areas (with future expansion) etc. (vii) rainfall and run-off (viii) soil, subsoil and cover conditions etc. Although most of these information are available from the relevant updated topo-sheets of the area, a site visit by the drainage engineer is obligatory. He/She can collect many of the vital information needed for drainage design by interacting with local people, panchayats and district authorities, central and state Govt. organizations (e.g. PWD, Irrigation, Agriculture etc.) who may be in possession of similar data to meet their own requirement. Broadly, the data may be grouped as follows:

3.1Topographic Data

Various topographic features as stated above are available from topo- sheets prepared and sold by Survey of India and other local bodies. Google earth software prepared from satellite imageries are extremely useful in finding natural drainage systems and their catchment areas, different topographic features, terrain slope, soil and sub-soil conditions, vegetative cover etc.

3.2 Survey Data

As per TOR prescribed by the road authorities, it is mandatory to conduct road survey to fix up alignment of the road indicating general features, streams, canals, water bodies like ponds etc. crossing/adjacent to the proposed road. Levels are taken for preparing L-sections and cross-sections of the road indicating ground levels. Contour maps are prepared for every kilometer of the road by interpolation using suitable softwares. These information collected from site together with the topo-sheets (either from SOI or from Google earth) form the backbone for planning and designing the drainage works, both longitudinal and cross drainage.

3.3 Hydrological Data

It includes intensity, duration and frequency of rainfall needed for estimation of flow of different return periods. Rainfall data are available from Flood Estimation Reports prepared jointly by CWC, IMD, RDSO & MORTH, Govt. of India, for the 23 sub-zones each having similar hydro-meteorological characteristics. Iso-pluvial maps indicating rainfall of different duration and return periods and their hourly distribution are available in these reports published by Hydrology division of CWC, Govt. of India. The report also explains the procedure of estimating run-off with the use of rainfall data. RDSO (1990) publication RBF-16 also gives valuable data for determining run-off from small catchments.

3.4 Stream Data

L-section and cross-sections of all the streams/nallas/canals etc are to be plotted indicating bed and bank levels, ground levels , HFL/ FSL etc. for the design of drainage and cross-drainage works like bridges and culverts. In case Gauge-Discharge (G-D) stations are there on the streams, annual peak flow and corresponding HFL data should be collected from the competent authorities. Stream flow data like depth, discharge, HFL etc. are also available from Water Users Association (WUA) in many a states. Morphological characteristics of the streams, their meandering, tortuisity and skewness to road alignment, debris carried during flood season, weeds and jungles growing in the stream bed and bank etc. are very vital information needed for the design of drains and cross drainage structures

3.5 Sediment Data

Besides water, all streams carry sediments either as bed load or as suspended load. Many of the CWC/State G-D stations have arrangements to measure the size and mass rate of sediment flow, especially during flood seasons when most of the sediments flow. Sediment sample should be collected from stream bed and banks for determining mean size (d_{50}) of the sediments by sieve analysis.

3.6 Soil and Ground Data

The flow running through the drains and culverts are often found to scour the unlined bed and bank causing flow tortuisity and damage to the road and road structures. It is, therefore, necessary to broadly group the soil to find the roughness and maximum permissible velocity as per table-6 of IRC:SP:42,essentially needed to decide which stretches of the road drain require lining or protective works. Usually, the bed slope of the drain follows the existing ground slope along the road. Ideally, top level of the drain should coinside with ground level at as many points as feasible in order to avoid excessive cutting or filling. It may be necessary to change the bed slope wherever ground slope changes. In steeply sloping ground, it may be necessary to construct drop structures or provide drain with stepped bed/chutes..

3.7 Sub-Soil Data

Sub-soil data e.g. depth of water table, soil textuture, permeability of sub-soil etc. will be useful for the design of subsoil drainage system and GSB layer. Sand and gravel filled sub-soil drainage trenches covered with graded filter or geo-synthetic/geo-jute textiles are very effective in sub-soil drainage, especially in the waterlogged and marshy areas,. Such highly pervious trenches filled with sand and gravel and protected with textiles permitting unidirectional flow movement (i.e. from sub-soil under the paved road towards the shoulder only and not vice-versa) constructed at the junction of metalled road and unpaved shoulders help in controlling moisture content of soil under the pavement thereby reducing the possibility of differential settlement and undulation of road surface.

4 PLANNING OF ROAD DRAINAGE SYSTEM

As stated earlier, a road acts as a barrier against the free movement of water which used to occur prior to the road construction. Longitudinal drains running parallel to the road intercepts the flow from countryside and transfers the drain water downstream through cross-drainage works e.g. bridges and culverts. When the road runs along a ridge or water shade lines, the cost of road embankment and the drainage works is the least. However, unlike a canal, a road has to connect rural and urban areas and it may not be always possible to align it along the ridgelines all along the road. No drain is needed where the road runs along the ridge/watershed line. In hilly and sub-hilly terrains, intercepting drains are required only along the foot of the hills. In areas where the road is in cut, drains are needed on both sides of the road. In a sloping terrain, intercepting drain is needed on the upstream side only. Usually unlined drains are provided in rural and agricultural areas where land is cheap and available ROW is sufficient to accommodate unlined drains having larger size compared to lined ones. In the urban and built up areas where cost of land is high and land is not readily available, lined drains or covered concrete drains are preferred from the viewpoints of land availability, regular cleaning of the open drains used mostly as garbage bins, as well as from hyegenic/aesthetical considerations. Where the road runs on high embankments, provision of stepped drainage chutes along with toe drains keep the road in a healthy condition. Run-off from the road surface should be colleted in a road side gutter and disposed through the intermittent drainage chutes at suitable intervals so that the water flowing in the gutter does not spread out to the road surface beyond a permissible limit. The sloping faces of embankment in between the drainage chutes must be protected to prevent rain cut. Since stepped chutes are self dissipating structures, no additional energy dissipater is required at the toe of road. Where service roads are required in built up areas, it is desirable to provide an inner drain at the junction between the carriageway and the service road in addition to the covered outer drain top of which can be used as footpath. In the super elevated reaches, special arrangements are needed to collect the water in the median and direct the flow to the countryside through buried pipes.

After collecting all relevant information from the site visit, topo-sheets and the survey data (L-section and X-section of road indicating ground levels), drainage requirement in the different stretches of road should be indicated both in plan and L-sections drawn through the centre line of the proposed drains indicating the cross-drainage structures where the drains terminate / outfall. It is desirable to prepare separate drawings for the drains indicating ground levels, bed levels of drains, change points where the slope changes or there is a change in the flow direction in the drains..

5 DRAINAGE DESIGN

Design of drainage involves hydrologic, hydraulic and structural considerations which are discussed in.IRC:5 1998 (for major and medium bridges),IRC:SP:13,2004 (for small bridges and culverts, IRC:SP:42 (for road drainage) and IRC:50,1990 (for urban drainage). Some important steps to be followed in the hydrological and hydraulic design of road drains are mentioned in the following paragraphs.

5.1 Hydrological Considerations for Design of Road Side Drains

Hydrological considerations e.g. design discharge, design storm, time of concentration etc. are vitally needed for design of any drainage system. Although they are discussed in detail in the relevant IRC guidelines, a brief summary of the procedures involved are mentioned underneath.

5.1.1 Estimation of Run-off by Rational Formula

As already stated, the most important consideration for the hydrological design of road drainage is the determination of design run-off (Q). Since the area of catchment contributing flow in the drain is small, usually rational formula given by equation (1) is used for the estimation of run-off.

$$Q = 0.082\, P_m I_c A \qquad (1)$$

Where Q is the inflow rate in m^3 /sec, P_m is the mean run-off coefficient of the catchment area contributing flow to the different drainage elements. P_m value can be found by the relation given by equation (2)

$$P_m = \Sigma(P_i\, A_i) / \Sigma A_i \; (i=1,2,3....) \qquad (2)$$

P_i is the run-off coefficients for the different types of areas A_i contributing run-off to the drain as given in table-2 of IRC:SP:42 (1994) and table-4.1 in IRC:SP:13 (2004), ΣAi is the total catchment area in Ha , I_c is the critical design rainfall intensity in cm / hr corresponding to time of concentration, t_c given by Eq.(3)

$$I_c = (F/T)\,[(T+1) / t_c + 1)] \qquad (3)$$

where F is the depth of rainfall in cm over a period of T hours.

5.1.2 Determination of Design Storm Rainfall

F-values for different durations (T- Hrs) are available from the iso-pluvial maps for different regions in India given in the flood estimation reports prepared jointly by CWC,IMD, MORTH & RDSO , Govt. of India, as well as RDSO report (No.RBF- 16-1990). Design rainfall i.e. F- value to be used for finding I_c vary with frequency or return period of rainfall. IRC : SP:42 recommends a return period of 25 years for optimum cost of road - side drains for national and state highways. Fig.1 illustrates a typical iso-pluvial map showing 24-hr rainfall with 25 year return period for sub-zone 3e in India. AASTHO (1991), however, suggest return periods varying from 5 to 50 years depending on the road classification , traffic speed and permissible spread of water in road side gutters (Mays,1999). They also recommend that the I_c –value should be checked from the consideration of hydro-planning and visibility criteria in high speed roads for road safety (ASCE,1960).

Since the iso-pluvials are normally available for 24 hours (recorded in discontinuous non-recording type rain gauges), in equation (3),T is put as 24. As t_c for road drains is small (of the order of fraction of an hour), it is desirable to find mean hourly rainfall (F/T) from smaller duration storms (say 1 hr or so depending on t_c -value). Flood estimation reports published by CWC for different regions of India give the ratio between T-hour rainfall and 24 hour rainfall as illustrated in Figure-2. for storms of different duration.. Having found F-value for hourly rainfall, equation (3) may be used to determine I_c corresponding to time of concentration t_c. Approximate values of rainfall frequency factors to convert rainfall of 2-10 year return period to higher return periods are as follows:

Return Period	Frequency Factor
2-10	1.0
25	1.1
50	1.2
100	1.25

5.1.3 Estimation of Time of Concentration

It is defined as the time required for run-off from the hydraulically most remote part of the catcment area to reach the point of reference. For various routes of travel, t_c is taken as the longest time of travel to the reference point. Since I_c reduces with increase in storm duration, duration of storm to be considered for design of drainage should be as short as possible. However, if the rainfall duration is smaller than t_c, then only a part of the catchment area will contribute towards run-off at the point of reference. For the entire area of catchment to contribute, the shortest time to be considered is, therefore, t_c.

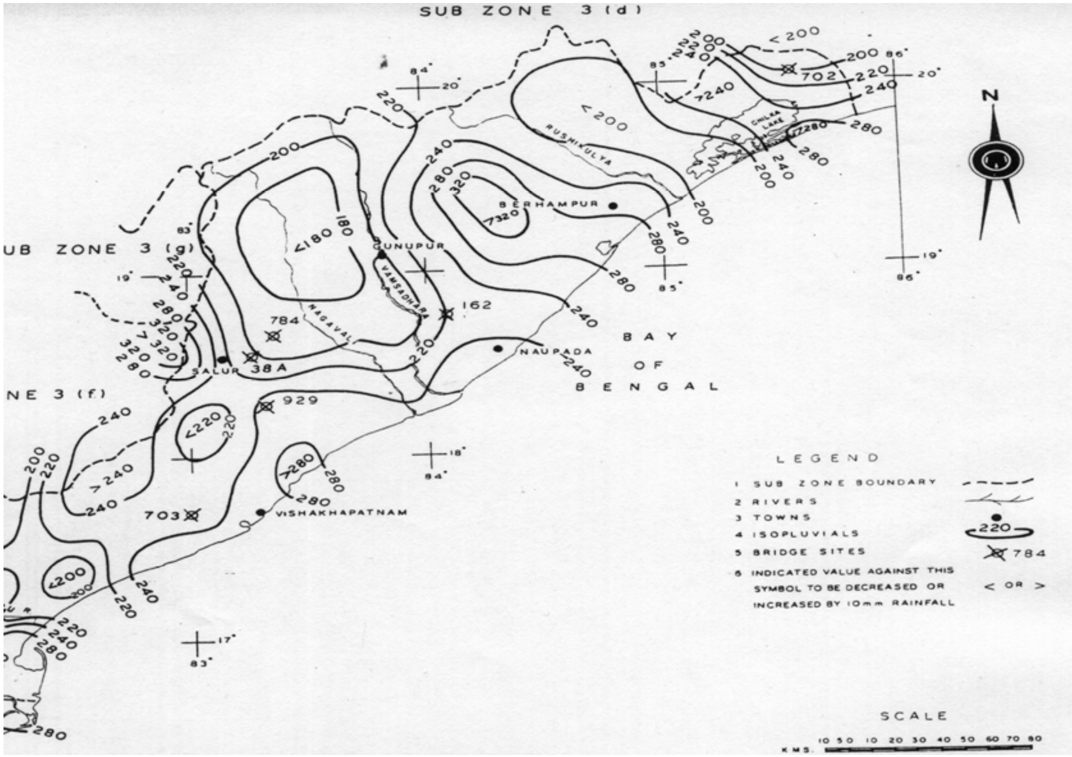


Fig.1 Showing Iso-Pluvial Lines -24 Hr. Rainfalls with 25 year Return period in Sub-Zone 3e in India

Time of concentration can be estimated by adding up the times of travel over the land surface (as sheet flow) with time required to flow through the drain up to the point of reference. Out of the many empirical equations, Manning's kinematic solution (Overton & Meadows,1976) as given by Eq.(4) can be used to estimate overland flow time.

$$T_{t1} = [0.007\ (NL)^{0.8}] / [(P_2)^{0.5}\ S^{\ 0.4}] \quad (4)$$

Where, T_{t1} = Sheet flow travel time in Hr.

N = Manning's roughness coefficient

L = Flow length in feet

P_2 = 24- hr. rainfall of 2-year return period in inches

S = Land slope

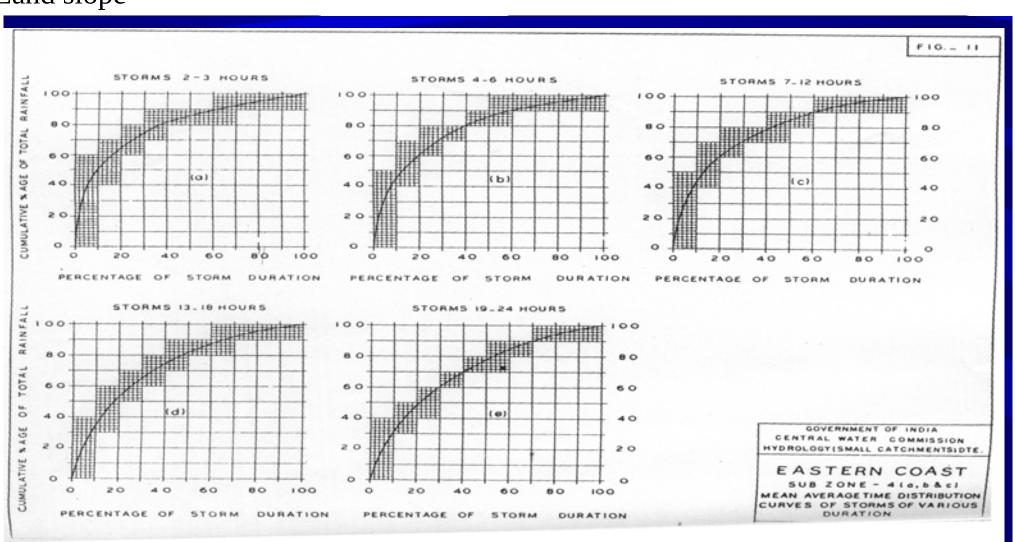


Fig.2 Showing Distribution of Rainfall for Different Storm Durations in Sub-Zone 4a,b,c in India

Times of travel through different sections of the drainage channel/conduit up to point of reference (T_{t2}, T_{t3} ……) can be found by using Manning's equation (5)

$$T_{tn} = (L / N) (R^{2/3} S^{1/2}) \quad (n=2,3….) \qquad (5)$$

Where,

T_{tn} id the travel time in seconds (n=2, 3 ..)

L is the length of the channel in meter

R is the hydraulic mean depth in meter

tc i.e. time of concentration is found by adding up up the values of T_{t1} (from Eq.4) with T_{tn} (from Eq.5).

5.1.4 Hydrological Computation of Design Discharge for Drainage

After deciding the types and arrangements of drainage discussed under section-4, design discharge for the drains (Inner& outer drains, road side gutters. Inlets, median etc) in straight and super elevated reaches in rural and urban areas should be found by using equations (1) to (5) in a tabular form given below. While preparing the table, the stretches of road should be sub-divided in to different sections depending upon change points and outfalls, indicating chainages, slopes, type of drain, flow direction, cross-draiage structure etc.

Chainage		Length of	Type of Drain	Bed Slope	Inflow	Direction	Outfall	Remarks
From	To	Drain in m	Lined / Unlined	+ / -	Q in m^3/s	of Flow	Point	

Where there are inner drains in between the carriageway and service road, the design discharge for inner drains is to be found based on the drainage area of carriageway and median .The flow into the outer drain is usually from catchment area consisting of service road and the countryside limited up to a width of about 30m beyond ROW, In case the catchment area beyond ROW is large, run-off from the service road may be diverted towards inner drain by providing camber towards the inner drain. In the super elevated stretches, the inner drains towards the inner side of the road are to carry the flow from the whole of carriageway. Distribution of run-off amongst the inner and outer drains in straight and super-elevated reaches should be carried out carefully as per the road surface profile.

5.2 Hydraulic Considerations for Design of Road Side Drains

Roadside and median drains are usually open-channel type with free surface flow. These mostly outfall into natural drains like nallas, streams, ponds, marshy bodies etc. It is desirable that outfall should be a free fall to avoid any backwater effect on the road side drains resulting in stagnation of flow and siltation of the drainage channels. It is therefore obligatory for a drainage engineer to determine the HFL of the water bodies in to which the drains discharge. An attempt should be made to find the general HFL all along the road from local enquiry before fixing up the bed level of drains. If necessary, the drains are to run in filling on embankment to avoid submergence and ensure efficient disposal of water from the road. When the ground slope is adequate as in a rolling terrain, the drain bed slope should match with the ground slope to avoid excessive cutting or filling. In a hilly terrain with steep ground slope, it may be necessary to provide drops at interval to avoid supercritical flow through the drain. Drains with stepped bed are self dissipating. In flat terrains, however, it may be necessary to provide a minimum bed slope to ensure self cleansing velocity. This can be done by providing an elevated bed (in filling) at starting point with bed below ground (in cutting) near outfall point. Bed slope can also be artificially increased (more than available ground slope) by providing shallow drain at the starting point and deep drain near outfall. It is, however, necessary, to ensure that at no point the design water level of the drain is not above the sub-grade level of the road and the drainage water does not enter the sub-grade soil. Inner drain water level should always be below the bottom level of drainage layer to ensure free seepage flow from sub-grade to the inner or outer drain.

Flow in a roadside drain is of spatially varied type, since the flow in the drain increases with length in the direction of flow. But for all practical purposes, it may treated as uniform flow by dividing the length into small stretches as the slope changes from section to section. Even if the slope remains constant, the drain length should be divided into several stretches for economy. The design discharge for each section should be the maximum flow at the ends of each stretch so that the conveying capacity of the drain at all other upstream point in a given stretch is more than the inflow in to the drain at the section.

After deciding the different stretches, the bed slope (S) for a given stretch is found from bed level at the ends. Required bed width and depth of flow in the drain at the end of each section can then be computed by knowing the drain geometry (e.g. Rectangular, trapezoidal, triangular, parabolic etc.) by using Manning's formula in steps given below :

(i) Compute the maximum drainage discharge (Q) at the end of each drainage stretch as stated under 5.1.4

(ii) Determine the conveyance (K) required from Manning"s equation: $K = Q / \sqrt{S}$ where K is given by $K = (A/N) R^{2/3}$

(iii) Find the required section factor $Z = KN = AR^{2/3}$

(iv) Find the required bed width and flow depth for hydraulically most efficient channel with a given B/Y ratio.

(v) In case the bed width provided is more than required from practical consideration, recalculate the flow depth and draw the flow line

(vi) Calculate the flow velocity in the drain to check that it is less than the permissible value for the given type of drain (lined or unlined)

The above methodology of drain design is called permissible velocity method. Critical tractive stress approach for design of open channel drains can also be used in determining the drain size and geometry. These methods have been discussed in several textbooks (Chow,1970, RangaRaju,1993, Hendersen,1966).and Drainage Manuals (ASCE,1992; WSDT,1997; ERA, 2002)

6 DRAINAGE DRAWINGS

More often, drainage of a road is found to be neglected and half heartedly executed due to absence of proper drainage drawings indicating types of drain, bed level, bed slope, change point, outfall points, invert levels and HFL of all cross-drainage structure , flow direction etc. The plan and section of the drains should be prepared for every kilometer of the road. Detailed drawings of different types of drains e.g .earthen drain, masonry drain , concrete drain (both covered or uncovered etc.) must be prepared and cross-referred in the drainage drawings For clarity and better execution, it is advisable to prepare kilometer wise drainage drawings separately for left and right drains as well as inner and outer drains. A few typical drainage drawings are furnished in Figs.3 to 10.

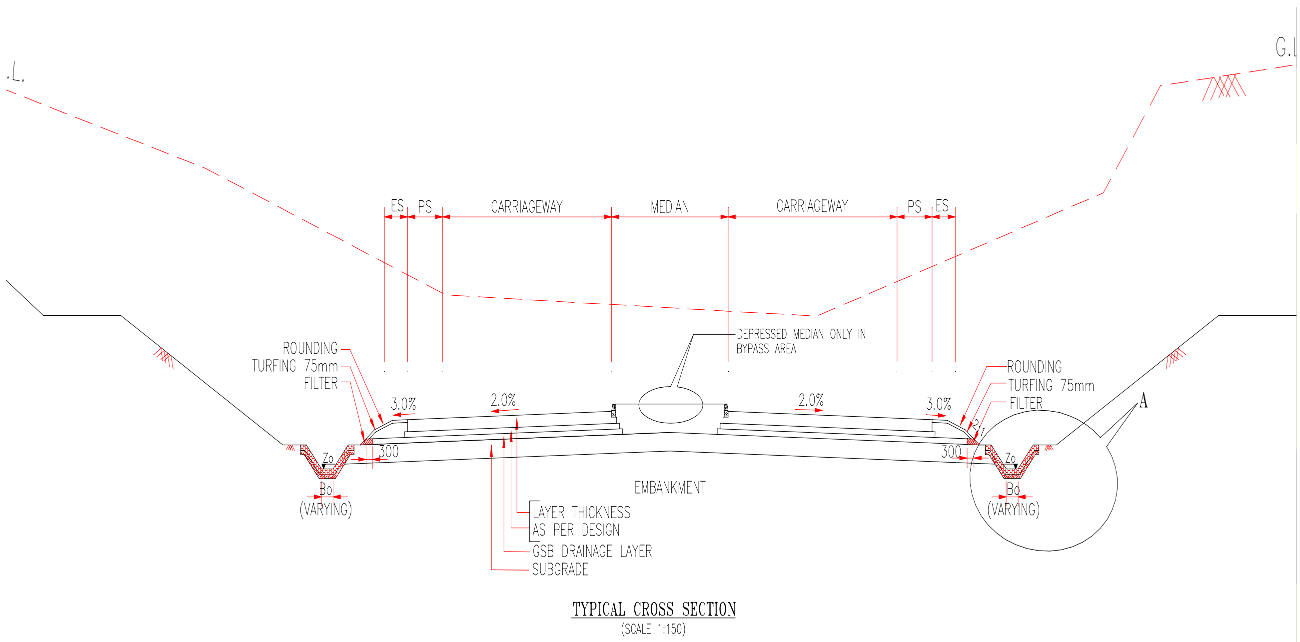


Fig.3 Showing open Drains on Either Side of a Road in Typical Cut Sections

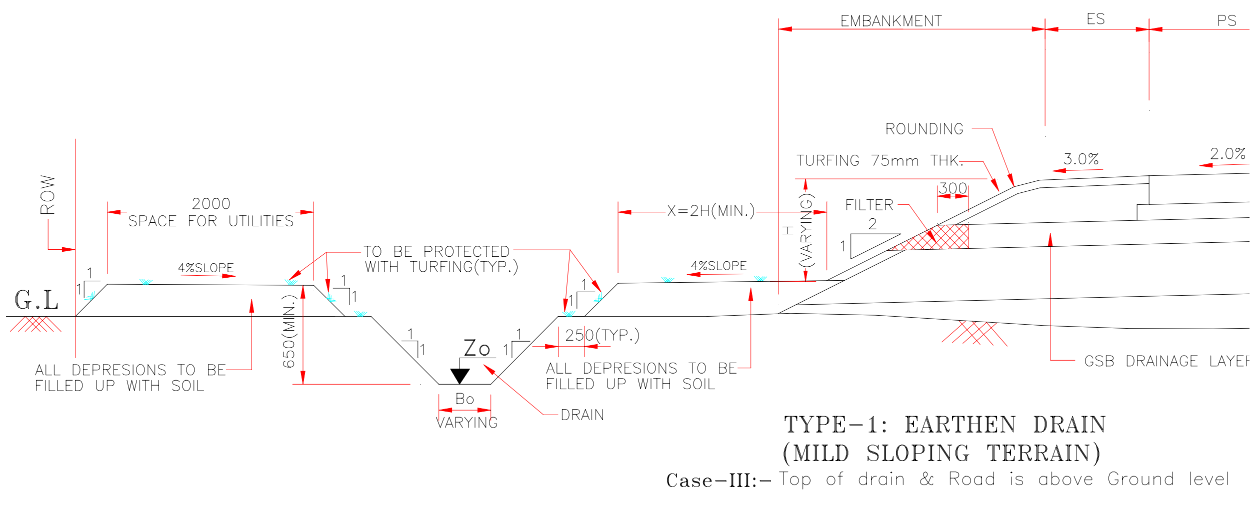


Fig.4 Showing a Typical Earthen Drain (Type-1: Case III) Depending on Relative Level of Ground

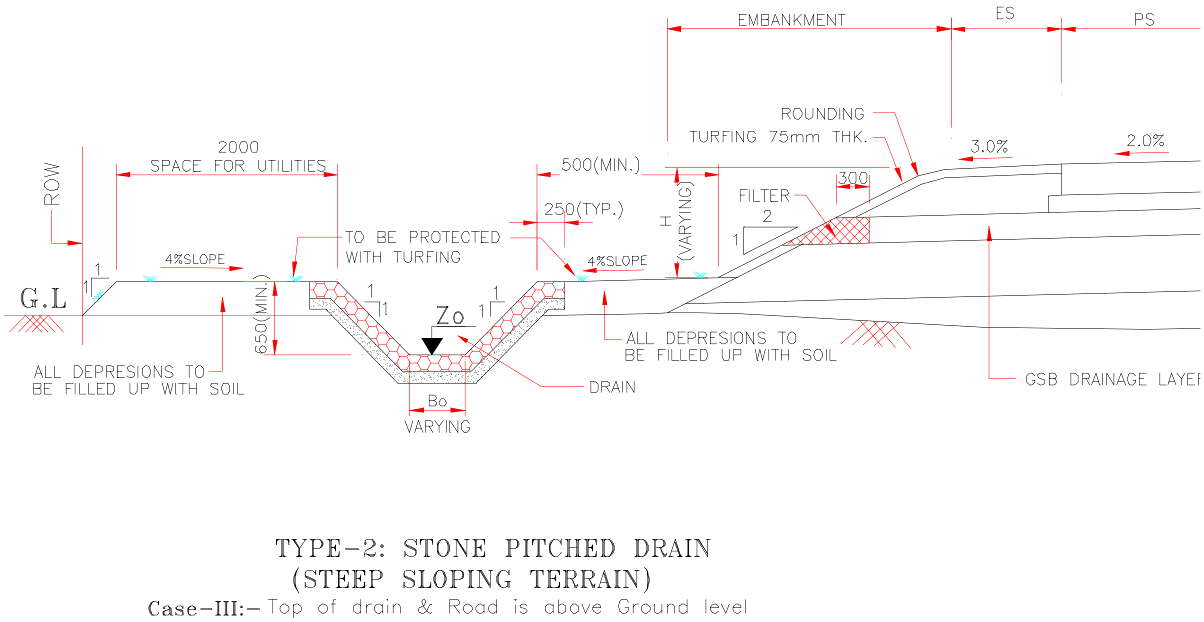


Fig.5 Typical Stone Pitched Drain (Type2:Case III) Depending on Relative Level of Ground

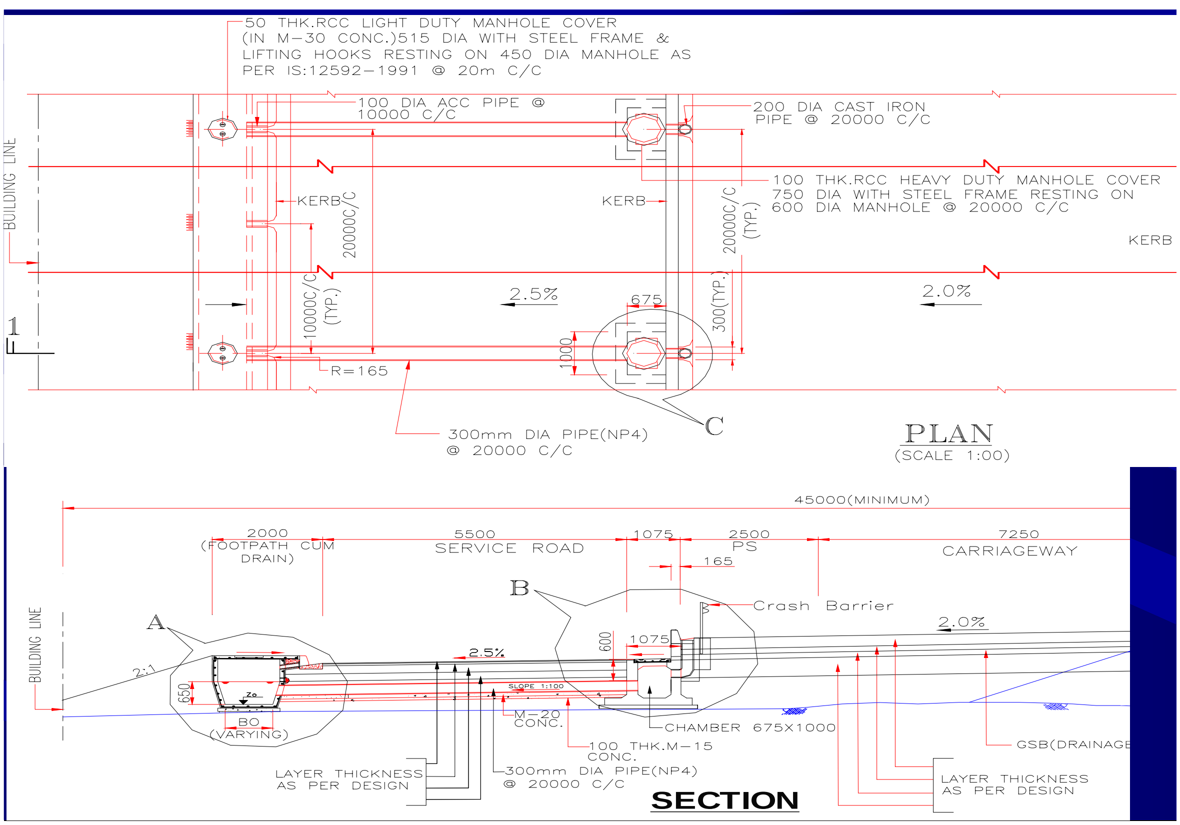


Fig.6 Plan & Section Showing Drainage Arrangements in Urban Areas with Service Road

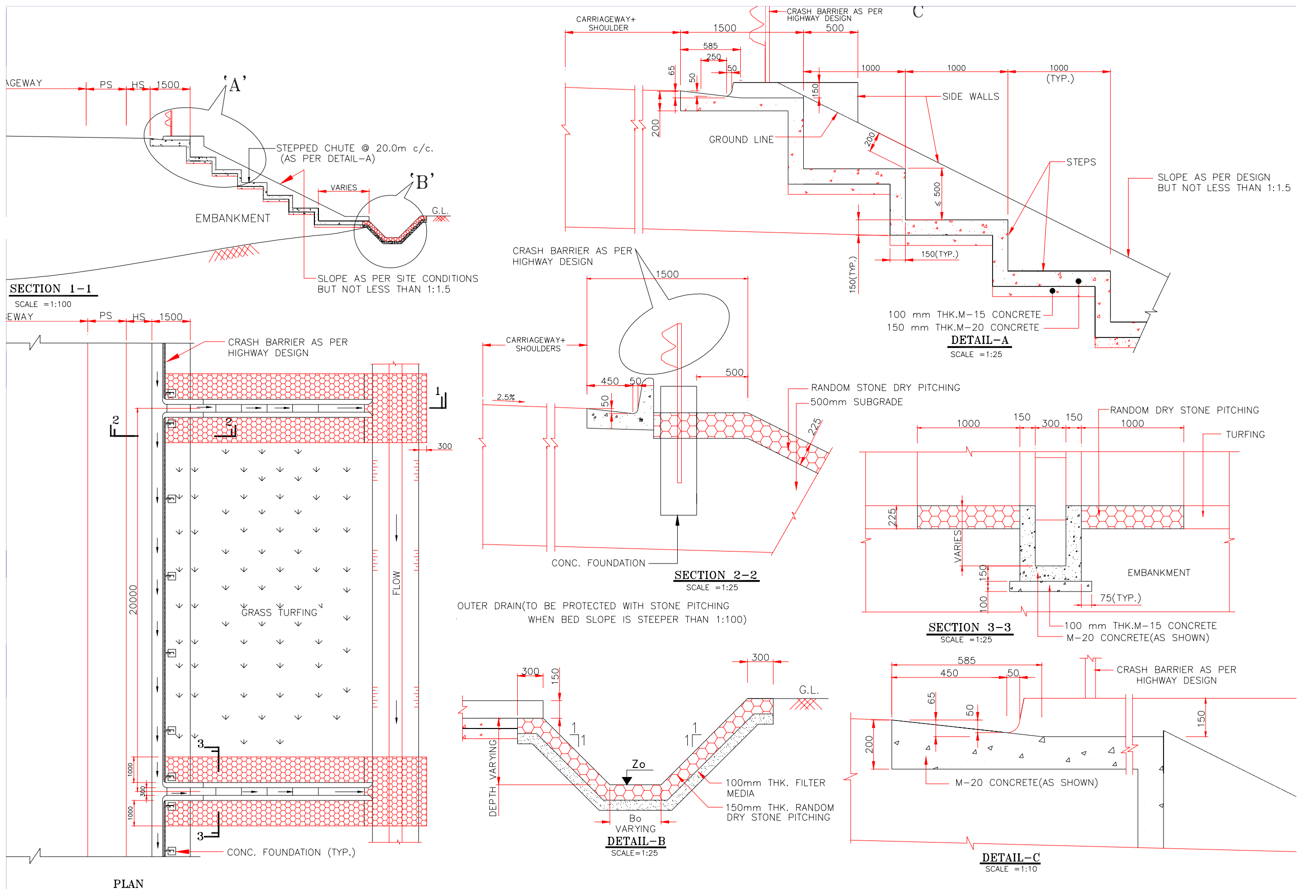
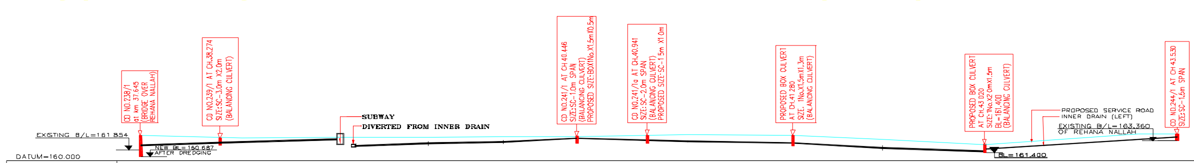


Fig.7 Showing Details of Stepped Type Drainage Chutes in High Embankments



REF POINTS	A	B	C	D	E	R1	F	G	H	I	J
CHAINAGE (Km)	37 645	38.274	39 090/39.110	39 600	39.880	40.446	40.941	41 280	42.200	43.020	43 530
DISTANCE (m)	629 000	816.000	490.000	280.000	566.000	495.000	339 000	920 000	820 000	510 000	
SERVICE ROAD R.L AT INNER EDGE (m)	164 250	163.895	163.955	163.995	164.017	164.062	164 601	164 290	163 600	162.754/162 669	164.491
LONG SLOPE		1:1410	1:1440	1.1000			1:1100		1.1600	1:260	
INVERT R.L	162.616	163.062/163.062	163 655/162.576	162.916	163.196	163.762/163 762	163.295/163.295	163.004/163.004	162.168	161.656/162.019	163.991
DEPTH OF DRAIN (m)	1.634	0.800	0.300	1.079	0.821	0.3	1.088	1.286	1.432	1.054/0.65	0.5
DESIGN Q (m^3/s)	0.835	0 45	0/0.719	0.439	0 160	_	0 145	0.328	0.852	2.123/0.382	0
Bf (m)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	1.000
K (REQUIRED)	31.354	16.897	0/22.737	13.882	5 060	0	4.585	10.879	28 258	84.920/7.111	–
DEPTH OF FLOW Y (m)	1.036	0 632	0/0.799	0.545	0 261	_	0.243	0 453	0.951	1.059/0.333	–
FREEBOARD (m)	0.598	0.168	0.3/0.58	0.534	0 56	0.3/0 3	0 895	0 833	0 481	0.005/0.317	0 500

INNER DRAIN (L.H.S) NOTE:- FOR MORE DETAILS REFER INNER & OUTER LONGITUDINAL PROFILES.

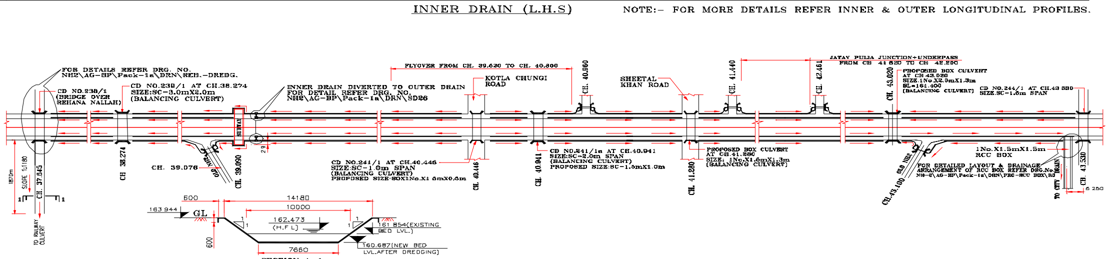


Fig.8Typical Plan and Section of Drains for NH-2 Passing Through Firozabad Town in U.P

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