HIGHWAY DRAINAGE STRUCTURES.

Sadek Kuwatly.

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SCHOOL OF ENGINEERING

PROJECT REPORT

AMERICAN UNIVERSITY OF BEIRUT

"Investigation of present practices in Syria and Lebanon in the design of DRAINAGE STRUCTURES and the study of standardized types of such structures to be used in primary and secondary highways in these two countries."

Prepared by

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May 20, 1953

School of Engineering
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May 14, 1953

Mr. C.Ken Weidner,
Chairman, Board of Directors,
School of Engineering
A.U.B.
Beirut - Lebanon.

Dear Sir,

With reference to your letter of June 23, 1952, I, herewith, submit the study on highway drainage structures for Syria and Lebanon that I have been authorized to do by your Board of Directors.

Yours truly,

S. Kuwatly

Sadek Kuwatly

ACKNOWLEDGMENT

I am deeply indebted to the Portland Cement Association and the Armco International Corporation for the references on drainage structures they sent me.

I also acknowledge the instructive help of Professors N. Manasseh and K. Yeramian and the valuable information from messers H. Khatib and M.A.Itani of the Public Works of Lebanon and Mr. Wadi' Zakka of the Public Works of Syria.

C O N T E N T S .

PART I

INTRODUCTION

CHAPTER 1

Highway Drainage in General

Except where needed for storage, recreational or other purposes, excess surface and ground water is detrimental to life and property and should be drained away. Drainage, then, may be defined, in a general way, as "the science of directing the removal of excess surface and ground water in such a manner as to safeguard and promote the best interests of all concerned" (1).

The cost of maintaining highways in good condition is directly related to the adequacy of the means provided for drainage. Pavements may fail because the load carrying ability of the subgrade is reduced by the presence of excessive amounts of water in the soil. Storm-water falling on or draining to the highway may cause severe erosion of slopes, shoulders and channels, and may undermine culvert outlets. Floods may destroy bridges and embankments.

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(1) Armco's "Handbook of Culvert & Drainage Practice " p.1

"Good drainage design depends on anticipating where surface runoff or ground water will occur, in what amount, and how often, and making provision for removal of excess water as rapidly as is necessary to avoid undue interference with operation of vehicles or excessive cost for maintenance" (1). I should add to this statement that good drainage structures should not introduce unnecessary hazards to traffic.

Drainage structures may be divided into three general classes:

1. Cross drainage structures
2. Surface drainage structures
3. Underdrainage structures

Cross drainage structures include culverts and bridges located at stream crossings, artificial drainage or irrigation ditches, low points on the road profile, equalizing culverts where the road passes through a naturally depressed sump area, overflow culverts in flodded areas, and ditch relief culverts on long grades. Paved fords may also be included under this type of structure.

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(1) O'Rourke's "General Engineering Handbook" p.262

Surface drainage structures include normal road-section, crowns and ditches, shoulders and side slopes, and intercepting ditches. With all these, prevention of erosion should be taken into consideration. Surface drainage includes also drainage through retaining walls.

Under-drainage structures consist of decreasing ground water in and under the pavement by means of road bed stabilization or providing outlets for such water by means of tile drains, blind drains, deep ditches, drop inlets, etc....

CHAPTER 2.

Purpose and Scope of the Thesis

Purpose

In general drainage structures for highways in Syria and Lebanon are not designed according to modern principles. They are inadequate in many ways and have to be improved.

The purpose of this paper is the investigation of the present practices in these two countries in the design of drainage structures and a study of standardized types of such structures to be used in primary and secondary highways.

Scope

This paper includes information about present practices in highway drainage structures as taken from officials in the Public Works of Syria and of Lebanon, and as made out of investigations on site. It will be too general to give this information in one chapter, so it is given in almost every chapter with relation to the type of drainage structure involved.

With the exception of bridges and soil stabilization almost all parts of cross drainage, surface drainage and underdrainage structures as given in chapter I are discussed, studied and standardized where possible. A bridge is too large a structure to be included in this paper. The study of standards for bridges is a project by itself. Soil stabilization is not a drainage structure like a bridge, culvert or a subdrain tile to include it in our scope.

Many charts and tables are given to make it easy for the engineer to pick up the data needed. Various diagrams and examples are included to facilitate the understanding of the different problems studied.

All references used for this project are American and consequently units are in the British system. Quantities in metric units, corresponding to those in British units, are added to make the use of standards given, practical in Syria and Lebanon.

PART II

HYDRAULICS OF DRAINAGE STRUCTURES

CHAPTER 3

Determination of Culvert capacities

It is considered good practice in culvert design that a culvert should not, except in extreme cases, run full or under a head. "Desirable features in culvert location are:

1. Adequate vertical clearance to elliminate possibility of culvert running under a head at flood periods. Culverts may be subjected to a considerable head without danger, but the likelihood of erosion at the lower end of barrel and also of damage to the fill adjacent, is such as to render this construction poor practice.

2. Adequate vertical clearance for ice or drift. This in many cases requires a clearance several feet above extreme high water" (1).

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(1) From U.S. Dept. of Agriculture, Bulletin 1486, April 1927.

There are five general methods of determining the required size of a culvert. These are:

1. Inspection of old structure to be replaced or structures on the same stream.

2. Use of an emperical formula to estimate the waterway opening required.

3. Calculation of discharge at culvert by using a certain formula and data taken from survey of water course.

4. Calculation of discharge at culvert by using more exact formulas that depends on hydrological data.

5. Use of formulas to determine the size of culvert required for the discharge stated in (3) and (4).

First Method:

The most practical method of determining the proper size of a culvert is to investigate the old existing structure to see how much water it was required to carry. Where no culvert exists, it may be possible to make such an examination of old culverts either upstream or downstream from the opposite site. Sufficient allowance or factor of safety should be added in case old highwater records are doubtful or not extended over a period of at least ten years.

Second Method

Emperical formulas are used extensively for determining culvert sizes. They are based on a large number of observations of culverts that have proved adequate to carry the water from watersheds of various general characteristics. It is true they are approximate and allow an ample factor of safety under all except extreme conditions, but due to the many hydrological factors involved, culvert sizes do not ordinarily lend themselves to mathematical precision. Therefore, emperical formulas are the simplest and most practical to use.

The Talbot formula is recommended because of its simplicity and ease of application. It gives the area of the culvert directly:

$$A = CM^{3/4}$$

A = waterway opening in sq.ft.

M = area drained in acres

C = a coefficient that depends on the slope and character of the watershed. Values of C are given in table 1.

This formula is stated in many books on highways without any condition or limitation. As a matter of fact it was developed for the conditions which exist in the

Midwest of the United States and was based on a rainfall intensity of about 4 in. per hour. By its use one can obtain satisfactory results in other places as well, by dividing the computed waterway opening, as given in Table 1 , by 4 and multiplying by the rainfall rate for the locality considered. In Syria and Lebanon, having no intensities of rainfall available, adopting the formula as it is would be better than modifying it.

The waterway opening in the formula is given directly with no consideration given to length or shape of culvert, type of inlet or outlet, slope of barrel and frictional resistance offered by the wetted surfaces of the culvert. Since capacities are most often based on roughly estimated volumes of water, it is not justifiable to introduce the effect of such variables in selecting the size of the average culvert. This does not mean, however, that hydraulic properties of the culvert are ignored. Smooth surfaces as in concrete drainage structures insure the maximum discharge for a given waterway opening, thus introducing a generous factor of safety.

Third Method

For large, important drainage structures it is advisable to survey the expected water course. Then having determined the average slope of the stream bed and the cross-sectional area up to high water stage, the volume of flood flow may be computed by hydraulic principles. High water stage is detected from marks left by past maximum flows. The common way of doing this is by the use of the Chezy Formula:

$$Q = CA\ (rs)^{\frac{1}{2}} \quad \text{in which}$$

Q = discharge in c.f.s.

A = cross-sectional area of drainage channel up to high water level, in sq.ft.

r.= hydraulic radius in ft.(A/wetted perimeter)

s = slope (change in elevation, in ft.divided by length considered, in ft.)

C = coefficient of roughness of channel

Approximate values of C for different types of drainage channels are:

C = 60 to 80, for clean earth channels

C = 45 to 60, for stony earth channels

C = 35 to 45, for rough rocky channels

C = 30 to 35, for badly obstructed channels

Fourth Method

This method deals with more exact formulas, either emperical or rational, to determine the critical rate of runoff reaching a culvert.

By critical rate of runoff is meant that rate which will produce the maximum volume per unit of time which is economically feasible to provide for in control channels. This depends on the following factors:

1. maximum intensity of rainfall and its frequency. A 25-year frequency is generally good for design of average drainage structures.

2. watershed characteristics. This includes roughness of surface, kind of soil and vegetation, slope, size and shape of area, and hydraulic conditions of drainage channels.

3. "time of concentration". This is the time required for a given particle of water from the most remote part of the watershed to reach the point of exit. This factor is dependent on the first and second factors.

A number of methods, and emperical and rational formulas for estimating storm water runoff have been developed.

The Burkli-Ziegler Formula is very generally used, especially for sewers and storm water drains. It is as follows:

$$Q = MRc\left(\frac{S}{M}\right)^{\frac{1}{4}}$$ in which

Q = quantity of water reaching culvert or sewer in c.f.s.

M = drainage area, in acres

R = average rainfall intensity in in/hr.

S = average slope of ground, in ft./1000 ft.

c = emperical coefficient varying with the character of the surface.

Values of c (1) less than 0.31 apply to country watersheds, 0.20 being used for average rural sections.

A rational method of computing runoff is given by the formula:

Q = AIR where

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(1) values of c concerned with cities are not mentioned.

Q = rate of runoff in c.f.s.

A = area to be drained, in acres, determined by a survey.

I = percentage of imperviousness of the area.

R = maximum average intensity of rainfall over the entire drainage area, in in/hr.

Values of I are as follows:

I = 0.40 to 0.65 for impervious soils (heavy)
I = 0.30 to 0.55 " " " , with turf
I = 0.15 to 0.40 " slightly pervious soils
I = 0.10 to 0.30 " " " soils with turf
I = 0.05 to 0.20 " moderately " "
I = 0 to 0.10 " " " " " "

These values are for slopes from 1% to 2%

Another method of estimating peak runoff is shown in chart 1. (1). The curve in this chart is based on statistical analysis of actual records of runoff on small agricultural watersheds (2). It indicates for the humid section of the U.S. the probable peak rate

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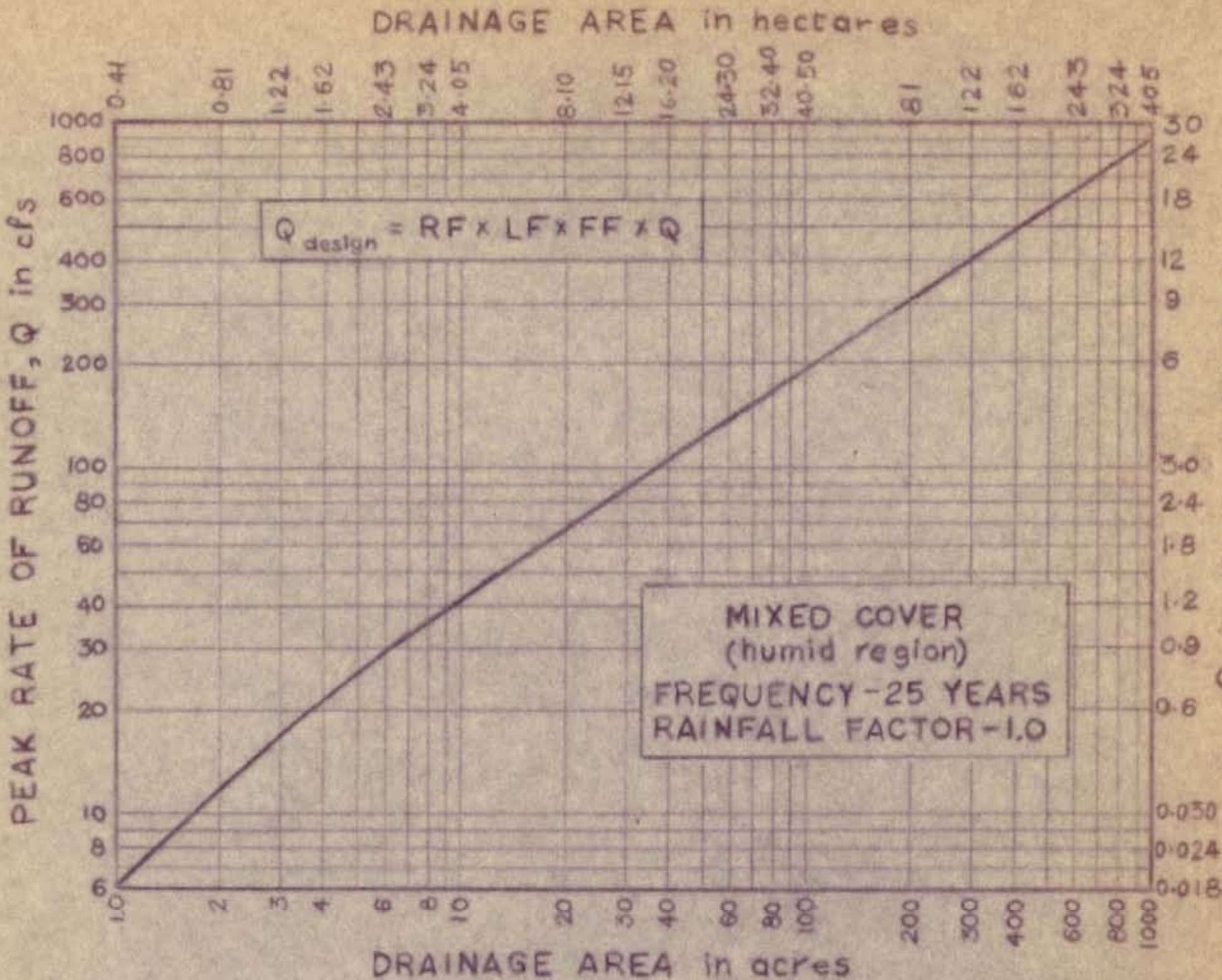
(1) Taken from "Theory and Practice of Highway Improvement and Utilization in the U.S.A. Hydraulic charts p.1021 - 10
(2) Derived in part from Potter's "Surface Runoff from Small Agricultural Watersheds", Research Report No. 11-B, Highway Research Board 1950.



RAINFALL FACTOR (RF) = $\frac{\text{rainfall intensity in/hr}}{2.75 \text{ in/hr}}$

LAND USE AND SLOPE FACTORS (LF)

Land Slope	Steep over 2%	Flat 0.2%	Very flat, no ponds
100% Cultivated (row crops)	1.2	0.8	0.25
Mixed cover	1.0	0.6	0.2
Pasture	0.6	0.4	0.1
Woods, deep forest litter	0.3	0.2	0.05

FREQUENCY FACTORS (FF)

Frequency, years	5	10	25	50
Factor	0.6	0.8	1.0	1.2

EXAMPLE

GIVEN: 80 hectares near Zahleh; cultivated land, sloping about 0.5%; 25-year intensity of rainfall assumed 75 m.m. per hr. (3 in/hr).

REQUIRED: Peak runoff for 10-year frequency.

SOLUTION:

RF = $\frac{3}{2.75}$ = 1.09, say 1.1

LF = 0.9 (from table)

FF = 0.8 (" ")

Q = 9 m³/s (" graph)

Q_{10} = RF × LF × FF × Q

= 1.1 × 0.9 × 0.8 × 9

= 7.12 cu.m. per sec.

CHART I _ PEAK RATES OF RUNOFF

(between pp 13 & 14)

of runoff which will be equaled or exceeded on the average of once in 25 years on a watershed with mixed cover for areas up to 1000 acres. By mixed cover is meant land partly cultivated and partly in pasture.

Readings from this curve can be applied to mixed cover regions of Syria and Lebanon if data on intensity of rainfall is available. This is because of the various factors subject to adjustment according to the conditions encountered.

The adjustments are made by multiplying the peak runoff (Q) for a given size of drainage area, read from the curve, by the product of the land use and slope factor (LF), frquency factor (FF) and rainfall factor (RF). The first two are taken from the tables on the chart while the factor for rainfall intensity is found by dividing the one-hour rainfall expected to be equalled or exceeded on the average of once in 25 years at the location of the drainage area by 2.75 in/hr. The latter is the rainfall intensity taken as a base.

Fifth Method

Having computed the amount of water reaching the culvert, as in the third and fourth methods, the next step is to determine what size of culvert opening is required to pass that quantity. The following formulas (1) result from careful experiments and cover some of the usual conditions found in culverts. Basic conditions for all these formulas are straight end-wall entrances and culverts flowing full.

Box culverts with square cornered entrances:

$$A = \frac{Q\left(1 + 0.4\,R^{0.3} + \frac{0.0045\,L}{R^{1.25}}\right)^{1/2}}{(2\,gH)^{1/2}}$$

Box culverts with rounded lip entrances:

$$A = \frac{Q\left(1.05 + \frac{0.0045\,L}{R^{1.25}}\right)^{1/2}}{(2gH)^{1/2}}$$

Concrete pipe culverts with square cornered entrances:

$$A = \frac{Q\left(1 + 0.31\,D^{0.5} + \frac{0.026\,L}{D^{1.2}}\right)^{1/2}}{(2\,gH)^{1/2}}$$

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(1) "The Flow of Water through Culverts", Bulletin 1, University of Iowa, Iowa City.

Concrete pipe culverts with beveled lip entrances:

$$A = \frac{Q\left(1.1. + \frac{0.026\ L}{D^{1.2}}\right)^{1/2}}{(2gH)^{1/2}}$$

In these formulas,

Q is discharge in cubic feet per second

A is cross-sectional area of opening in sq.ft.

g acceleration of gravity (32.2 ft.per sec.per sec.)

H head on culvert in feet (the difference between the elevation of water surface at inlet and at outlet, if the inlet is submerged)

D inside diameter of circular culvert in ft.

R mean hydraulic radius in ft.

L Length of culvert in ft.

For determining the discharge of small culverts it is customary to assume H = 0.5 ft. For large culverts, heads of 1 ft. or more may be assumed according to the judgement of the engineer.

Of the five methods given for determining the capacity of a culvert, I suggest that the fourth method , that of calculating discharge by more exact formulas or by the chart based on statistical analysis, be not used in Syria and Lebanon at the present time. This is because rainfall intensities needed in these methods, are not available. Using an approximate but safe formula as that of Talbot is more correct than using more formulas such as the Burkli-Ziegler formula and assuming erroneously a rainfall intensity of 3,4 or 5 in/hr. These more exact formulas together with chart 1 are given so as to be used when rainfall intensities will be available in future.

Present Practice in Syria and Lebanon

In Syria as well as in Lebanon no hydraulic means are considered in determining culvert capacities. The only methods used are inspection of old structure to be replaced or structures on the same stream and detection of high water marks on the stream course. Information on traces of floods as given by local people is sometimes depended upon.

In all cases an ample size of opening of culvert is estimated. This is safe, but when big culverts are needed, reliance on these methods is not economical.

Besides for floods that occur once every 15 or 25 years, due to intense storms , capacities assumed might de deficient and the structure might be damaged or even undermined and traffic becomes hazardous.

Rainfall in Syria and Lebanon

In Syria and Lebanon the only data available on rainfall is the total daily rainfall and average annual rainfall in few stations in these two countries. These data are the result of measurements taken by ordinary rain gauges once or maximum twice a day for the last 25 years (1).

I tried to convert the daily or yearly rainfall into intensities of rainfall per hour, but I could not. Neither laws and formulas of probabilities nor comparisons of rainfall for different countries could help me out. From rainfall data in different parts of the United States, I found no constant relation between daily or annual rainfall and intensity of rainfall. This is reasonable because rainfall totaling say 4 in. in one

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(1) These data are available at Ksara Observatory, Zahleh, Lebanon.

day might fall in two hours or twenty hours without any law governing it.

I suggest that automatic gauges giving integral recordings of rainfall be installed in different stations in Syria and Lebanon. Intensities of rainfall given by such gauges are of great importance for efficient design of drainage structure.

CHAPTER 4

Discharge in Ditches

It is very difficult to give an exact estimate of the amount of water flowing into ditches from side slopes and pavement but the following method (1) has proved to be adequate.

It is desirable to use special intercepting ditches if much water flows from the adjacent lands onto the road right of way. Assuming that this has been done, the road ditch proper carries the water from only one-half the road section plus the area of back-cut slopes or small areas of farm land. The runoff from the pavement proper is about 80 to 90 % of the rainfall for showers of say 10-minute duration. The runoff from the shoulders and backslopes is perhaps 60% under favorable conditions. An average runoff of about 75 to 80 % of the rainfall for the area of half the total right-of-way can be assumed.

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(1) Harger's "Handbook for Highway Engineers".p.334

PART III

CROSS DRAINAGE STRUCTURES

CHAPTER 5

CULVERTS in GENERAL

Definition

"A culvert may be defined as a transverse drain or waterway under a road, railroad, canel or channel. By ordinary engineering usage, however, culverts refer only to short structures through roadway or railroad embankment, serving as passageways for water and normally not acting under hydrostatic head.(1)"

"Culvert-structure for purpose similar to bridge, but of span less than the minimum span defined for a bridge, one foot (0.30 m) or more but less than 10 feet (3.00 m)"(2)

The last definition implies a limit between a culvert and a bridge, but a better way of differentiating between the two is that the floor of a bridge is a continuation of the roadway at each side of the stream, whereas, in the case of a culvert, there is generally some fill between it and the road surface.

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(1) Portland Cement Association's "Concrete Culverts and Conduits". p. 6

(2) Brown & Runner's "Engineering Terminology" p.105

Advantages over Small Bridges.

1. less cost and maintenance

2. simplicity in installation. Less interference to traffic during construction.

3. unobstructed roadway and shoulder space. Smooth roadway approach. Visibility not limited on curves.

4. cheaply lengthened when a wider roadway is necessary.

Culverts are excellently adapted where the following factors do not control:

1. Need for a long single span. This is important for wide crossings where stream bed conditions are unfavorable for culvert floor slabs or division walls.

2. Long spans obstruct the passage of debris during flood stages far less than do culvert openings. This factor may eliminate culverts in timbered or drift-littered watersheds. The possibility of ice jamming culvert inlets in cold regions is another deterrent.

Choice

The type of culvert to be used in any particular location depends upon such factors as topography of site, importance of hydraulic and structural efficiencies of available types, familiarity of the builder with construction procedures and cost.

It is important , first, to choose a culvert shape that will best fit the waterway of the drainage channel. In narrow deep channels likely to carry high flows during the rainy season, it is usually cheaper to install tall comparatively narrow culverts to fit the natural waterway than to use wide, low structures. The latter type will require heavy excavation in the sides of the channel and more elaborate headwalls and inlet transitions. On the other hand, in flat areas having no well defined ~~wate~~ waterways, the flood may be large in volume but of shallow depth. Unless water is allowed to back up - undesirable for many reasons - the capacity of a culvert above the flood level will be entirely wasted. A wide box culvert consisting of several cells or openings is better for these conditions.

Where hydraulic efficiency is important as in the case of long culverts or storm drains, the superior features of circular culverts are deciding factors. For a given perimeter, a circular section has the greatest area of any shape, which means maximum economy of materials. Furthermore, for a given area a circular section will give the greatest flow due to the larger hydraulic radius (area divided by wetted perimeter). There is also less interference and disturbance of flow through a smooth circular bore than through other shapes. A factor in favor of box culverts occurs where wing walls or other transitions are required, as such appurtenances may be easily designed to permit a greater reduction in entrance losses than for circular culverts.

The structural properties of culverts and the availability and cost of materials used are important and varied, making it advisable to consider the different types separately.

The types that I am going to introduce are: box culverts:- reinforced concrete, top-slab, and stone, and pipe culverts. Every type will be discussed separately, but of the box culverts, due to its advantages over other types, reinforced concrete will be given most emphasis.

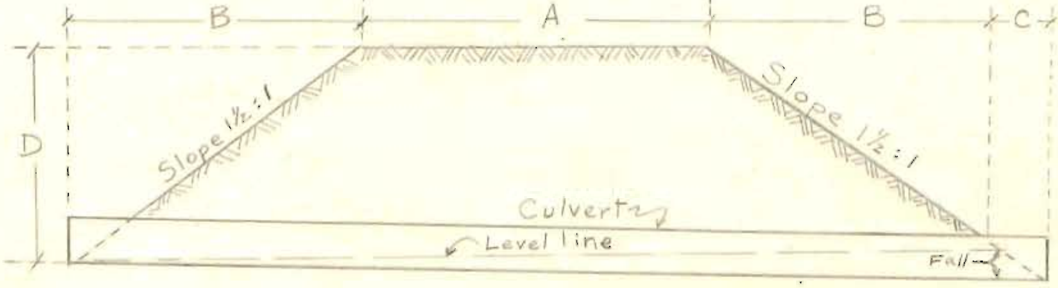

Diagram Showing How Culvert Lengths Are Computed.

Example

A= Width of roadway   Assume A = 8.00 m
D= Depth of fill at inlet   " D = 3.00 m
B= Side slope X D   = 1½ X 3 = 4.00 m
F= % fall X (A + 2B)   = 2%(assumed)X(8+9) = 0.34 m.
C= Approx. 1½ F   = 1½ X 0.34 = 0.51 m
L= Length of culvert = A+2B+C = 8.00+8.00+0.51 = 16.51 m.

Use 16.5 m. culvert

Fig. 1 Simple method of computing required length of culvert at right angles with the center line.

In the absence of such a sketch, the length may be obtained by adding the width of the roadway and shoulders, and twice the slope ratio times the height of fill at the center of the road. The height of fill should be measured to the flow line of the pipe if head-walls are not to be used, and to the top of the pipe when headwalls are to be installed. If the culvert is skewed (i.e. making an angle other than 90° with the center line of the road), multiply the length by the cosecant of the skew angle.

Example : A roadway is 10 m. wide on top, 1½:1 side slopes and at the center of the road the height of fill over the flow line of the culvert is 3 m. The center line of the culvert makes an angle of 70° 0' with the center line of the road. What is the required length of culvert? (Fig. 2)

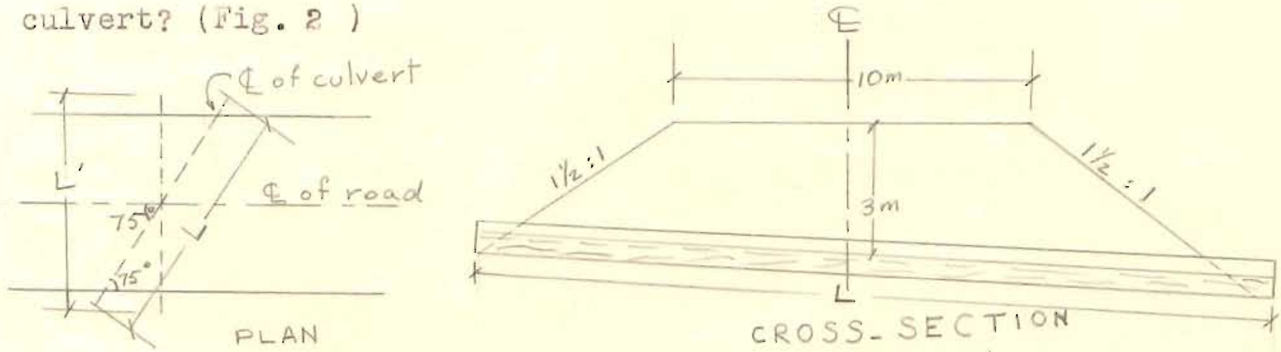

Fig. 2

Solution

Assume no head walls are required.

$L' = 10 + 2 \times 1\frac{1}{2} \times 3 = 10 + 9 = 19$ m.

$L = L' \csc 75^\circ = 19 \times 1.035 = 19.67$ m.

Use 20 m. culvert

CHAPTER 7

Culvert Location

Requirements

The three important factors to be considered in culvert location for greatest efficiency and safety are: alignment, slope and elevation. Poor location of the structure is the most prevalent fault of the usual road drainage scheme.

A good location fulfils the following requirements:

a. Getting water across and away from the road as soon as possible.

b. Causing a fairly uniform velocity of flow both in the channel and through the structure in order to minimize scour or silting up of the waterway.

c. Preventing sharp changes of direction in the flow. Such changes check the velocity and produce ice or debris jams as well as tend to clog the channel with silt deposits.

In general, every culvert location is a case by itself. It is left for the engineer who is going to select the culvert to determine the proper location, but a few principles and examples that apply in the majority of cases will be given to aid him.

Present Practice in Syria & Lebanon

In general culvert location is poor in these two countries. Larger structures, namely bridges, are given more care in location due to the big change in cost effected by a small change in location.

I have seen many culverts in these two countries that are put at right angle with the center line of the road, while the stream is coming at a sharp angle with the center line of the road. Such culverts are shortest in length and are thought to be most economical, but when sharp changes of direction in the flow cause clogging of the waterway with silt and increases the erosion, they become inefficient and the cost of their maintenance outruns the savings in their first cost.

Alignment

A stream which is changing its course or which is very crooked, can sometimes be relocated and straightened out. This may not only make it more efficient hydraulically but may decrease the length of culvert required. It is a matter of economy to decide whether to leave such a stream course as it is and have a longer culvert, or to improve it and have a shorter culvert and more efficient flow.

Assuming that the alignment of the stream is satisfactory, or has been made so, two principles are recommended:

a. Proper alignment must fit the structure into the surrounding topography. This means that the axis of a culvert should coincide with that of the stream bed. The stream should have as direct an entrance into the culvert as possible; a direct exit is likewise desirable. Any abrupt change in direction at either end retards the flow and makes a larger culvert necessary.

b. Change of the course of the stream near the ends of the culvert should be prevented. Otherwise, the culvert may become inadequate, and then by backing up the water, cause a washout. Riprap, sod, or paving will protect the banks from eroding and changing the direction of stream flow. This prevention of bank erosion may also eliminate much sedimentation in the culvert.

The following examples are typical for good alignment:

<u>Case I . Simple right angle stream crossing</u> (Fig. 3)

There is never any doubt in this case. The structure is placed directly in the stream line and at right angles to the road center line.

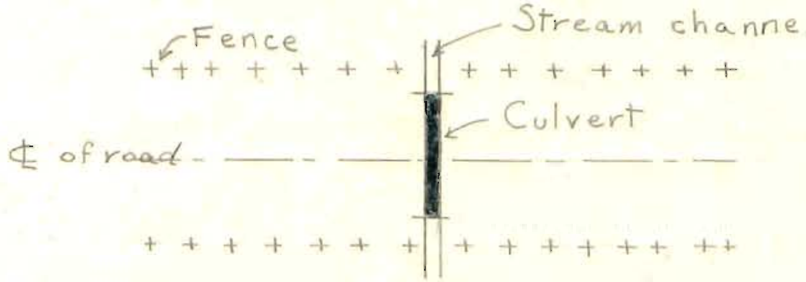

Fig. 3

Case II. Stream crossing on skew angle (Fig. 4)

In a case of this kind, it is desirable to place the culvert in line with the natural stream channel. The right angle location marked "poor" saves length of culvert, but generally requires four sharp changes in direction of flow which tend to check the velocity of flow and to produce scour and silting up at the angles. Considering maintenance cost, this type is generally poor economy unless the creek channel can be changed for some distance.

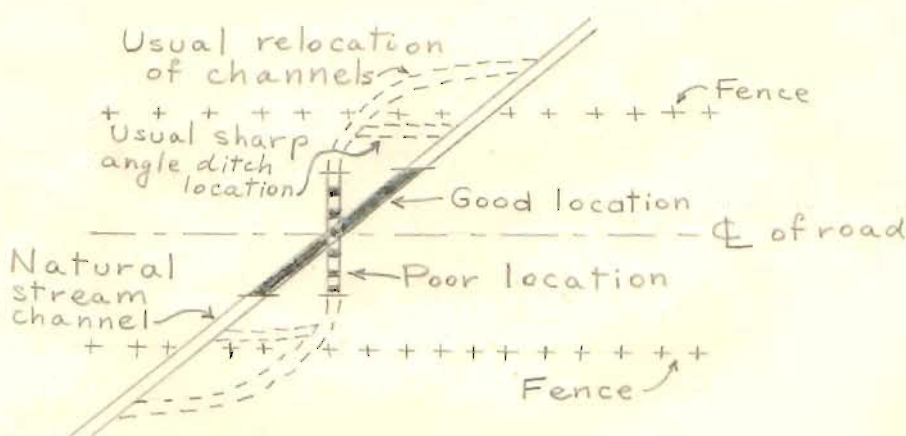

Fig. 4

Case III. Where stream must be carried along road for some distance. (Fig. 5)

The location marked "good" gets the water on to the low side of the road as soon as possible, minimizes sharp changes in the direction of flow, and is desirable unless houses or barns are located on the low side of the road, between the points at which the stream strikes and leaves the road.

Location "2" is desirable where houses are located on the low side of the road but not at the high side.

Location "3" is not desirable under any condition, as it checks flow and causes trouble by reducing the culvert capacity and encouraging scour and silting.

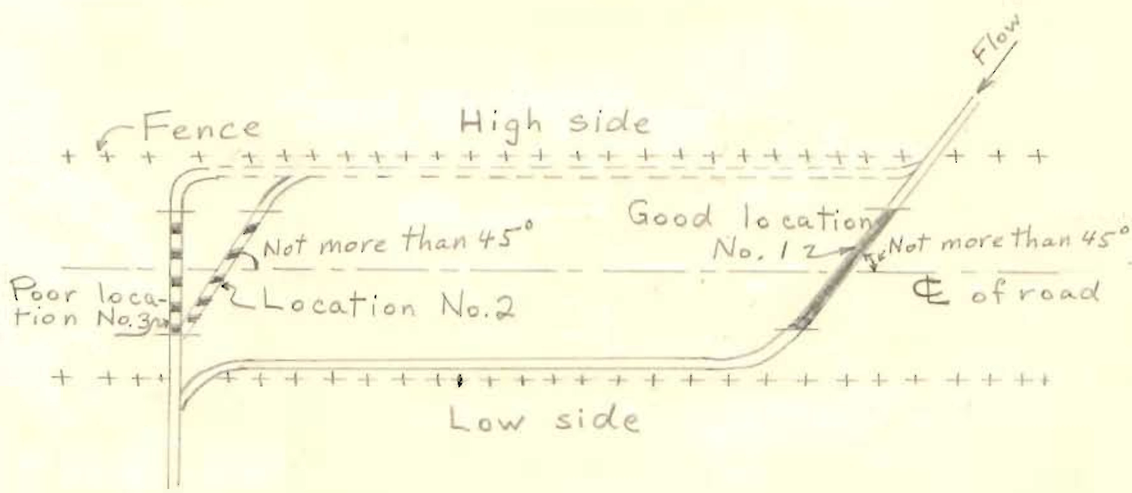

Fig. 5

Case IV - Ditch Relief Culverts on Side-Hill Location (Fig. 6)

Ditch relief culverts on side-hill locations are very desirable as they minimize ditch scour. They are placed at any natural gully formation and on uniform slope formations are spaced from 300 ft. (90 m.) to 500 ft. (150 m.)

The spacing between these ditch relief culverts on hill-side location depends on the grade, soil, ditch lining, and width of section. A narrow 10 ft. (3 m.) mountain road requires more relief than a 20 ft. (6 m.) road in the same location as even a small washout will put the narrower road out of a commission, while a moderately bad ditch scour will not stop traffic in the second case. No set rules on spacing can be given' but current practice favors ditch relief culverts on 8 % grades at intervals not exceeding 300 ft. (90 m.), and on 5 % grades not exceeding 500 ft. (150 m.). If cobble gutter or concrete ditch lining is used, the distance can be materially increased but is not advised.

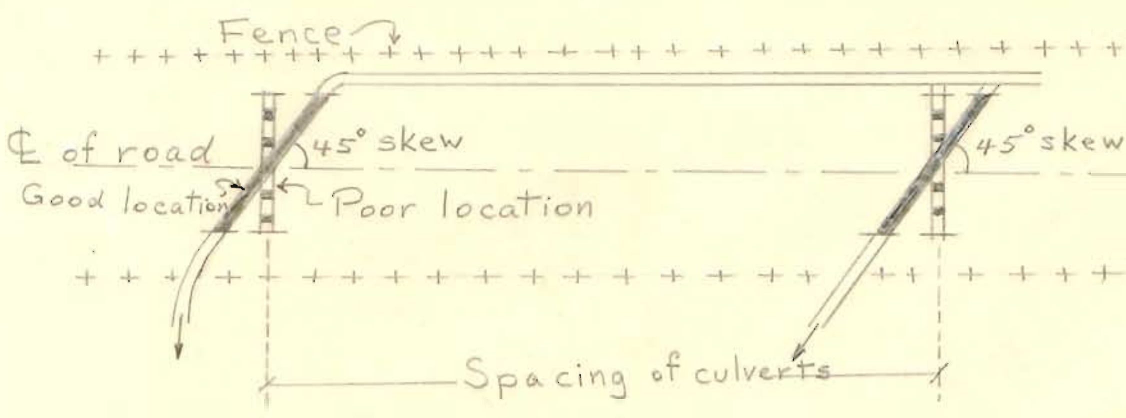

Fig. 6

Case V - Side Culverts (Fig. 7)

In designing culverts under side roads, the length must be great enough to provide an easy turn for traffic; many times a saving in length can be made by placing the culvert a short distance down the side road (at a), but this should not be done on steep grades.

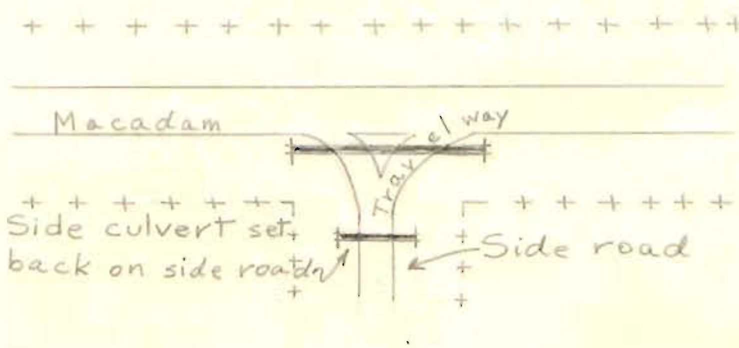

Fig. 7

Case VI - Relocation & Improvement of Channels (Figs.8 & 9)

Figs.8 & 9 illustrate road approach relocation and simple inexpensive channel improvement which betters road approaches, betters flow conditions and reduces cost of structure.

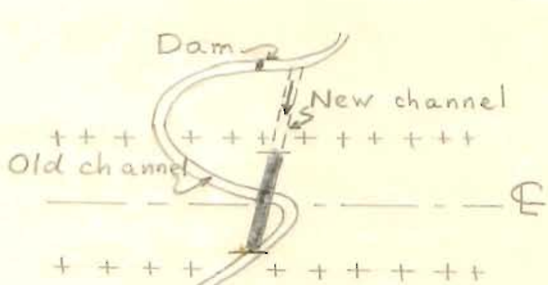

Fig. 8

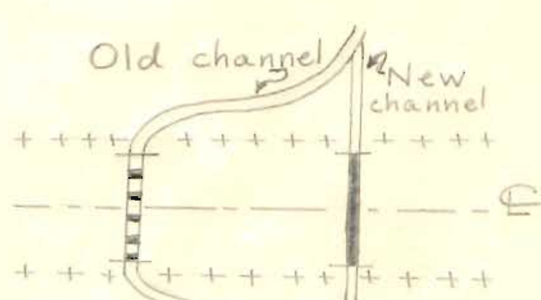

Fig. 9

Slope

In general drainage structures should be built to the same slope as the stream bed in the vicinity. If given a greater slope, with the idea of carrying more water and have a smaller opening, erosion and scouring take place, the outlet end tends to clog and the culvert might be undermined. Conversely, if given a lesser slope, with the idea of preventing erosion, the reduction in velocity will not only reduce the available capacity, but will cause sedimentation and blocks the waterway specially on the inlet end.

In connection with study of the erosive powers of a stream, its erosive power varies as the square of the velocity and its ability to transport the eroded material varies as the sixth power of the velocity.

Velocities of silt-carrying-water below the values in table (2) are liable to cause sedimentation. For velocities above those stated, erosion is likely to occur. Any change in the normal velocity of stream upsets the balance between erosion and sedimentation; and it is therefore important to maintain the status quo of well established streams.

Table 2 - PERMISSIBLE CANAL VELOCITIES AFTER AGING (1)
(Recommended in 1926 by Special Committee on Irrigation Research, Am. Soc. Civil Engineers)

Original Material Excavated	Clear water No detritus		Water transporting Colloidal silts		Water transporting non-colloidal silts, sand, gravel or rock fragments	
	Ft/sec	m/sec	Ft/sec	m/sec	Ft/sec	m/sec
Fine sand, non-colloidal	1.50	0.46	2.50	0.76	1.50	0.46
Sandy loam " "	1.75	0.53	2.50	0.76	2.00	0.61
Silt loam " "	2.00	0.61	3.00	0.92	2.00	0.61
Alluvial silts " "	2.00	0.61	3.50	1.07	2.00	0.61
Ordinary firm loam	2.50	0.76	3.50	1.07	2.25	
Volcanic ash	2.50	0.76	3.50	1.07	2.00	0.61
Fine gravel	2.50	0.76	5.00	1.52	3.75	1.14
Stiff clay, very colloidal	3.75	1.14	5.00	1.52	3.00	0.92
Graded, loam to cobbles, ~~and~~ non-colloidal	3.75	1.14	5.00	1.52	5.00	1.52
Alluvial silts, Colloidal	3.75	1.14	5.00	1.52	3.00	0.92
Graded, silt to cobbles, Colloidal	4.00	1.22	5.50	1.68	5.00	1.52
Coarse gravel, non-colloidal	4.00	1.22	6.00	1.83	6.50	1.98
Cobbles & shingles	5.00	1.52	6.50	1.98	6.50	1.98
Shales & Hardpans	6.00	1.83	6.00	1.83	5.00	1.52
Cobble gutters, grout filled	10-15	3-5	----	----	----	----
Solid rock & concrete "	15-25	5-8	----	----	----	----

(1) Armco's Handbook of Culverts & Drainage Practice P. 254

" In general a minimum slope of 0.5 % is recommended if it can be obtained without changing the velocity of the flow. A slope of 2 to 4 % is advisable when conditions permit." (1)

The principle of having the same slope in the stream bed and in the culvert may be modified wherever it is possible to reduce erosive velocities by means of a broken grade line or spillway, as illustrated in Fig. 10 (d)

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(1) Armco's Handbook of Culvert and Drainage Practice P. 256.

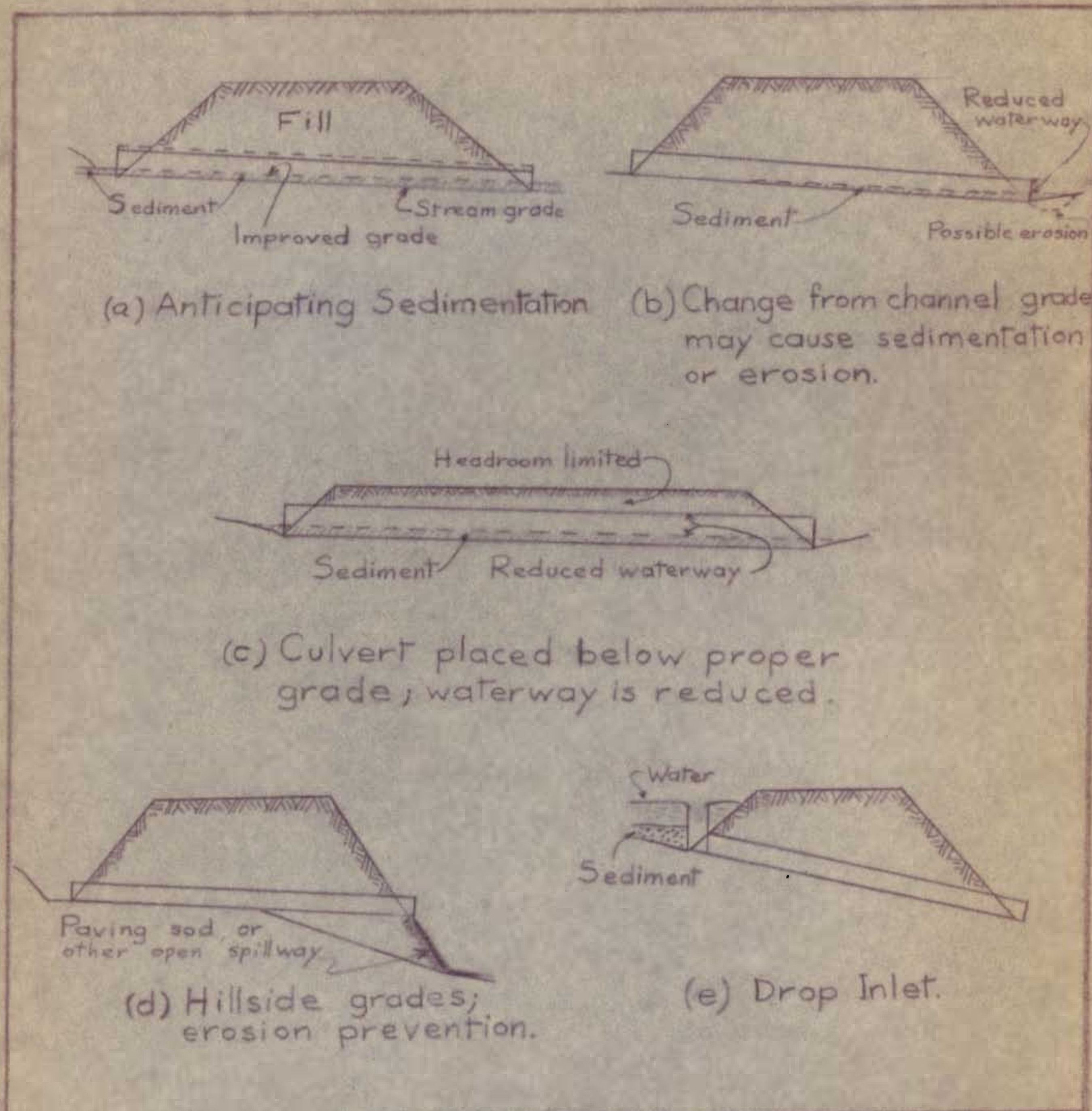

Fig. 10 - CULVERT GRADES

(Between pp 36 & 37)

Elevation

Ordinarily, a culvert should be installed with the invert at stream bed elevation and not lower. This general rule is particularly applicable to hilly country where underdrainage is not given much weight. It does not apply to drop-inlet culverts. In any case the elevation of the invert is made low enough to drain all surface water from the upstream adjacent lands.

In flat country, where underdrainage is practised, the culvert should be made low enough to act as an outlet for farm underdrains.

In order to prevent serious ponding and damage to crops in flat country, all culverts on channels of any importance should be placed at such an elevation that the top of the waterway opening is as low er lower than the surrounding farm land.

Figure 11 illustrates this point. The waterway areas of two culverts A & B are the same in size. In order to get the full capacity of A, however, the water would have to back up and overflow the surrounding lands. Culvert B carries the flood flow without serious ponding. The use of culvert openings similar to A generally cheapens the culvert, but is undesirable if it causes damage to the abutting properties.

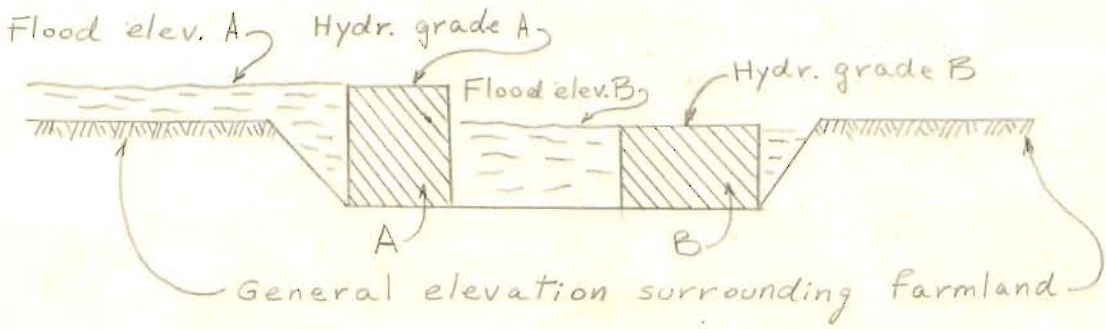

Fig. 11

In case the invert elevation is lowered at the inlet, the channel down stream should be cut to the new grade and slope, if greater drainage is to be secured.

Whether an earth cushion is put between the top of the culvert and the bottom of the pavement, its depth might control the culvert invert elevation where the topography and road grade make a low invert needlessly expensive or impracticable.

CHAPTER 8

Minor Culverts

Relief Culverts:

Relief culverts are used on sidehill roads to relieve ditches on steep slopes . Their spacing depemds on the grade of the ditch and the amount of water carried.(1)

They are also used wherever a road intercepts surface water either in cut or on fill to drain the water to the low side and if possible away from the road as quickly as possible before it can do damage by erosion. This can be done wherever natural drains cross the road and at intervening points.

Another use of the relief culvert is at the beginning of a curve where the water is diverted across to the outerside ofthe curve instead of permitting it to cut into the inside shoulders.

A pipe culvert having the required size is usually used for such culverts.

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(1) Current practice spacing is given on page

In Syria and Lebanon I have seen many side ditches on side hill roads flooded because they were not relieved by culverts. Relief culverts are also missing where needed for the conditions stated above. Installing relief culverts where needed prove to be more economical than maintaining parts of the road damaged by water.

Equalizers:

Culverts are sometimes installed in low places where there is no channel for the water, but where it is desirable to have the back water or standing water at equal elevations on both sides of the fill. For this purpose a pipe culvert can be placed at right angles across the road and with a level grade. Equalizers are not practised in Syria and Lebanon.

Driveway Culverts:

Culverts under drives or farm entrances cause more drainage troubles than any other feature as they are usually constructed by the property owner instead of being included in the road contract.

In Syria and Lebanon, I have seen many culverts under drives made cheap and smaller in size than required. There is no law enforced by highway officials to control the building of such structures. The size of these structures should be fixed on the road plan and designed from the same standpoint as a culvert or a bridge.

Paved Fords:

Paved fords are recommended only where traffic is light and unimportant, where floods are infrequent and of short duration and where stream bed conditions are treacherous and unstable. These conditions exist in dry mountainous areas and the underdeveloped sections of the country where funds for adequate bridges are not available.

The practice is to have a depression or ford in the low embankment, paving it from toe to toe of slope. The alignment is straight and the location of the pavement is shown during flood by four marking posts, two at each end, which also indicate the depth of water, so that it can be used even if covered with water unless the depth is too great for safety, which can be determined by the gages on the range posts. One or more pipe culverts are placed under the paved ford at the low point to provide for ordinary or low water flow. Due to the little fill above them, concrete pipe culverts used have to be reinforced.

In Syria and Lebanon, the paved fords used do not have marking posts to guide the traffic during floods and are thus hazardous.

CHAPTER 9

REINFORCED CONCRETE BOX CULVERTS

ADVANTAGES

One of the principle reasons why I am going to put more emphasis on this type than on other cast-in-place types is because of its strength, simplicity of construction, and adaptability to different topographic and structural conditions and economy.

Inexpensive forms may be used, placement of reinforcement is not difficult and contractors can use methods little different from those learned through experience in ordinary building construction.

A cost analysis shown in a later chapter proves that, for general conditions, this type is cheaper than slab-top culverts as used in Syria and Lebanon.

Box culverts are most suitable for average conditions, comprising moderate or low fills. As embankment loads increase, they become less economical. This is also true when internal hydrostatic pressures become greater than external loads. Culverts of several cells are adapted to moderate embankment fills and requirements of large waterways. A great advantage of this type, and the single box as well, occurs when a roadway grade is fixed and headroom is restricted. Sufficient waterway opening is made by using a wider structure to make up for loss of height.

Box culverts can be shaped according to topographic conditions. They can be made square or rectangular of one or more than one cell.

Superior foundation conditions are achieved by box culverts for nearly any type of foundation material. In unstable compressible materials of low bearing capacity , the pressures are distributed more uniformly and over a wider area than for other types. Settlement is less likely and therefore the possibility of highway depressions is reduced. On rock foundations, the thickness of the bottom slab may be reduced, or perhaps entirely eliminated by use of small footings.

In case a portion of a highway having a culvert is to be relocated, the old box culvert can be taken out and installed in its new position instead of constructing a new one as in the case of other types (excluding pipe culverts). This was done frequently in Palestine without any damages to the structure.

DESIGN CONSIDERATIONS

The standard types of concrete box culverts I am going to introduce (sheets 1 & 2) are taken from "Concrete Culverts and Conduits", a recent publication of Portland Cement Association. These were designed as precisely as sewers or pressure conduits with ample consideration to strength as well as economy.

I will not go into the actual designs of these culverts due to the many design charts that are depended upon such as those giving loads on culverts for different fills or depths of sections and tensile and compressive steel areas for different moments produced by different thrusts. It would be meaningless to the reader to go over the details of design with frequent references to charts that are inaccessible to him. It would be enough to go over the fundamental data and assumptions considered in the design.

Live loads

The standard truck train loading of the American Association of State Highway Officials is adopted, except that the width of traffic lane is taken as 10 ft. instead of 9 ft. In the United States, the H-10 (10 ton) loading is thought to be severe enough for design of culverts on average secondary highways, while the H-15 (15ton) loading is used for heavily travelled secondary highways and even for most primary highways. In Syria & Lebanon culverts designed according to H-10 loading would be adequate for secondary highways while those designed according to H-15 loading would be adequate for primary highways.

The effect of impact is taken as $\frac{50}{125 + \text{span}}$ of the live load with a maximum value of 0.40. Its effect is ignored for fills more than 9 ft (3 m) thick above the culvert.

Embankment loads

Vertical loads are taken as the weight of fill material uniformly distributed on top of culvert. A unit weight of 100 lb/cu.ft. (1600 kg./cu.m.) of fill material is assumed. Frictional forces acting downward (or upward) on the fill above the culvert due to a greater (or smaller) settlement in adjacent material to the culvert were ignored.

For lateral pressures, only active pressure (action of ambankment in assuming its natural condition of repose) is considered, while the passive pressure (induced by movement of structure against supporting material) is neglected. Lateral pressures at any point are considered equal to one-third the vertical downward pressure at the point.

Hydrostatic Pressures

These pressures are taken for water filling up the culvert, with no hydrostatic head above its top.

Outside lateral hydrostatic pressures in excess of lateral earth pressures are not considered.

Load combinations

Combination of forces are considered on culvert full of water or empty, depending on which causes the most severe design condition at a particular point. Other loads are assumed to be acting.

Allowable unit stresses

It has been the custom to use very conservative working stresses for culvert design because of uncertainties in load and use of approximate methods of analysis. Modern procedures of load determination, better methods of analysis and concrete of high strength all combine now to produce factors of safety far greater than those formerly obtained by use of low allowable stresses alone. It is entirely reasonable, therefore, to use allowable stresses more in line with present conditions.

The following allowable unit stresses have been used here: Allowable tensile stress in steel....f_s = 18000 psi (1265kg/cm^2)

Ultimate compressive stress in concrete (28 days)..f_c = 3000 psi (211kg/cm^2)

Extreme fiber stress in compression.....f_c = 1200 psi (85 kg/cm^2)

Unit shear in members having end anchorage of bars, but no web reinforcement...v = 90 psi(60kg/cm^2)

Unit bond, plane bars, ordinary anchorage............. u = 135 psi (9.5kg/cm^2)

Do.do but with special anchorage..u= 200 psi (14 kg/cm^2)

Water-Cement ratio & mix

For a concrete strength of 3000 psi, 6 US gal. of water per sac of cement is required by the A.C.I, 1951 Code (1).

This is equivalent to 26.7 liters per national bag of cement or a ratio of 2:3 of water to cement by volume.

a 1:2:4 mix is to be used.

Construction Joints

Horizontal joints near bases of walls should be located slightly above the floor level to permit easy cleaning and to provide a stub on which wall forms may grip. Structurally speaking, this location is better than at the floor level as it is in a region of lower shearing and flexural stresses.

For walls as thin as those of culverts, roughened horizontal surface joints are prefered on keyed joints because they are easier to form and keep clean, though the latter provide greater watertightness and restraint against shearing forces.

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(1) Concrete ingredients are assumed to be dry.

Vertical construction joints are to be used in long culverts and are spaced according to limitations of casting and lengths of forms, with a maximum spacing of about 30 to 35 ft (9 m to 11 m). Longitudinal reinforcement is continuous through such joints.

Expansion & Contraction Joints

"For average field conditions it is thought to be the best practice to use no expansion joints in the culvert barrel" (1).

General Remarks concerning the tables

The tables listed on Sheets 1, and 2 are copied with the following changes:

1. Equivalent metric units are added to render the use of tables practical in Syria & Lebanon. These units are rounded up to the best advantage of safety. A 5 in, for example is rounded up to 13 cms. for thickness of slab and to 12 cms. for spacing of bars.

2. Square bars, being non-standard in Syria and Lebanon, are replaced by round bars. a ½ in sq.bar is changed to 9/16 in round bar; although the latter is non-standard, its equivalent, 14 mm round bar, is standard.

(1) Portland Cement Association's Concrete Culverts and Conduits - p. 25

3. a column of costs of culverts (excluding head walls or wingwalls) is added in each table to compare them with costs of other culverts in a later chapter. These are based on an approximate cost of L.L. 100.00 per cubic meter of reinforced concrete.

Head Walls, Wing Walls and Cutoffs

Good practice in head wall design and location depends largely upon the judgment of the engineer. Each location presents a new problem and the engineer must adjust his general design to meet special requirements. For this reason I shall not make standardized designs of concrete headwalls or wing walls; but general considerations for importance, location and design of such walls will be stated.

Importance of headwalls

Some type of headwall is necessary for even small unimportant culverts. The upstream end of the culvert must be protected from water getting behind the concrete, saturating the backfill and carrying away light material. This "piping action" is dangerous during storm flows, damaging and sometimes undermining the structure. Any saving made by eliminating head walls may be offset many times by high maintenance charges. I have seen many small culverts in Syria & Lebanon without headwalls, and I have seen the consequent results mentioned above. It should be noted that head walls are even more necessary for light, flexible pipe culverts than for those of reinforced concrete. The former borrow strength, stability and weight from the backfill, which,therefore, must be protected.

A downstream headwall is used chiefly to protect fo foundations from scour in silted stream beds. A common occurance is for erosion to start a short distance down stream from a culvert and to advance upstream, becoming more serious as it proceeds. If a headwall or cutoff extends down to firm foundation the culvert will not be endangered.

Location of Headwalls

Head walls are located parallel to the roadway, usually near the point where top of culvert meets the sloping embankment. A saving in headwall height can be made by lengthening the culvert, and the engineer should compare the added culvert cost with this saving. The possibility of future widening of roadway should be considered before headwalls are located. Ample width should be provided when there is uncertainty in this respect.

Cutoffs.

Cutoffs or toe walls at inlet and outlet of culverts are helpful not only in preventing scour, but also in anchoring the structure in place and in reaching firmer foundation. The minimum depth below bottom slab is usually specified as 2 ft. (60 cms.), with the provision that it may be increased at the discretion of the supervising engineer. Observations made on the character of the channel will indicate whether a cutting or a filling action is in progress. Rocky, boulder-strewn beds, different from surrounding surface, mean that erosion is occuring, so cutoff walls should be deeply founded.

Wing walls

Wing walls are used as extensions of head walls for large structures, to provide greater protection for embankment material. They also have important hydraulic qualities, which may be utilized in obtaining maximum capacity of culvert.

No general rule can be given for best radius of curvature for rounded entrances. Any short radius will improve entrance conditions, a large radius not being more efficient proportionally than a short radius. "For small culverts a radius of one half the clear span will reduce entrance losses nearly 50 % from losses due to a square cornered entrance."(1)

The angle with the channel axis to which wing walls should be set depends on several factors. Their main purpose is to form a transition between channel and culvert. The less abrupt and disturbing this transition is, the smaller will be the entrance losses. When there is a change in direction of stream flow at the culvert entrance, the wing walls are best made short and nearly perpendicular to the culvert, while the wing wall at the outside is long and placed at a stategic angle to deflect the main flow into the culvert without turbulence.

For the usual location in which culvert and channel axes are the same symmetrical wing walls at 45 degree inclinations are most often adopted. They should be located so that inside faces are flush with the edge of the culvert opening. Slightly greater efficiency is claimed for wing walls having angles of 20 degrees with the axis, but in

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(1) "The Flow of Water through Culverts", Bulletin 1, University of Iowa City, Iowa.

view of the possibility of water cutting in back of the wing walls such small angles should not be arbitrarily used.

Curved wing walls are not only attractive but minimize entrance losses and give more stability to the structure against lateral pressures. However, because of the curved surfaces, forming costs are higher and except for first class primary highways, they are not feasible.

Details

Fig.12 illustrates some details of a typical straight end wall cast integrally with culvert (1). It shows the arrangement of concrete sections and reinforcement; the actual design is left for the engineer selecting the culvert to do in accordance with the conditions encountered. The height of wall depends on the elevation of sloping embankment surface and the length is such that the embankment is protected from direct impact of water. Cutoff walls extend down below the limit of erosion, often taken as 3 ft. (90 cms.) minimum.

The wall section out from the culvert must be designed as a retaining wall, independently of the restraint

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(1) Taken from Portland Cement Association's "Concrete Culverts and Conduits" - p. 53

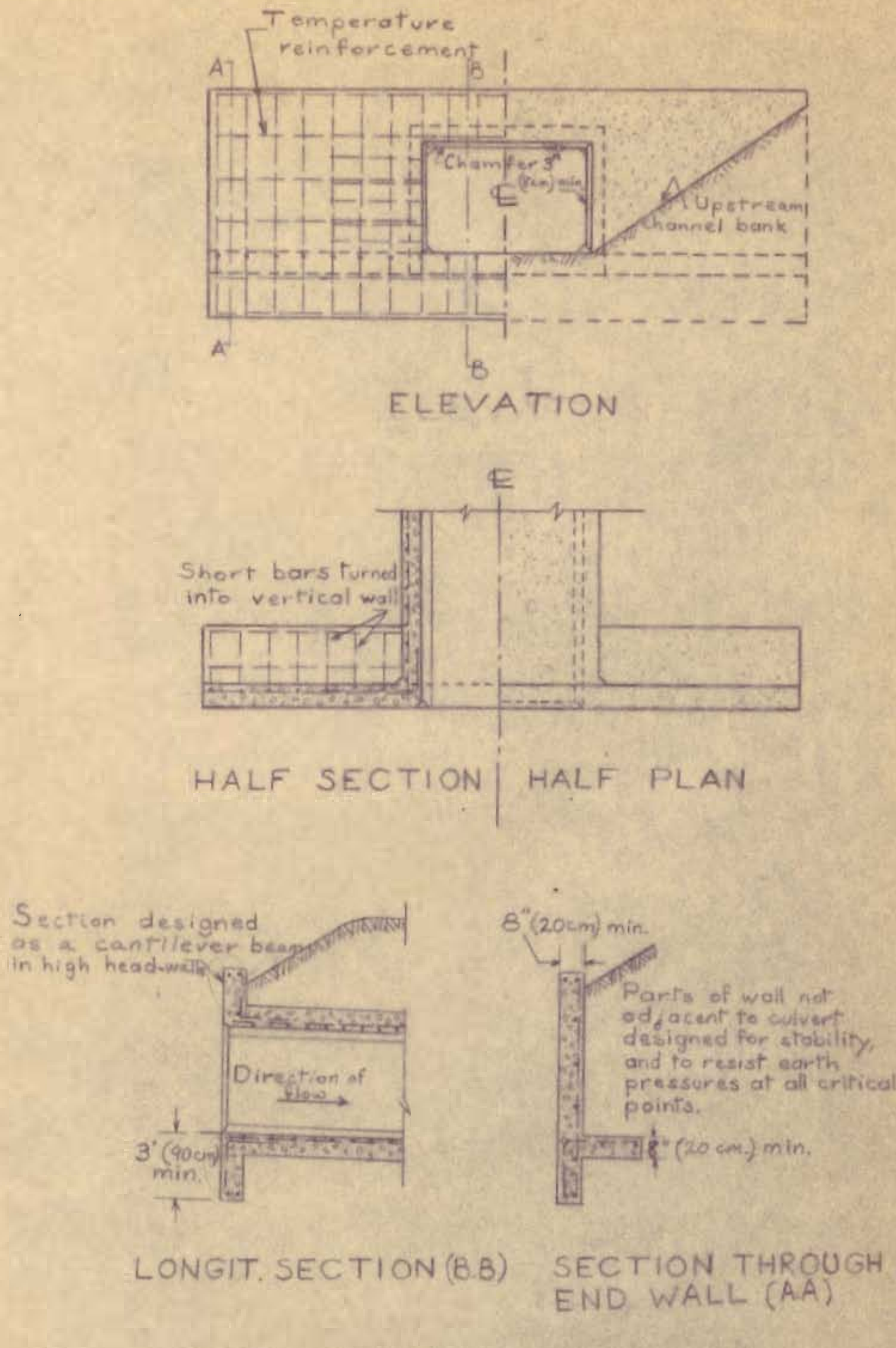
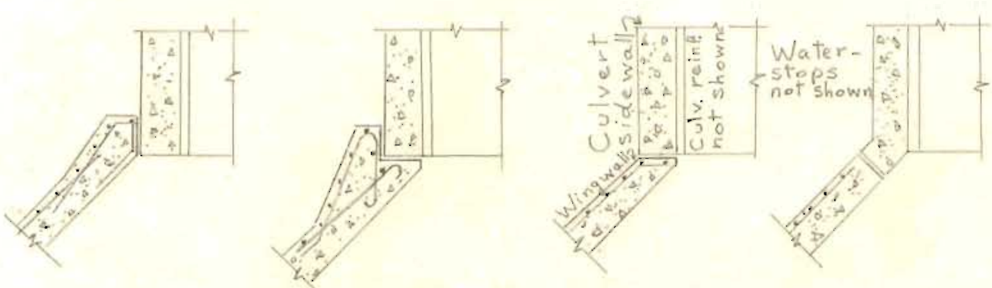


Fig. 12. Details of straight end walls cast integrally with culverts.

at culvert. An additional layer of light reinforcement near the exposed face is used in thick walls to resist shrinkage and temperature effects.

Small wing walls can be cast integrally with the culvert head wall, but large ones are usually cast with a definite joint that should not cause damages due to lateral pressures.

Joints are of two general types depending on the anticipated magnitude of lateral pressure. Where low pressures are expected, a type of joint which will close slightly under wing wall movement is often adopted. Two details of this type are shown in Fig. 13 (a) & (b). Type (a) is poor for structural as well as hydraulic reasons. The narrow joint can accomodate very little tilting at top of wing wall without bearing on the culvert side wall. Cracks or spalled concrete may occur at the joint to mar the appearance. For hydraulic efficiency, the exposed face of wing wall should fit flush with the side of culvert opening. Detail (b) is elaborate, but improved over type (a).



(a) Poor (b) Improved (c) Poor (d) Good

Fig. 13

If lateral pressures against wing wall are indeterminate and possibly high, the joint should be detailed so that wall movement cannot damage the culvert. Fig.13 (c) is of this type but is otherwise unsatisfactory since wall movement will open the joint and allow backfill materials to be carried away. Type (d) is more satisfactory, as heavy pressures can tilt the wing wall without opening the joint.

It is common practice to cast high wing walls to tilt backward 1/16 in per ft.(0.5 %) of height above footing. Lateral pressures are presumed to tilt the wall forward to the desired position.

Joint filler may consist of bituminous felt or premolded rubber and copper or rubber water strips may be added for water tightness.

Headwalls and wing walls are made as thin as 8 in (20 cms) for small structures, with 10 or 12 in (25 to 30 cms) thickness common for average cases.

CHAPTER 10

Slab-Top Reinforced Concrete Culverts

This type of culverts is made of a concrete slab on top supported on two retaining walls made of masonry and a concrete foundation that usually lies all across the culvert. In general it is used for spans from 10 to 20 ft. (3.00 to 6.00 m.) (1). For larger spans, T-beam and concrete deck-girder spans are used.

I am not going to set standards for this type for the following reasons:

1. There are standards already used in Syria and Lebanon.

2. Reinforced concrete box culverts that I have already put standards for, are more favorable due to their having more rigidity and strength, better hydraulic properties, and , in general, less costs for spans less than 10 ft. (3 m.).

It would be sufficient to go over the standards used in the present practice, comment on them and analyze some of their designs.

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(1) Urquhart's "Civil Engineering Handbook" - p. 133

Present Practice in Syria

The only standard culverts used in Syria are slab-top culverts and pipe culverts. No reinforced concrete box culverts, reinforced concrete arch culverts, or masonry arch culverts are standardized because they are not used. Sheet 3 shows the standard slab-top culverts used for any type of highway in Syria.

This sheet is taken from the original copy of the Public Works with the following changes:

1. Arabic and French words, letters and numbers were changed to English.

2. Building materials that were drawn without any indication were named.

3. A list of costs for the different culverts, excluding the headwalls and wing walls was added to compare them with other types of culverts.

The following items are some of the remarks against these standards:

1. Headwalls and wing walls.

To have a wing wall made in the form of a quarter of a cone is not efficient from the hydraulic point of view. Before the water will pass through the culvert, it will strike the headwall, form turbulence and thus its velocity and discharge would be decreased.

Only 0.50 m. of the height is masonry, while the rest is earth. The radius of the cone is (H + 0.45) while its height is (H + 0.45 + e). This means that the slanting height makes an angle of more than 45^{o} with the horizontal, an angle which can hardly leave moist earth at rest. If the earth is wet (angle of repose = 30^{o}) or very dry (angle of repose = 38^{o}), it will fall down. Moreover if the height of flow is more than 0.50 m., the water will wash the earth away, retards its flow and block the culvert.

A better way, though more expensive, would be to continue all the wing wall with masonry for two courses of stones. A still better method would be to make a quarter of a cylinder instead of a quarter of a cone so that the wall will take the shape of the water and increases the hydraulic efficiency of flow.

2. Foundations

The foundation is standardized as 0.25 m deep at middle and (0.7a + 0.10) deep below retaining walls for the culvert and headwalls, and 0.50 m deep for wing walls. This is not economical for all conditions of soil. A rocky ground requires less depth of foundation than does a sandy or clayey ground. It should be left to the engineer in charge to vary the depth of foundation as required.

3. Retaining walls

The top of the masonry retaining wall is fixed as 0.60 m. This looks ridiculous when there is a varying height (H - 0.25), a varying base (a), and a fixed batter (15 %). The correct dimension would be

$$\text{top width} = a - 0.15\ H$$

4. Top Slab

In this part of the structure the following details are missing:

a. depth of cover is not mentioned. An insulation of 2½ (two and a half) cms. from face of slab (of depth e') to center of reinforcing for e' less than or equal to 18 cms., and 3 cms. for e' more than 18 cms., should be put down.

b. nothing is mentioned about the bent portion of bars "A". Having straight bars on top, and bending every third bar would be sufficient for negative moment. .

c. nothing is mentioned about the place where bars "A" are bent up. Assuming a moment coefficient of 1/9, and 30% of steel bent up, $\frac{0}{5}$ would be the distance from the inner side of the support to the section where bars are bent up.

d. the thickness of slab varies from e' at the edges to e at the middle. This is safe and gives a good arching effect but is not necessary. A uniform thickness would be more economical if depth is governed by shear and makes it easier for casting..

5. Height of side wall of culvert

There are two H in section A-A, one in the middle of the culvert, the other on the right side of the figure. Assuming the former to be the right H, the latter should be

(H + e' - 0.10)

Present Practice in Lebanon

The only standard culverts used in Lebanon now are slab-top culverts. With pipe culverts, that are not standardized, they are the only culverts now in practice. Sheet 4 shows the standard slab-top culverts used for any type of highways in Lebanon (1).

(1) Designed by N.Ilinsky in 1946.

The remarks mentioned in the present practice in Syria that apply to that in Lebanon will not be repeated.

A row of plinth stones put on both edges of the highway is cheaper than a balustrade casted integrally with the slab but is hazardous to traffic and should be prevented.

For spans of 1.50 m and above, the top slab is not very rigid. A one similar to that of the standard culvert for Syria would be better. The bars as listed under longitudinal reinforcement are ambiguous. For example, for a span of 1.50 m, 11 Ø 10 mm. might mean 11 round bars of 10 mm. size, for all the span or per meter. Actually the latter is the one meant. A better expression would be 11-10 mm Ø per meter or 10 mm Ø/ at 9 cms. c.c.

I have been told that the design of these slabs was not done very precisely and I could not get the loading for which the design was made. Due to the many factors involved, it is more accurate to compare the present design with standard designs made with more accuracy and economy than to revise it. Table 3 gives this comparison ~~for~~ with two types of loading for exposed slabs and 30 % of L.L. impact.

	Span in m (1)	Thickness in cms. $\frac{b+c}{2}$	Main reinforcement ("A" bars)
Present practice	0.60	11.5	10 mm Ø at 10 cms. c.c.
15-ton loading	0.62	15.0	10 mm Ø at 7 "
20-ton loading	0.62	16.5	10 mm Ø at 6 "
Present practice	1.00	17.0	14 mm Ø at 10 cms. c.c.
15-ton loading	0.92	16,5	14 mm Ø at 15 "
20-ton loading	0.92	18.0	14 mm Ø at 14 "
Present practice	1.50	20.0	14 mm Ø at 9 cms. c.c.
15-ton loading	1.53	18.0	14 mm Ø at 14 "
20-ton loading	1.53	20.5	14 mm Ø at 12 "
Present practice	2.00	24.0	14 mm Ø at 8 cms. c.c.
15-ton loading	2.13	19.5	14 mm Ø at 14 "
20-ton loading	2.13	22.0	14 mm Ø at 12 "
Present practice	2.50	26.5	16 mm Ø at 9 cms. c.c.
15-ton loading	2.44	21.0	16 mm Ø at 14 "
20-ton loading	2.44	23.5	16 mm Ø at 13 "
Present practice	3.00	28.5	16 mm Ø at 13 cms. c.c.
15-ton loading	3.05	23.5	16 mm Ø at 11 "
20-ton loading	3.05	27.0	16 mm Ø at 10 "

Longitudianl bars ("B" bars) for both loadings and all spans are 12 mm Ø at 60 cms. c.c.

Table 3 (1)

(1) The rows along 15-ton and 20-ton loadings are interpreted from Kitchum's "The Design of Highway Bridges", p. 131

CHAPTER 11

Stone Box Culverts

Use

In localities where a good quality of stone is cheap, stone box culverts are the cheapest form of permanent construction for culverts of medium capacity, but their use is decreasing owing to the frequent difficulty in obtaining really suitable stone within a reasonable distance of the culvert. The clear span of the cover-stones varies from 2 to 4 ft.(0.60 to 1.20 m)

Present Practice

In Syria and Lebanon, I have seen some stone box culverts in secondary highways that were built long ago and they are still in good condition. Now there are few built where stones are of the right quality and accessible, but no standard designs of this type are made in the Public Works.

Design

The required thickness of the cover-stones is sometimes calculated by the theory of transverse strains on the basis of certain assumptions of loading as a function of the height of the embankment and the unit strength of the stone used. Such a method is simply another illustration of a class of calculations which look very precise and beautiful, but which are worse than useless - because misleading - on account of the hopeless uncertainty as to the true value of certain quantities which must be used in computation. In the first place the true value of the unit tensile strength of stone is such an uncertain and variable factor that, calculations based on any assumed value for it, are of small reliability. In the second place the weight of the prism of earth lying directly above the stone plus an allowance for live load, is by no means a measure of the load on the stone nor of the forces that tend to fracture it. All earthwork will tend to form an arch above any cavity and thus relieve an uncertain and probably variable proportion of the pressure that might otherwise exist. The higher the embankment, the less the proportionate loading, until at certain height an increase in height will not increase the load on the cover-stones. The effect of frost is likewise large, but uncertain and not computable.

The usual practice is therefore to make the thickness such as experience has shown to be safe with a good quality of stone, i.e., about 10 or 12 in. for 2 ft. span (25 or 30 cms. for 0.60 m. span) and up to 16 or 18 in. for 4 ft. span (up to 40 or 45 cms. for 1.20 m. span.). The side walls should be carried down deep enough to prevent their being undermined by scour or heaved by frost. The use of cement mortar is also an important feature of the first-class work, especially when there is a rapid scouring current or a liability that the culvert will run under a head.

In figure 14 is shown a standard plan for single and double stone box culverts (1) that I suggest to be used in secondary highways where stones of the right quality are accessible and cheap.

Wooden Box Culverts

This form serves the purpose of a temporary construction, but due to the high cost of timber in Syria and Lebanon, it is not feasible to use it in these two countries.

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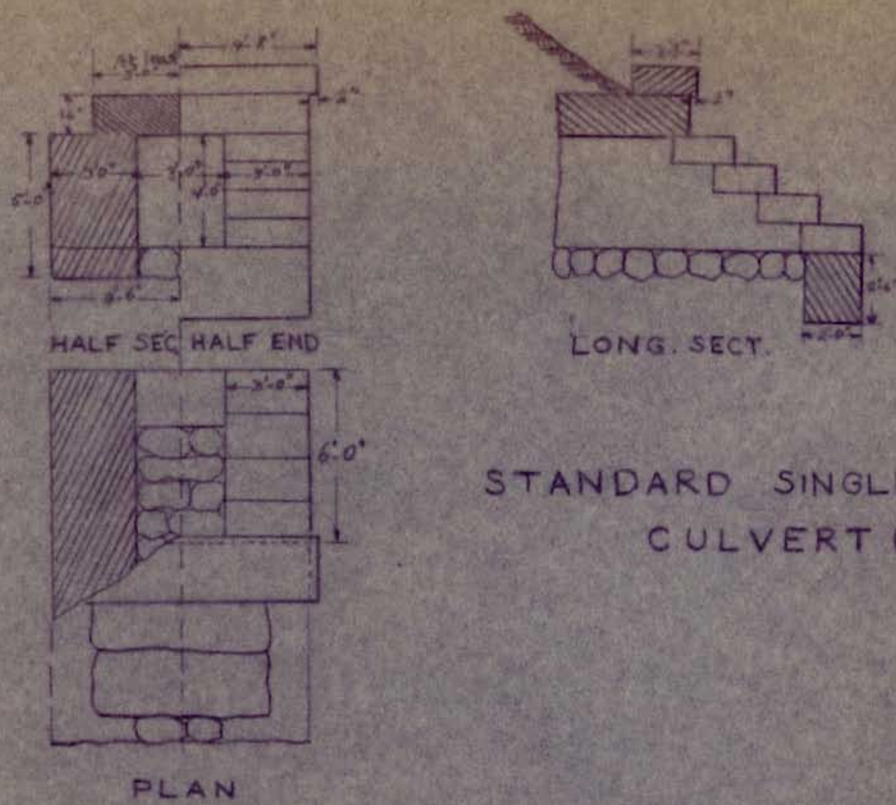
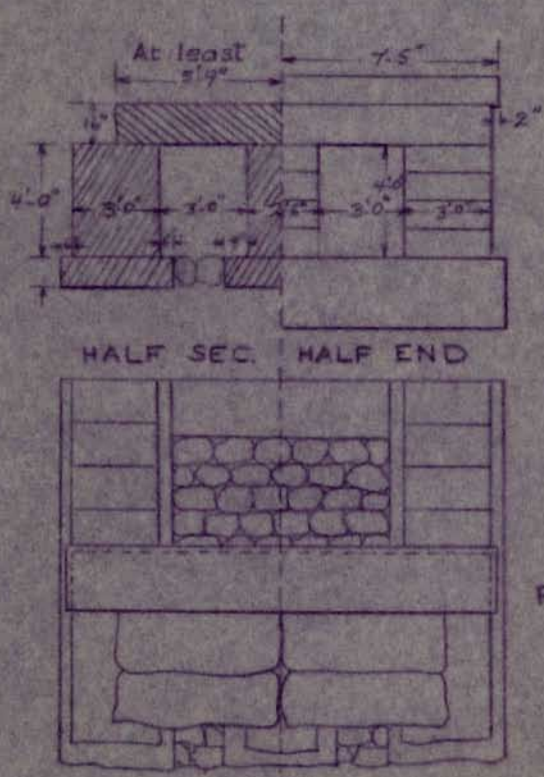
(1) Used on the Norfolk & Western R.R. - taken from Webb's "Railroad Construction", pp. 259, 260.



STANDARD SINGLE STONE CULVERT (3'x4')



STANDARD DOUBLE STONE CULVERT (3'x4')

Fig. 14

CHAPTER 12

Pipe Culverts

Advantages

1. ease of installation.

2. ease of replacement when life time is over and ease of shift when road is relocated.

3. availability for immediate use.

4. hydraulic efficiency. Pipe culverts pass a larger volume of water in proportion to the area than other types of culverts.

5. economy resulting from these advantages.

Use

Pipe culverts are suitable where small openings are necessary. The size of the pipe varies from a minimum diameter of 12 in (25 cms.) to a maximum diameter which varies with the strength and practical limits of manufacture of material from which the pipe is made.

Where headroom in a shallow fill is limited or a paved ford is used, a battery of two or more pipe culverts with a common headwall will be satisfactory.

Kinds

Vitrified clay, cast iron, steel plate, corrugated steel, plane concrete or reinforced concrete pipes are used for culverts.

Clay pipes are rarely used as culverts because of their comparatively low strength. Where, high loads are encountered, or where the culvert has little cover over it, extra strength clay pipe with a concrete jacket is used. This renders it uneconomical in comparison with a concrete culvert of equal strength.

Cast iron, steel plate and corrugated steel pipes are not manufactured in Syria and Lebanon. Importing these culverts is not only uneconomical but is a hindrance to the encouragement of national production.

For the reasons stated above, the only kind of pipe culverts I shall introduce is concrete.

Concrete Pipe Culverts

For small culverts exposed to small loadings, plane concrete circular pipes may be used. For large culverts exposed to big loadings, reinforced concrete circular pipes have to be adopted.

The pipe culverts I am going to introduce as standards (1) are cast-in-place and have circular bores. These are large in size and most economical when used under high embankment fills where heavy pressures are anticipated. Sheet 5 shows these culverts designed for 15-ton loading and for cover ranging from 1½ to 20 ft. (0.50 to 6.00 m). Smaller culverts will be discussed with relation to present practice.

Stresses are the same as those considered in the design of reinforced concrete box culverts (2). Similarly for the water-cement ratio and mix of concrete.

Shape

The shape shown in figures (i) and (ii) on sheet 5 has the hydraulic values of a circular tube, the load carrying qualities of a circular arch, and the flattened base so desirable in the box culverts. Such a base gives uniform bearing and provides greater thickness and strength at the sides to transmit the large thrusts uniformly to the foundations and less thickness at the

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(1) Taken from Portland Cement Association's "Concrete Culverts and Conduits".

(2) See P. 47

invert to resist the smaller shears and pressures.

Figure (ii) of sheet 5 illustrates two slight modifications in the cross-section. In figure (ii) (a) the bottom face of invert is bounded by straight lines rather than the arc of a circle. The outer face of the section in figure (ii)(b) consists entirely of segments of straight lines. Either of these modifications may be advantageous in obtaining simpler excavation or less expensive outside forms.

Reinforcement

Three arrangements of reinforcement in figure (i) of sheet 5 are specified. Both elliptical and circular reinforcements are shown.

Elliptical hoop reinforcements are advantageous when tension steel requirements are nearly alike at vertical and horizontal diameters and no compression reinforcement is required. Elliptical reinforcement is difficult to bend and place, however, and when there is uncertainty regarding the way this may be done, the arrangement of the reinforcement shown in figure (i) (b) section A - alternate, should be adopted.

Two layers of concentric reinforcement are economical when the concrete is thick enough to make compression reinforcement effective, in which case some saving in concrete can be made. This happens, under the stresses used, for t greater than about 13 in (33 cms.)

Construction Joints:

If construction joints are necessary near the base of the side walls, they should be cast with some locking action as shown in figure(i)and should be perpendicular to adjacent concrete faces. Horizontal joints are usually prohibited in circular conduits subject to high internal pressure.

The joint of Section B, figure (i) (c) is difficult to form when elliptical reinforcement is used, as the bars occur where the groove should be located. That shown in figure (i) (a) solves the problem.

Bedding Conditions

The bedding conditions of a culvert is of great importance, not as it affects the magnitude of pressures, but as it influences the distribution of reaction pressure under a culvert. Careless or improper field construction methods may be detrimental in causing subsequent failure of a culvert under moderate loads. This applies particularly to circular culverts bedded in hard material not excavated to the shape of the conduit. Foundation pressures are thereby concentrated at one point, usually at the lowest part of the pipe producing much higher stresses than if the reaction had been distributed uniformly.

There are two classifications of beddings: "Projection bedding" and "Ditch bedding". Projection bedding means that the culvert is bedded so that it projects into the embankment above the plane of the natural ground surface. Figure(iii)of sheet 5 illustrates the different types of projection bedding. Ditch bedding means that the culvert is burried in a ditch below the plane of natural ground surface. Figure(iv)illustrates the different types of ditch bedding.

Present Practice in Syria & Lebanon

Present Practice in Lebanon:

In Lebanon pipe culverts are not standardized. Plane or reinforced concrete pipes having diameters of 60 cms. (24 in.) and 80 cms. (32 in.) are commonly used as single or multiple pipe culverts.

In this country concrete pipes cast centrifugally are manufactured (1). Although they cost about twice as much as ordinary concrete pipes, they have the advantage over the latter in being stronger and more durable, in having less percolation of water through their walls and in having smoother interior finish rendering their hydraulic properties more efficient.

Centrifugal concrete pipes are made both plane and reinforced. They are available in the market in diameters up to 60 cms. (24 in) and in lengths of 1.00 and 2.00 m (3 & 6 ft.). The reinforced pipes are made to resist pressures of 1, 2 and 3 atmospheres or 10.3, 20.6 and 30.9 kgs/cms^2. For bigger diameters or larger pressures centrifugal pipes are manufactured on order.

I suggest that centrifugal concrete pipes be used, when there is no necessity of using the standard cast-in-place concrete pipes mentioned. Due to the short lengths of culverts in comparison with other conduits, it is not a waste of money to install centrifugal pipes

(1) Araman factory - Beirut

instead of ordinary pipes and gain their advantages.

Present Practice in Syria

In Syria concrete pipe culverts having flat bases together with headwalls and wing walls are standardized for diameters of 0.50,0.60 and 0.80 m. (20, 24 and 32 in.)

Sheet 6 is a copy of these standards with the following changes:

1. One sheet is made out of 6 sheets that had numerical dimensions on every drawing. A table was added to give all the dimensions for every size of pipe.

2. Arabic terms were changed into English

These standards were designed in 1949 and up till now they have been used and have proved to be satisfactory. Except for the follwoing two points I see no reason$ for amending them:

1. The foundations of headwalls and wing walls should not be fixed as shown. Their depths and widths have to be set according to the soil conditions encountered.

2. Bedding conditions have to be made in accordance with figure (iii)or (iv) of sheet 5 .

CHAPTER 13

Relative Costs of Culverts

This chapter is intended to give a comparative cost analysis of some types of culverts for different waterway openings. This analysis excludes costs of excavation, headwalls and wing walls.

It is impossible to give exact prices for culverts in general because of the varying factors involved. The cost of materials and labour varies from time to time and place to place. Steel prices, for example, fluctuate from day to day, and are not the same in Syria as in Lebanon. Stone, gravel and sand might be brought from a place nearer to one culvert than to another, making the cost of transportation varying. The prices given on sheets1 , 2 , 3 , 4 , 5 are very rough but are good for comparative purposes.

Cost Analysis:

The cost of reinforced concrete used in concrete box culverts and slab-top culverts, is assumed to be 100.00L.L. or L.S. This is in accordance with the

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(1) the difference in value between Syrian and Lebanese currency is neglected.

following analysis:

Item	Amount per M.C.	Unit cost	Cost per M.C. in L.L. or L.S.
Cement	6 bags	4.00/bag	24.00
Gravel	0.80 M.C.	7.00/M.C.	5.60
Sand	0.40 M.C.	3.00/M.C.	1.20
Steel	70 kgs.	0.45/M.C.	31.50
Labour & forms		25.00/M.C.	25.00
			87.30
Contractor's profit & expenses 15%			13.10
		Total	100.40

Say 100.00

The cost of reinforced concrete used in the reinforced concrete pipe culverts (sheet 5) is assumed to be 125.00. This is due to the more complicated wood forms involved. The amount of steel is assumed to be the same.

The cost of plain concrete used for the foundation of slab-top culverts is assumed to be L.L. or L.S. 40.00 in accordance with the following analysis:

Item	Amount per M.C.	Unit cost	Cost per M.C. in LL. or L.S.
Cement	4 bags	4.00/bag	16.00
Gravel	0.80 M.C.	7.00/M.C.	5.00
Sand	0.40 M.C.	3.00/M.C.	1.20
Labour		10.00/M.C.	10.00
			32.80
Contractor's profit & expenses 15%			4.93
		Total	37.73

Say 40.00

The cost of rubble masonry (dabsh) used in slab-top culverts is assumed to be L.L. or L.S. 22.00 in accordance with the following analysis:

Item	Cost per M.C. in LL. or LS.
Stone	5.00
Mortar	7.00
Labour	7.00
	19.00
Contractor's profit & expenses 15%	2.85
Total	21.85

Say 22.00

The cost of stone facing (naht) 25 cms. in width used in slab-top culverts is assumed to be LL. or LS. 24.00 in accordance with the following analysis:

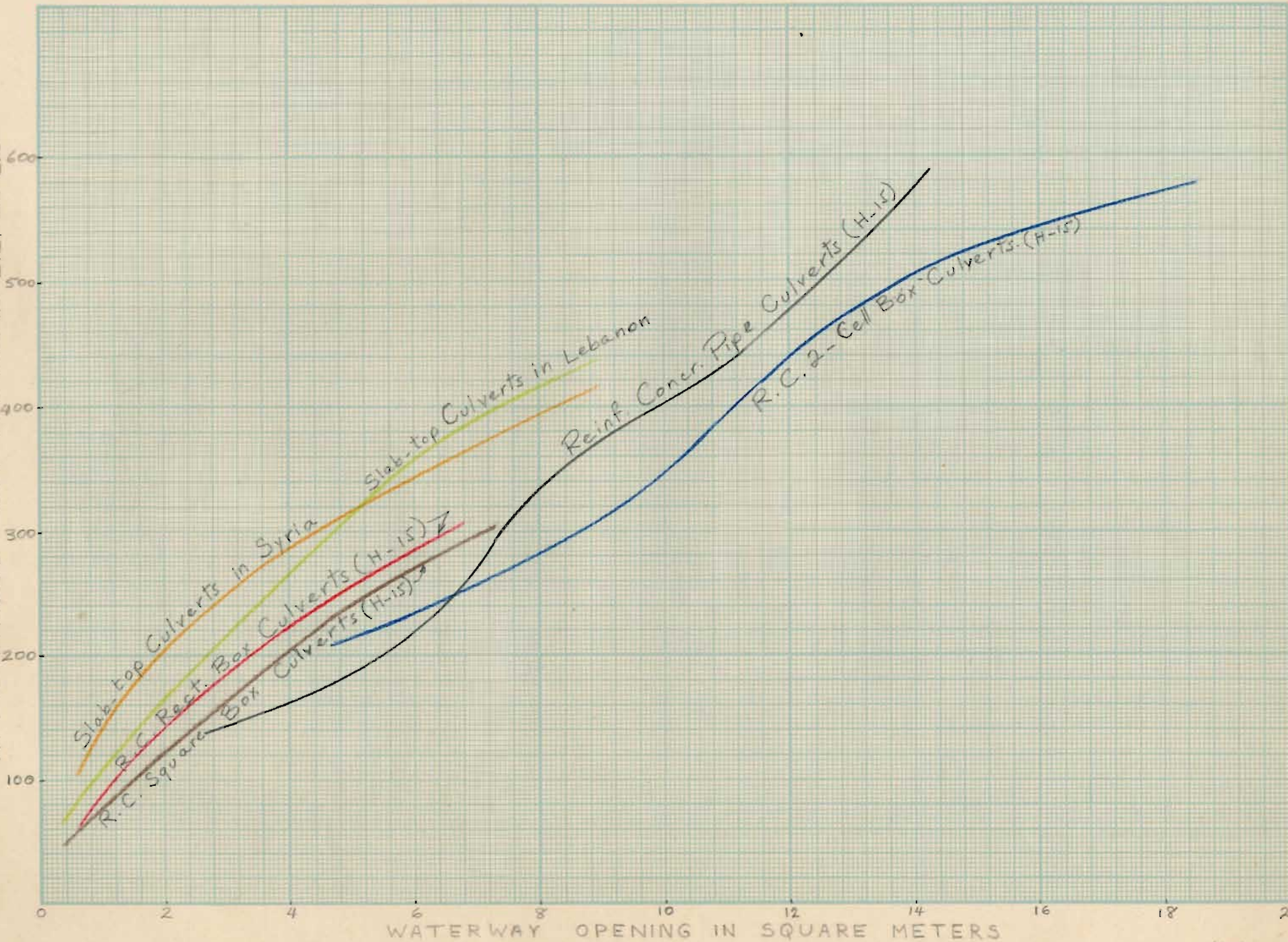
Item	Cost per M.S. in LL.or LS.
Stone	7.00
Mortar	1.50
Labour	12.00
	20.50
Contractor's profit & expenses 15 %	3.10
Total	23.60

Say 24.00

The prices listed on sheets 1,2,3,4, & 5 are a result of these unit prices assumed and calculations of volumes or areas of the sections of the structures. Chart 2 shows the relative costs per M.R. of culverts for fills of 1.5-5 ft. (0.50-1.50 m) plotted against different waterway openings.

CHART 2 _ RELATIVE COSTS OF CULVERTS

DE-5



PART IV

SUBSURFACE DRAINAGE STRUCTURES

CHAPTER 14

Purpose

The purpose of subsurface drainage is to intercept the ground water before it reaches and softens the subgrade.

Present Practice in Syria & Lebanon

I am sorry to say that in both Syria and Lebanon highways subdrainage is not practised. As a result, about 85 % of all surface failures are caused by spongy, unstable subgrades due to uncontrolled ground water.

What is done now is treating the effect and not the cause. Continuing surface repairs are done after waiting for the damage to increase and become a hazard to traffic. This is inefficient and a waste of money. It is like rubbing liniment on a broken leg in that it may provide temporary relief but can never cure the real cause of the trouble.

The only sure cure is to install an adequate subdrainage system that will drain the water out and keep it out where needed. For the long run this method of treatment is more effective and more economical than that practised now in these two countries.

Requirements

For designing subdrainage structures two requirements are needed:

1. Know the conditions affecting the highway.

2. Provide an installation to meet those conditions.

General Conditions

Geological structure, the location of the highway, and the climatic conditions give different conditions, but in general two conditions are encountered., in both of which, capillary water may rise to cause subgrade trouble.

Class I - Sidehill Seepage Condition (Fig. 15)

Sloping water table, or water-bearing strata, found in slightly rolling, hilly and mountainous terrain; lies immediately above a strarum of impervious soil: in general, approximately parallel to original ground surfaces; often functioning under a head.

In this case, the seepage is easily drained because outlets are generally available for drains of the needed depth. The problem is to intercept the water before it reaches the roadway area.

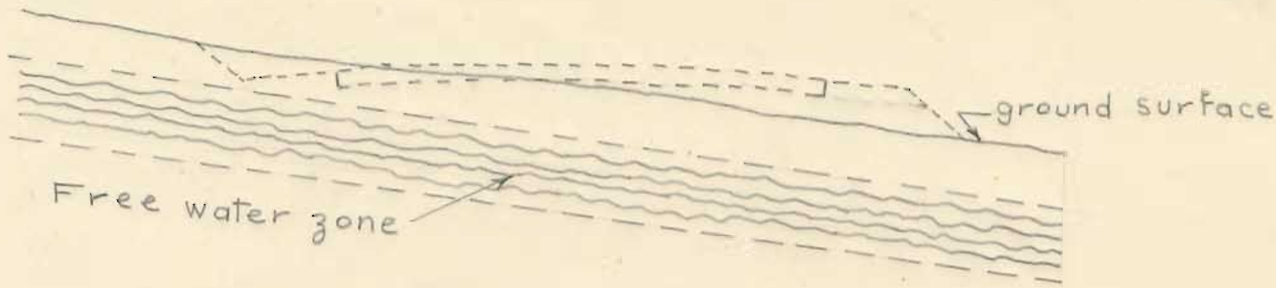


Fig. 15

Class II - Level Water Table Condition (Fig. 16)

This condition is found in level country and particularly in swampy sections. The free water has little or no lateral flow, but may rise or fall during wet and dry seasons.

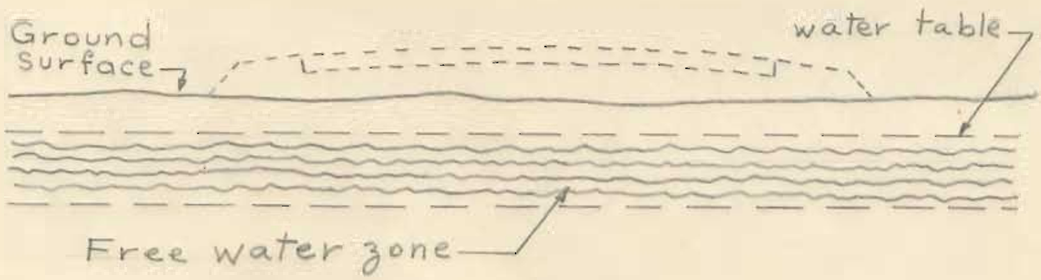


Fig. 16

The problem in this case is to lower the water table below the effective capillary rise limit. This limit for each soil class has not been definitely established by soil scientists, but for the usual soil drains 5 to 6 ft. (150 to 185 cm.) below the road surface will be effective. The difficulty in this condition lies in providing outlets to sufficiently deep drains. When it is known that the soil will not support the pavement due to capillary water weakening it, and no outlet for drains is available, the soil of the roadbed has to be stabilized by introducing material of low capillarity.

In both conditions, where subsurface water is not in evidence, a simple survey, using an earth auger, will quickly provide data on drainage characteristics, stability of the subgrade and the location of the water table or seepage areas.

<u>Location and Depth of Intercepting Subdrains</u>

<u>Case I - Sidehill Seepage Conditions</u>

1. General conditions

(a) Relatively narrow seepage zone (Fig.17)

In this case the top of the seepage zone is approximately 2 to 4 ft. (60 to 120 cms.) deep and the bottom is approximately 7 ft. (215 cms.). Although the seepage zone may be less than 6 in.(15 cms.) thick, usually it is found to be approximately 3 ft. (90 cms.). For the condition illustrated, the damaging agent is capillary water which causes an unstable subgrade or frost heave. The solution here is to place an intercepting drain on the upper side of the road to completely shut off the free water before it enters the roadway area. The pipe drain is put just below the seepage zone. The alternate location shown in the figure needs less excavation for the same depth of the drain in the other location.

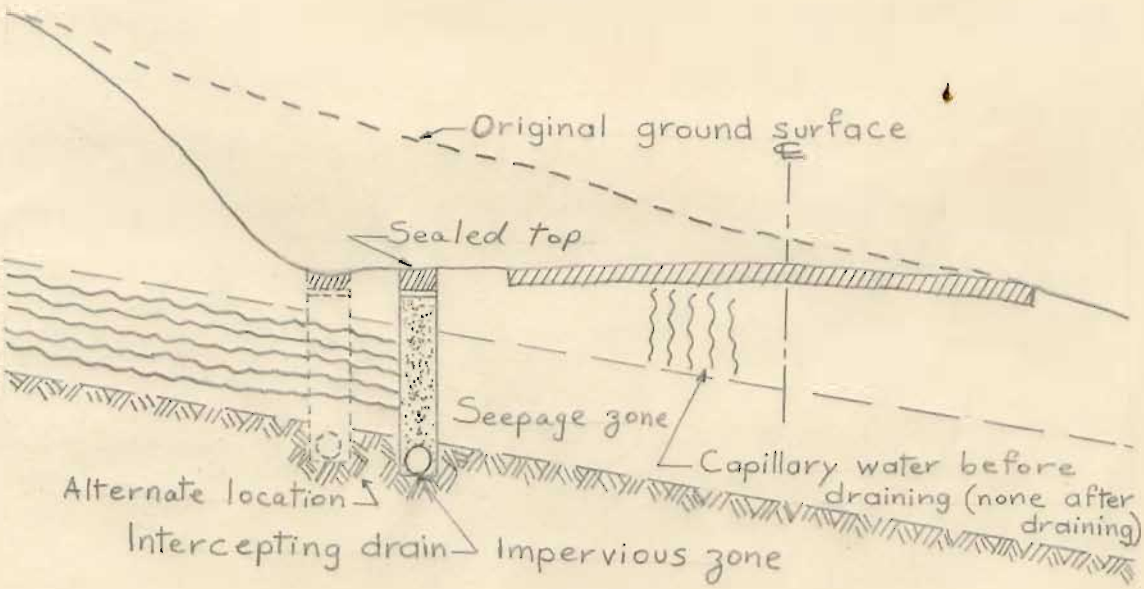


Fig. 17

(b) Wide seepage zone (Fig. 18)

In this case, the conditions are similar to those of (a) except that the seepage zone is thicker and the bottom is more than 7 ft. (215 cms.) below the road surface. The depth of the drain is governed by the capillarity of the soil above the newly established water table. The pervious soil in the seepage zone should be checked but it will probably be a rather low capillary soil, so that a drain 6 ft. (185 cms.) deep will probably be effective.

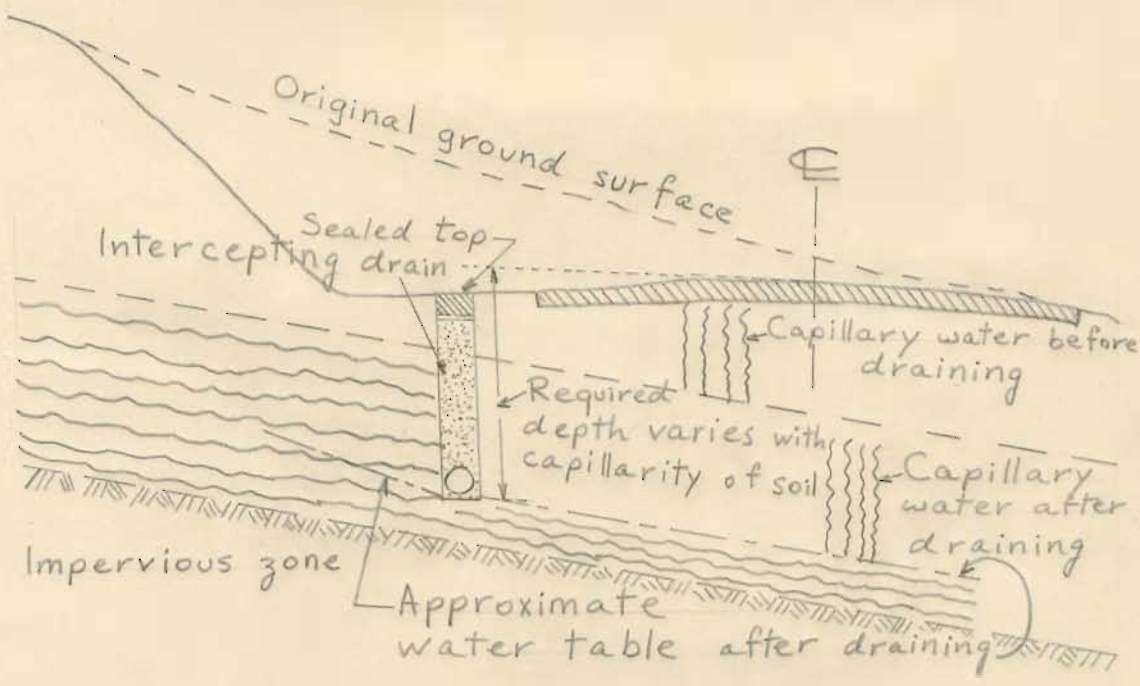


Fig. 18

2. Land slides

The presence of water in the soil is in the majority of cases the underlying cause or contributing factor of land slides. Naturally drainage is the logical mean of preventing or curing landslides.

The problem is to intercept the ground water before it reaches the mass that is subject to slides, but the solution is not so easy. The geologist who has examined the site can best tell where to apply the drainage so that it will be effective and cost least.

In general two typical landslides are encountered:

(a) Slide in fill section with seepage confined in a sloping zone (Fig.19). In this case a seepage zone lubricates the plane between the fill material and an impervious zone. The intercepting drain prevents the water to reach the possible slide area.

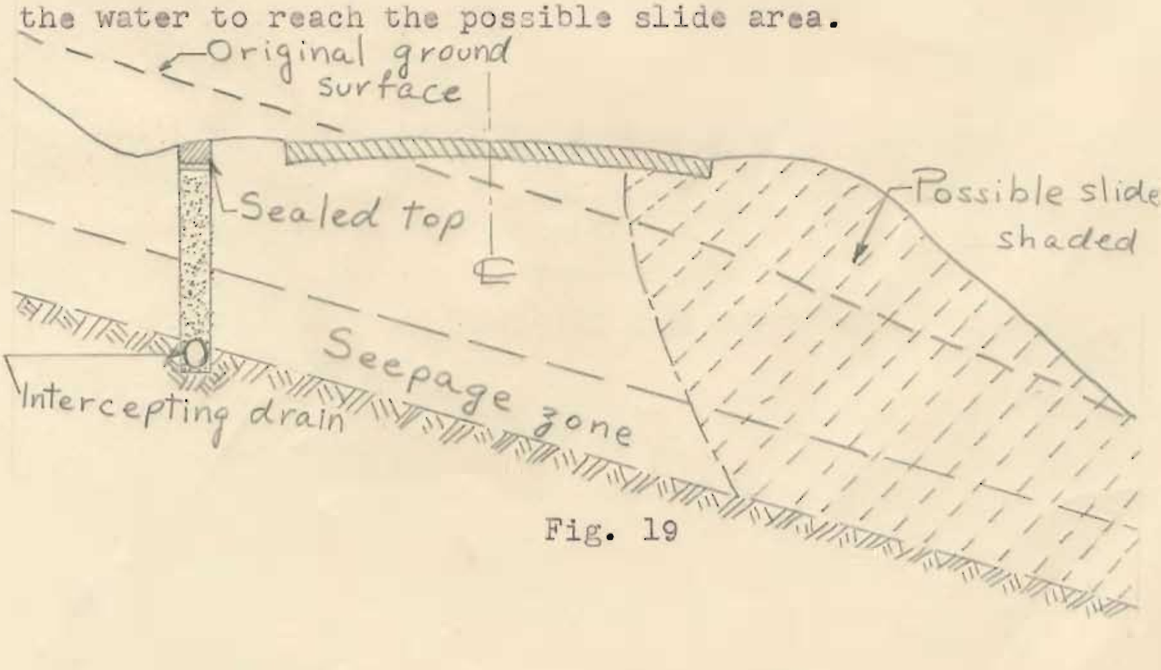


Fig. 19

(b) Slide above road (Fig.20)

The intercepting drain is put above the possible slide areas.

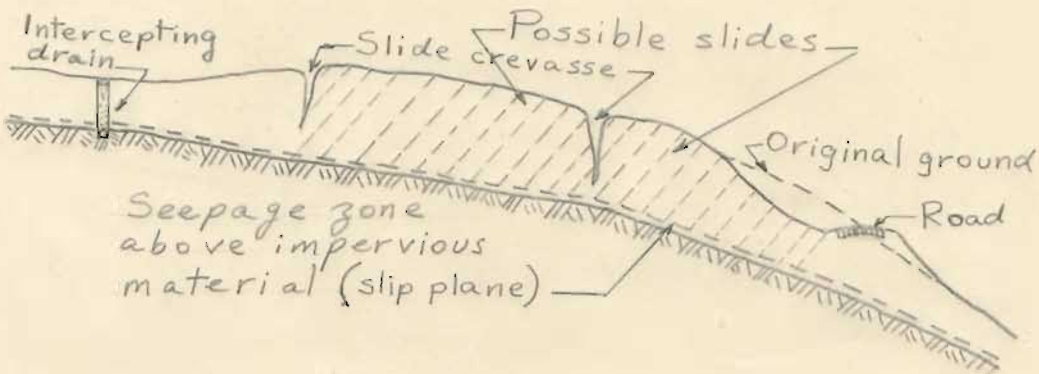


Fig. 20

3. Breakups due to longitudinal seepage.(Fig. 21)

Road breakups usually take place on a hill or where the road section changes from cut to fill. Such cases may be due to "side hill" seepage but are more often due to "longitudinal" seepage. The breakup usually occurs at and below the point where the free water from the seepage zone contacts the subgrade.

The remedy consists of installing an intercepting drain across the roadway above the breakup, at right angles or diagonally across the road, but if the water also enters the roadway from one or both sides, an intercepting drain along one or both sides of the cut is preferable to a "herring bone" system under the roadway.

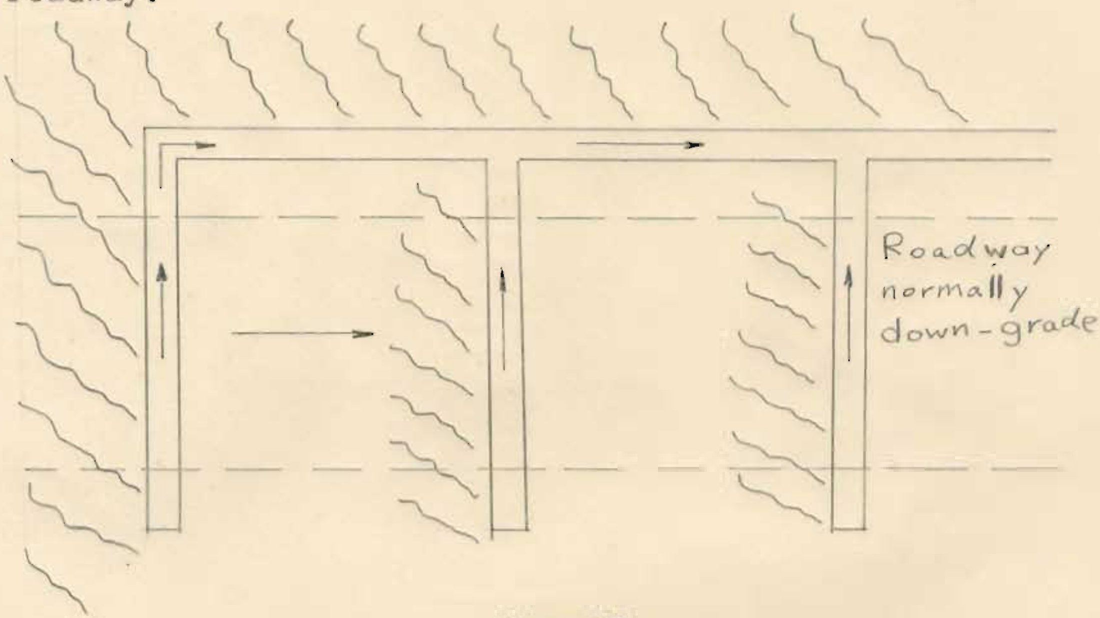


Fig. 21

4. Cut slope stabilization

This refers to the erosion of slopes by seepage water in contact with erosion by surface water. The former is more serious than the latter. It often results in mud and water and sometimes ice on the traveled roadway. Two cases are generally encountered:

(a) Relatively low banks - (Fig.22)

In this case, the bottom of the seepage zone is approximately 6 ft. (185 cms.) or less below the top of the bank. An intercepting drain is put on top of the bank which intercepts and collects the free water in the seepage zone.

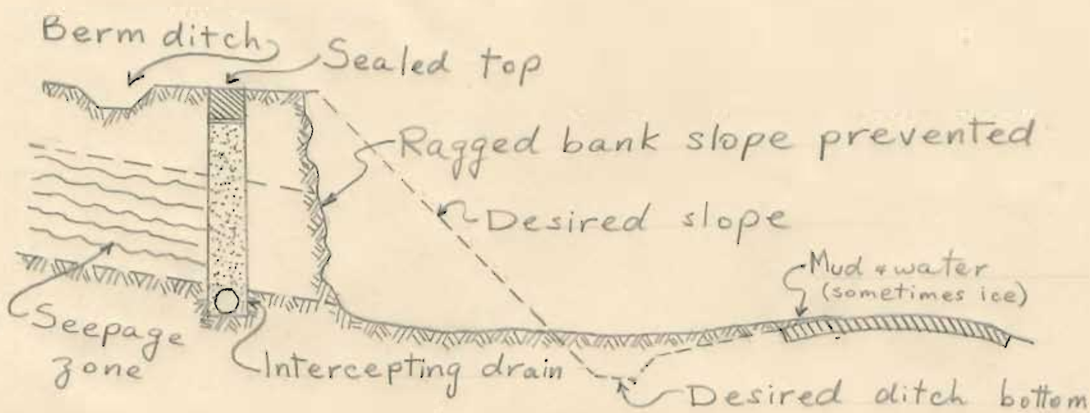


Fig. 22

(b) Relatively high bank with seepage in lower portion - (Fig.23)

The shelf provides better working conditions and reduces the depth of the trench to be excavated. The shelf also provides a suitable location for a surface water gutter to collect rainfall from the upper portion of the slope and thus reduce erosion on the lower portion.

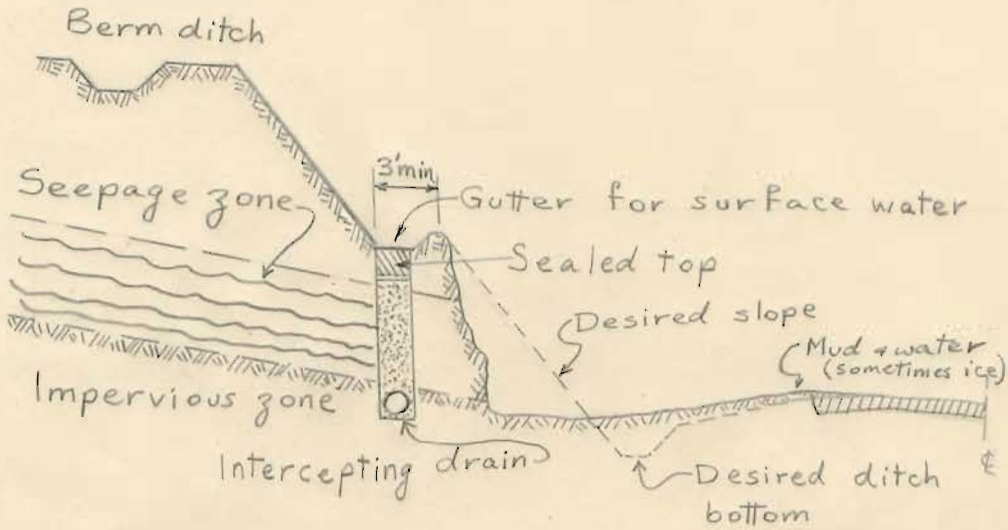


Fig. 23

Case II - Level Water Table Conditions

Acquiring a stable subgrade by drainage for the level water table condition depends upon the prevention of effective capillary rise to the subgrade zone. Therefore the required depth of the drains depends upon the capillarity of the soils which should be determined before a decision on drainage is made.

Two general cases will be given :

1. Where drains to prevent effective capillary rise are feasible - (Fig. 24)

In this case outlets are assumed to be available. Drains in both shoulder areas, shown in (a) and (b) are usually preferable to center drain shown in (c). This is due to three reasons:

i. They are more accessible in case of future widening developments.

ii. Water is intercepted before getting under the edges of the pavement.

iii. In case of repairing the center drain, the roadway has to be torn.

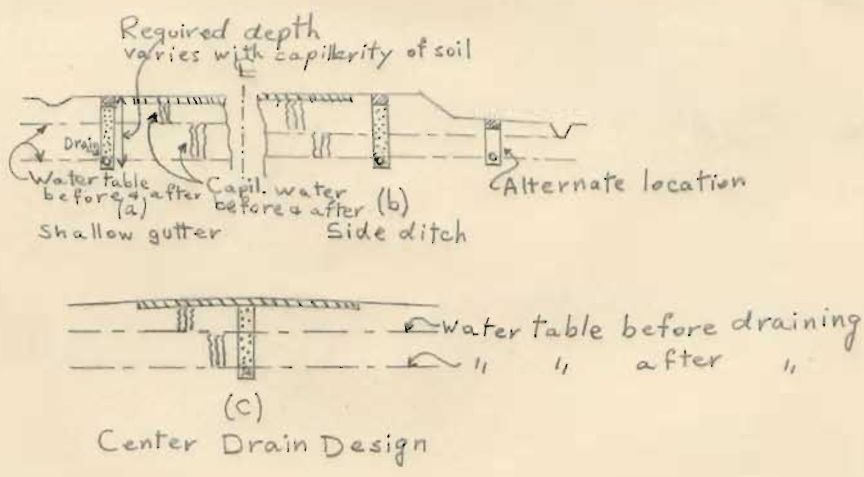


Fig. 24

2. Where drains to prevent effective capillary rise is not feasible - (Fig. 25)

In this case the choice lies between raising the grade with pervious materials or excavating and replacing the unsatisfactory soils with pervious material. In either case, shallow drains are recommended when necessary to prevent the accumulation of free water in gravel base and to drain away free water from the upper thawed frost zone. It is assumed that outlets are available only for very shallow drains and therefore no attempt is made to lower the water table. Drains are made as deep as outlets will permit.

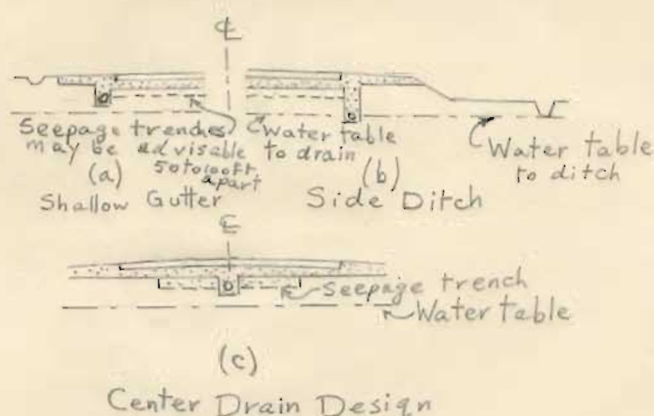


Fig. 25

Pipe Drains

1. Kinds of pipes

There are three kinds of pipes that can be used as tile drains: concrete tiles, unglazed farm tiles and perforated corrugated metal pipes.

The corrugated pipes are the best. They have adequate strength, they are more durable and the perforations they have take in the water easily, prevent clogging and get away with free joints as used in concrete and clay tiles. Unfortunately, in Syria and Lebanon, they have to be imported and are not economical, so they are not recommended in these two countries.

The concrete tiles are stronger than clay tiles, but the latter are more advantageous in that water percolates through them more easily. Moreover, clay tiles in general are cheaper than concrete tiles. A plane concrete pipe without bell and spigot ends costs about 18 piasters per cm.diameter per meter length (not centrifugally made) while an unglazed pipe costs about 14 piasters per cm. per meter length. These prices are for national products of average quality.

If concrete tiles are to be made porous and spongy, aluminum powder has to be added to the concrete mix, but this is too expensive for subdrains.

I recommend that clay tiles be used in general for subdrainage, except where the subdrains are expected to resist high pressures in which case concrete tiles are to be used.

2. Size of Pipe

The size of pipe required depends upon many factors such as the intensity of rainfall, the size of the area drained, the condition of the surface, the type of the soil drained and the grade on which the tiles are laid.

There are several formulas that can be used to determine the size of the pipe such as that given by I.O. Baker (1), but the assumptions that must be made according to these many factors, in applying a formula to any particular case are such as to render an accurate determination of the proper size impossible.

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(1) Blanchard's Elements of Highway Engineering P.114.

Moreover, the damage to the highway, due to insufficient capacity of the tile above a certain minimum is not great enough to warrant a thorough study involving all the factors involved. The increased capacity and the greater assurance of the proper functioning of the 6 in.(15 cms.) or the 8 in. (20cms.) over the 4 in.(10 cms.) size which is too frequently used as the minimum size of the tile, render their use favorable.

I would suggest that the 6 in. (15 cms.) and the 8 in. (20 cms.) tiles be used as standard for ordinary highway subdrainage problems. In case of exceptional seepage or springs, larger sizes have to be used. Lengths of one meter that are found in the market can be used, although shorter lengths are more favorable.

3. Laying the pipe in the trench

There are three important features of a modern intercepting drain as shown in Fig.26 (1)

(a) Trench is deep enough so that the entire pipe is below the seepage zone, in the impervious zone.

(b) A finely-graded pervious backfill is used.

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(1) Armco's Handbook of Culvert and Drainage Practice P.316

(c) Top of subdrain is sealed.

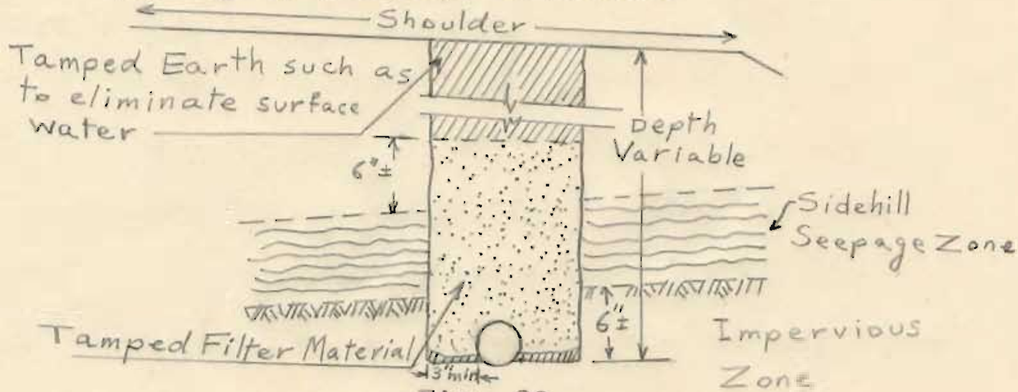

Fig. 26

4. Backfill Materials: Filters

Filters should be put in such a size as to prevent silting and plugging up of the drains. Coarse backfill materials with large voids (from 1/2" (13 mm.) to 3"(76 mm))(1) were once believed to be best. However, experience and research show that such backfills encourage silting, especially in the case of movement of ground water through coarse silts and fine sands.

Extensive experiments were made by the U.S. Waterways Experiments Station at Vicksburg, Miss., on the clogging of subdrains, using various types and gradations of pervious backfill or "filter" material. A graded material roughly equivalent to concrete sand (A.A.S.H.O.Specs.)

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(1) Blanchard's Elements of Highway Engineering P.114

has been found most suitable. Table (4) gives a typical analysis or maximum size of filter material.

Table 4

Maximum Size of Filter Material

for

Subdrain Pipe (Vicksburg Tests) (1)

Standard A.S.T.M. Sieve		Percentage Passing
3/8 in.	9.52 mm.	100
No. 3	----	92
No. 4	4.76 mm.	82
No. 6	3.36 mm.	66
No. 8	2.38 mm.	53
No. 10	2.00 mm.	48
No. 16	1.19 mm.	37
No. 20	0.84 mm.	26
No. 30	0.59 mm.	11
No. 40	0.42 mm.	0

This type of finely graded material does not only have a large percentage of voids with correspondingly great storage and infiltration capacity, bit it does lessen the vertical velocity of water entering the subdrain trench and thereby reduces erosion and silting.

The use of a sealed top prevents the entrance of

(1) Armco's Handbook of Culvert & Drainage Practice P.318

surface water which may carry silt and sand and thus plug up the pervious backfill. The locations of the drain shown in Fig. is in the shoulder and not in the ditch, only for the reason that sealing may be difficult in the latter location.

The material used to obtain imperviousness may be clay or an artificial mixture employing asphalt or other binder. If a material is used which may filter down into the backfill, a layer of straw or coarse hay is advisable.

5. Outlets

All drains must be carried to a proper outlet such as a culvert, ditch, or another drain. The outlets should be free to prevent clogging. Screens over the outlets may be used to prevent small animals from entering and building nests that clog the pipes.

6. Grade

The slope of the pipe depends on the grade of the road and on the elevation of the outlet.

"Where possible, it is desirable to use a 0.2 % minimum slope for all subdrainage lines. It is sometimes permissible to use an even flatter slope where necessary to obtain a free outlet"(1).

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(1) Armco's Subdrainage Pipe P.20

7. Joints

In general 1/2 to 1 in. ($1\frac{1}{2}$ to $2\frac{1}{2}$ cms.) spacing between the tiles is recommended. Joints should be surrounded by a layer of gravel. The size of the gravel should be more than that of the free joints to prevent clogging.

Blind or French Drains

A French drain consists of a trench loosely back-filled with stones, the largest stones being placed in the bottom, and the size decreasing towards the top. The interstices between the stones serve as a passage-way for the water.

Pipe drainage is preferable in all cases, but for small drained areas where outlets can be provided in a short distance, and where the subsoil is especially silty and the amount of water is small they will be effective and are comparatively very cheap.

PART V.

SURFACE DRAINAGE STRUCTURES

CHAPTER 15

The Crown

Requirements:

The crown of a road should provide sufficient slope to expedite the removal of the water from the road surface, thereby avoiding excessive percolation and the resulting softening of the road surface. At the same time, the slope should not be so great as to cause storms to erode the road surface and form channels or corrugations, and make travel hazardous and uncomfortable.

Units:

The crown can be expressed as the difference in inches or cms. in the elevation of the center line of the roadway and the elevation of the end of the travelled way. This should be accompanied by the width of the roadway. To make it more general, the crowns that I am going to specify are given as the average slope in inches per ft. and in cms. per meter or % for normal straight pavements. This means that for every foot (or meter) of half width of road, the pavement rises from the sides one or a fraction of an inch (or 8 cm.orless).

Present Practice in Syria & Lebanon

In Syria, crown slopes are standardized as 2% (3/8 in/ft) in all types of highways, whether single or double track, and whether earth road, water bound macadam or bituminous macadam.

Similarly in Lebanon a 5 cm per 4 m or 1.25% (1/8 in/ft) is used for all types of roads.

Such specifications do not conform with modern practice of efficient surface drainage. Different types of road surface materials require different slopes of crowns.

Moreover, these specifications are not applied fully in most highways of these two countries. In many of our highways we can see ponds and channels of water found on the surface of the pavements due to bad construction of crowns.

Standards to be used:

I suggest that crowns listed in table (5) be used as standards. In general circular arcs are recommended more than parabolic arcs.

Rural Highways - Typical Normal Pavement Crowns (1)

Table 5

Parabolic or Circular Suitable

Kind of Pavement	Aver. max. crown slope in/ft	cm/m or %	Aver. min. crown slope in/ft	cm/m or %	Aver. recommended crown slope in/ft	cm/m or %
Earth roads	1	8	1/2	4	5/8	5
Sand clay roads	3/4	6	1/2	4	5/8	5
Gravel roads	3/4	6	1/2	4	1/2	4
Single-track water-bound macadam	3/4	6	5/8	5	5/8	5
Double-track water-bound macadam	1/2	4	3/8	3	3/8	3
Double-track bitúminous macadam	3/8	3	5/16	2½	5/16	2½
Double-track bituminous concrete	3/8	3	1/4	2	1/4	2
Double-track cement concrete	1/4	2	1/8 (2)	1	3/16	1½
Double-track brick	3/8	3	5/16	2½	5/16	2½
Double-track asphalt block	3/8	3	1/4	2	1/4	2
Double-track stone block	1/2	4	3/8	3	3/8	3

(1) Harger's Handbook for Highway Engineers p. 950
(2) For the 1/8 inch crown use a straight line crown slope

CHAPTER 16

Side Ditches

Requirements

Side ditches should be designed to carry the peak runoff from the road surface and adjacent property with reasonable allowance for freeboard.

Good design of ditches should:

1. Eliminate excessive silting due to flattening grades.
2. Eliminate the damaging effects of erosion due to steep grades.
3. Reduce hazards to traffic by not having deep ditches.

The concept that the side ditch must have fixed cross-section and constant depth does not apply to modern highways. Typical cross-sections should be adopted according to:

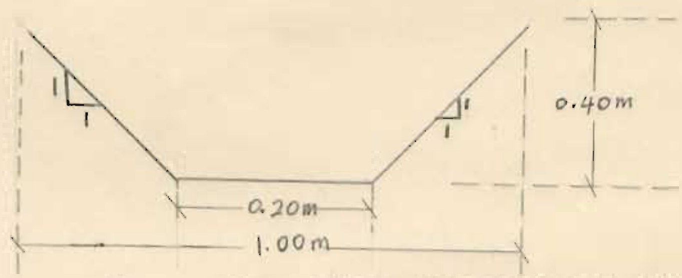
1. Prevailing runoff characteristics.
2. Topography.
3. Unit cost and amount of excavation.
4. Need for snow storage.
5. Type of highway.

Present Practice in Syria and Lebanon

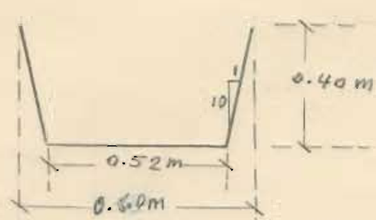
The side ditches used for highways in both countries do not fulfil the requirements of efficient designs stated above. One typical section for all kinds of highways under all conditions is used in each country. For rocky places this section is somewhat modified for economy.

In Lebanon two typical types are used:

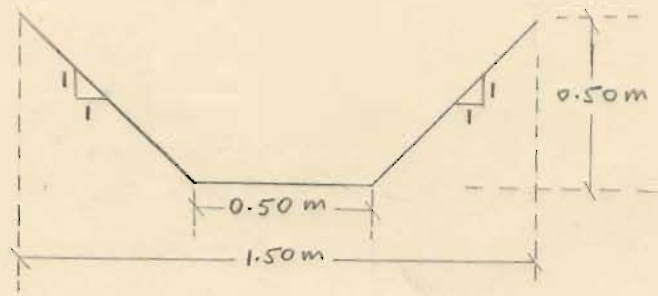
1. For non-rocky regions this trapezoidal cross-section is used



2. For rocky regions this trapezoidal cross-section is used



In Syria the following type is standardized, but may be modified in rocky places by the engineer who is designing the highway.



These ditches are sometimes flooded in places where the rainfall intensity is very high and the drainage areas are large. In some other places we can hardly see them half full during very heavy rains. This is because they were not designed according to hydraulic principles, and consequently not according to economic design.

One of the most important factors in ditch design, namely prevention of erosion, is completely ignored in the present practice. Neither concrete lining, cobblestone facing, or sodding is used where grades are very steep and high velocities of flow cause considerable erosion on the earth ditches. Intercepting ditches, used to decrease the quantity and thus the velocity of water in the main side ditches, are not used also. It is true that such methods of preventing erosion are expensive, but when costs of repairing the ditches frequently and reduction of hazards to traffic are considered, they prove to be economical.

Standard Cross-sections to be Used

The usual slopes used for culverts are V-shaped and trapezoidal. The former are generally preferred because they can be constructed and maintained by means of blade graders. On the other hand, the trapezoidal shape is advantageous where large capacity is required.

At present it is not feasible to adopt the V-shaped type in Syria and Lebanon due to lack of machinery, but both types would be given in case of increase in machinery in future.

"Minimum slopes of 4 horizontal to 1 vertical are desirable for through highways and many primary state highways are constructed with flatter slopes." (1)

"The side slopes from shoulder to bottom of the ditch in either case should not exceed a slope of 3 horizontal to 1 vertical."(2)

Flat slopes have 3 advantages:

1. They decrease the depth of flow for a given quantity of water, so the velocity is decreased and erosion is reduced.

2. They reduce hazards to traffic.

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(1) Bateman's Introduction to Highway Engineering. P.51

(2) Urquarck's Civil Engineering Handbook

3. They can be sodded easily. (1)

Charts 3, 4, and 5 (1) give recommended cross-sections of flat slope ditches that I am going to introduce as standards. In each cross-section only the width of the base (b) and the side slopes are given while the depth is chosen according to the discharge expected to pass through the ditches.

Using these charts, the depth of flow and the velocity for the estimated peak runoff may be determined for any grade and for several hydraulic roughness factors.

The depth of the channel would be the depth of flow plus an allowance for freeboard. In case drainage of the base course, in the absence of longitudinal underdrain, is to be provided by the side ditch, the flow line will be placed a minimum distance below the edge of the shoulder, depending on the thickness of the base course.

The velocity read is used to know where to put sodding or paving to prevent erosion.

Whether to use the section in chart 3 or chart 4 depends on the flatness of the country, the width of the right of way and the discharge expected.

For hilly rocky regions, widths and slopes of these

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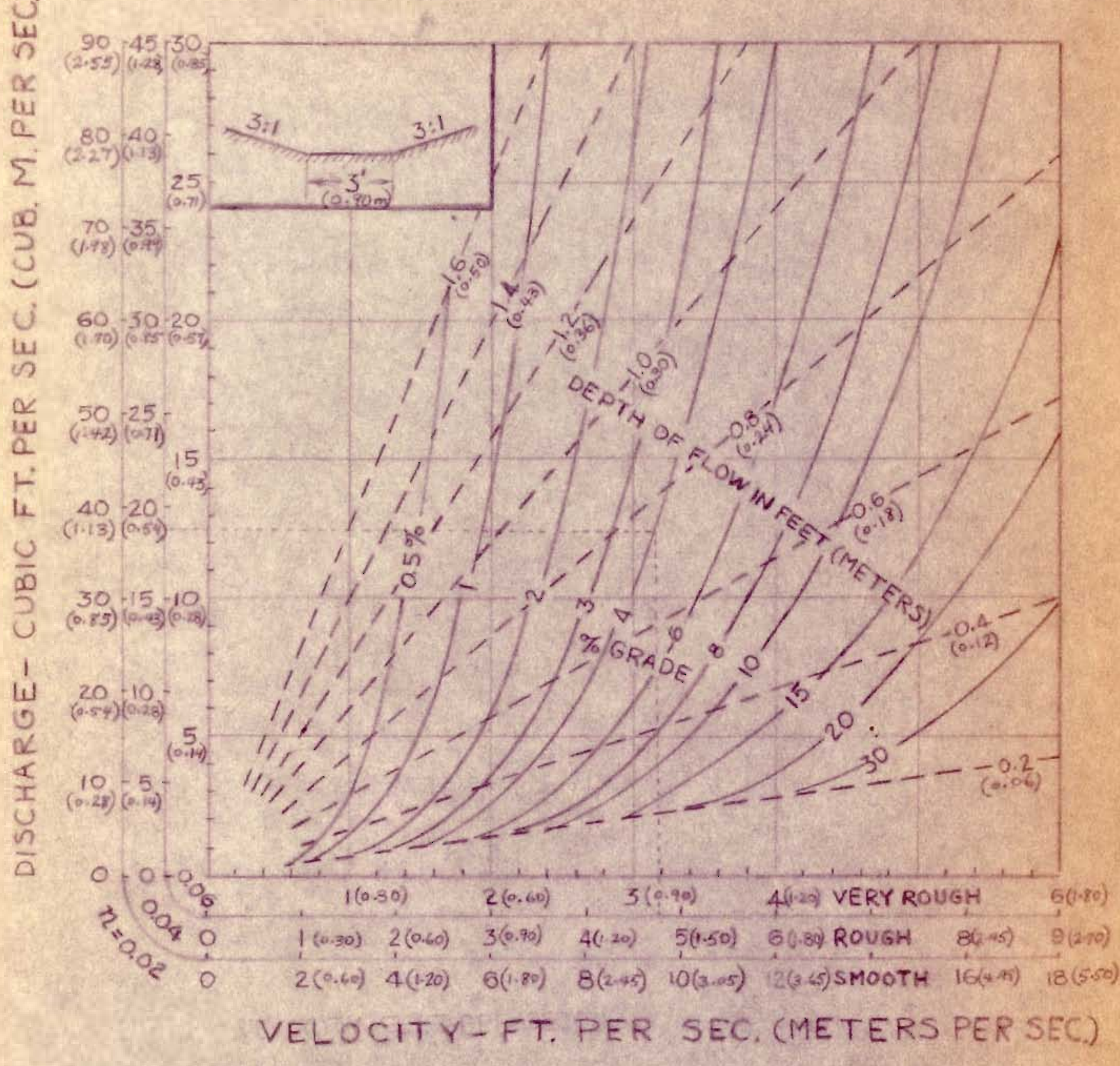
(1) Bureau of Public Roads - Theory and Practice of Highway Improvement in the United States of America 1952



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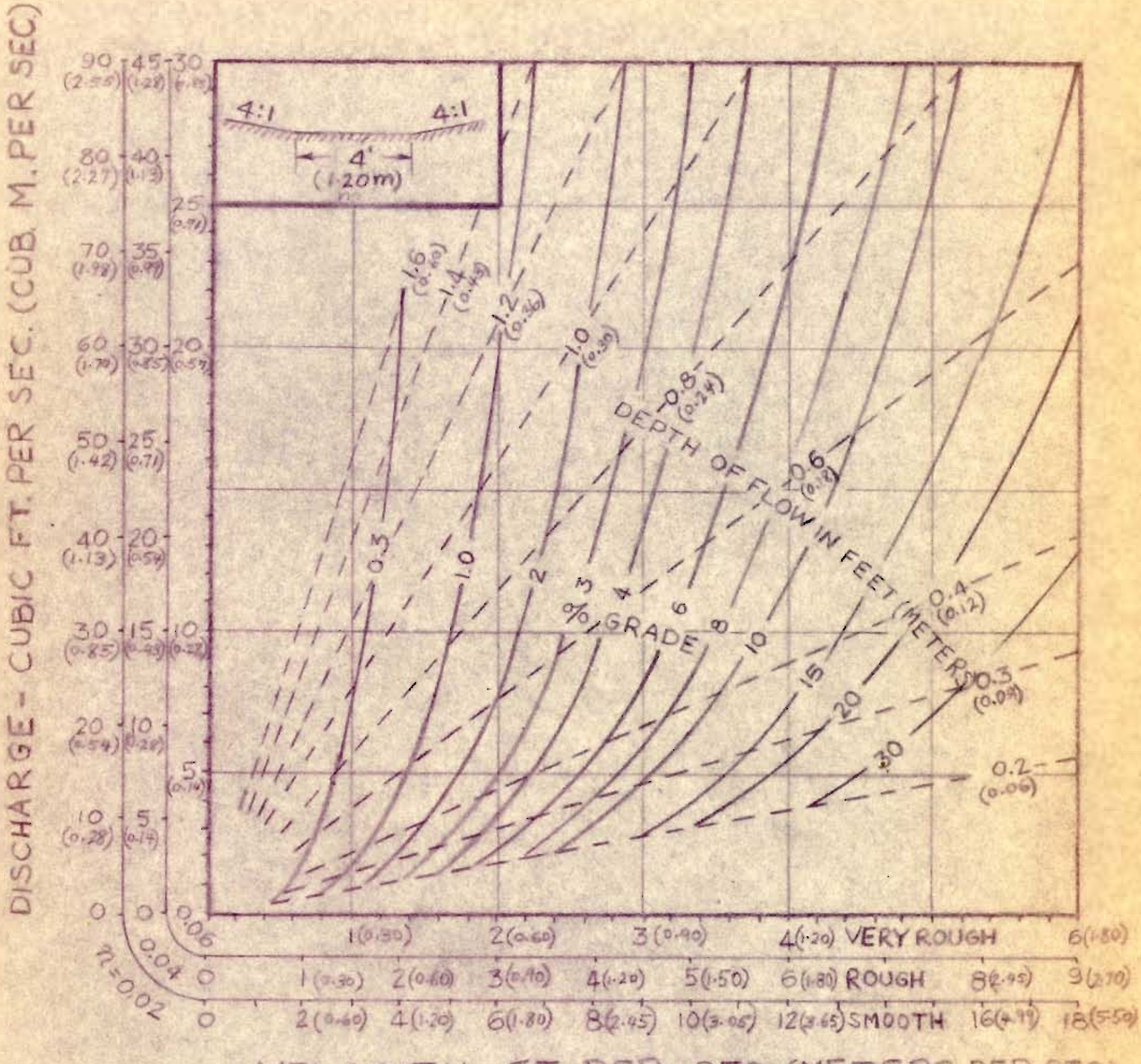
JUNE 1950

<u>Note</u>: numbers between parenthesis are in metric units.

CHART 3

(between pp 106&107)



Note: numbers between parenthesis are in metric units.

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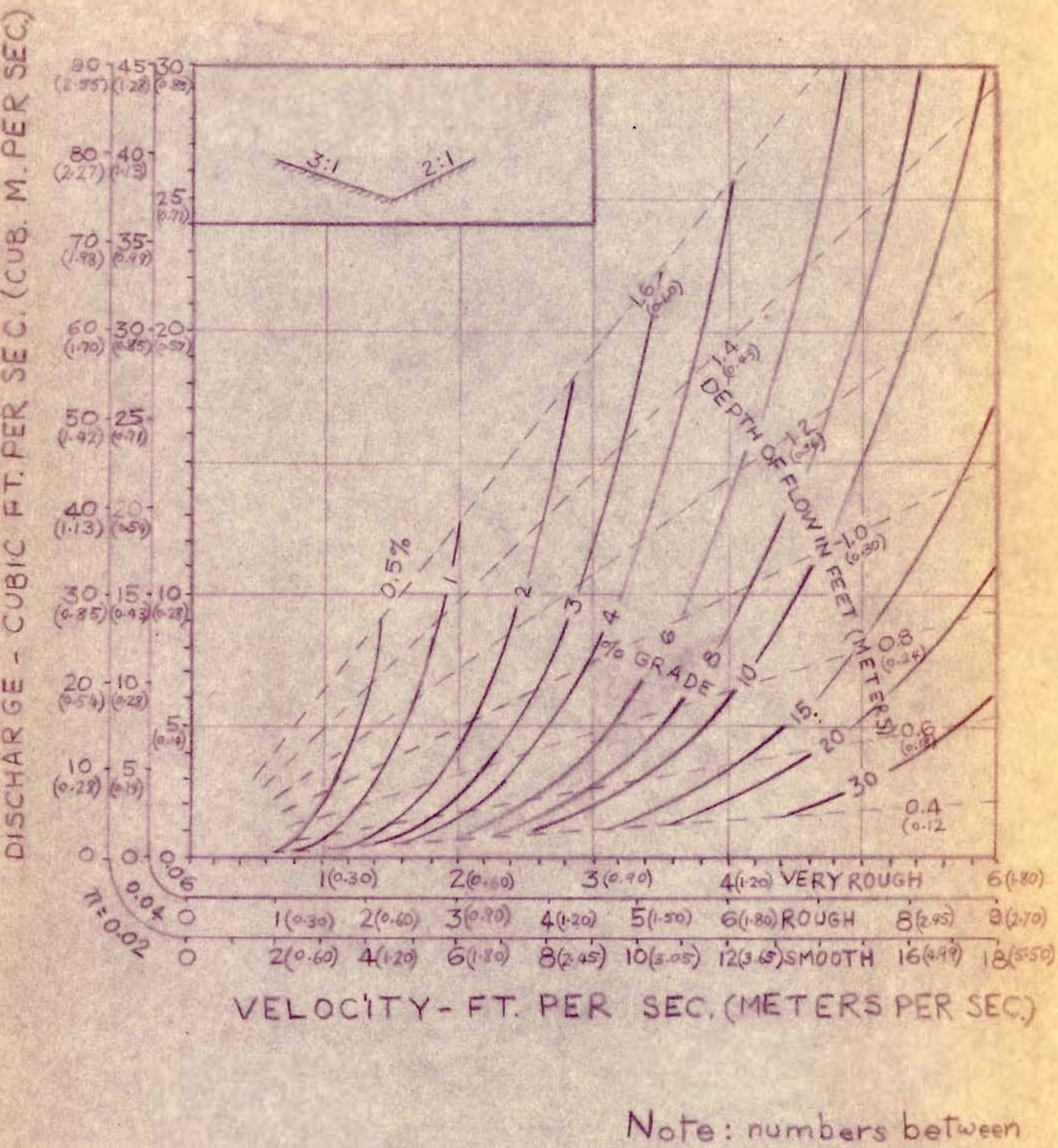
CHART 4

(between pp106 & 107)



Note: numbers between parenthesis are in metric units.

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CHART 5

(between pp 106 & 107)

sections may be modified to suit economical conditions.

Example for the Use of Charts

Given 1. Ditch having 90 cms. base and 3:1 side slopes.

2. Bottom and sides in average condition - rough

3. Estimated discharge = 50 cms^3/ sec.

4. Grade = 4 %

Required: 1. Depth of ditch

2. Velocity of flow

Solution:

From chart 3 , for a 50 cms^3/sec. discharge and 4 % grade the depth of flow and velocity can be read approximately as 23 cms. and 123 cms/sec. Allowing 7 cms. for free board, the depth of the ditch becomes 30 cms.

It should be noted that these charts are made according to maximum hydraulic efficiency and as a result the depths chosen are most economical.

Control of Erosion

Methods of Control

The control of erosion is based on two priciples:

1. Reduction of soil carrying capacity of flowing water by decreasing the velocity of the water.

2. Prevention of scour by lining with concrete, rubble or sod.

Soils scour at approximately the following velocities:(1)

Sand -------------------- 2-3 ft/sec.(0.6-0.9 m/sec.)

Loam --------------------2-3½ft/sec.(0.6-1.1 m/sec.)

Firm gravel--------------- 5-6ft/sec.(15.3-18.3m/sec.)

A good turf, in general, provides protection against velocities up to 8 ft/sec.(2.5 m/sec.)(2)

Velocity is read directly from the channel flow charts & with the permissible velocities stated above, it can be determined whether to leave the ditches bare or sod them. Where the velocity is excessive for turf, some economical type of paving becomes necessary.

Since paving is costly, even with the reduced cross-section made possible by decreased resistance, the possibility of diverting part or all of the flow to a relief culvert (3), or of intercepting a portion of the drainage area by an intercepting ditch above the cut slope, should be investigated.

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(1) Harger's Handbook for Highway Engineers P.335.

(2) Application of Sodding in Syria & Lebanon will be discussed separately.

(3) The location of relief culverts is discussed on P. 33

Paving

In case paving is necessary on steep first class primary highways, cobble gutter with cement joints on grades over 6% and sand or gravel joint filler on grades less than 6% where the volume of flow is not large make probably the best design, as they tend to retard the velocity of flow. Smooth concrete lining is not usually satisfactory on steep grades but is allowable if the cobble gutter is not available.

Where ditch protection is used, it is good practice to carry it for at least 200 ft.(60 cms.) along the road after the foot of the steep grade is reached, as scour often occurs through stopping the protection too closely to the bottom of the steep grade.

Intercepting ditches.

Intercepting ditches not only relieve the side ditches but also prevent erosion of the artificial slopes in cuts. They are used on natural slopes and are made trapezoidal in section. Fig. 27 shows the location and dimensions of an intercepting ditch.

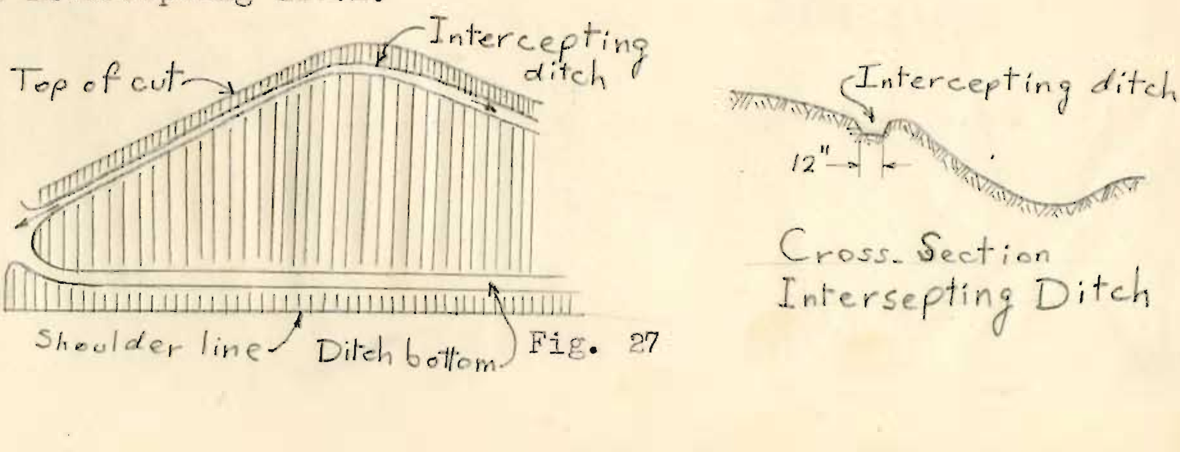

Fig. 27

CHAPTER 17

Drainage of Retaining Walls

Importance

Drainage of retaining walls is an important part of highway drainage structures. Next to the settlement of the foundation, water behind the wall is the most frequent cause of the failure of retaining walls. The water not only adds to the weight of the backing material but also softens the material and changes the angle of repose so as to greatly increase its lateral thrust. With clayey soil, or any material resting upon a stratum of clay, this action becomes of the greatest importance. Furthermore, the freezing of underdrained backfilling and the consequent expansion is a potent cause of the failure of retaining walls.

Present Practice in Syria & Lebanon

In Syria and Lebanon almost all retaining walls along highways are stone-block masonry walls. The usual practice for draining the walls is allowing one weep-hole, about 10 cms. (4 in.) wide and the depth of a course of masonry which is about 30 cms. (1 ft.), for wach 2 m^2. (22 ft^2.) of front of the wall.

I think this practice is adequate except that no measures are taken to prevent clogging of the holes with impervious materials.

When the backing is clean sand, the weep-holes will allow all the water to escape; but if the backing is retentive of water, a vertical layer of broken stone or coarse gravel or cinders should be placed next to the wall to act as a drain and prevent clogging of the holes.

<u>Drainage of Retaining Crib-walls</u>

Crib-walls are made of precast concrete units put as headers and stretchers in a bin-form and filled with backfill material. They have the following advantages:

1. Pleasing in appearance
2. Stability and strength
3. Ease of construction with little or no interference to traffic
4. Absorption of light - comfort to drivers
5. Adequacy and ease of drainage
6. Economy

A cost analysis made by Mr. A. Shabhar (1) proved that crib walls are much more cheaper than reinforced concrete walls and even cheaper than masonry walls. I suggest that they be introduced to highways in Syria and Lebanon. Figure 28 shows a typical retaining crib-wall. (2)

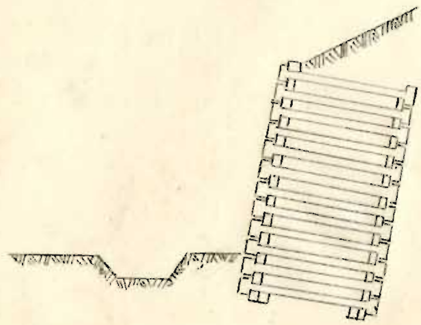

Fig. 28

As for its adequacy to drainage, cribbing permits water to pass through the wall freely and drain out to the side ditches. Expensive drainage tiles that are needed for reinforced concrete walls are not required for crib walls.

Gravel, crushed stone or other coarse granular material makes good back-fill for the cribs. Rock

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(1) "Preliminary Location Survey & Study of Drainage of the Highway between Shtourah and Damascus."

(2) Massey's Reinforced Concrete Cribbing - Catalogue Series "A" No. 1.

if accessible and cheap, may also be used as it affords good drainage. Clay or material having large percentage clay should not be used as it impedes the escape of water through the cfibs.

PART VI

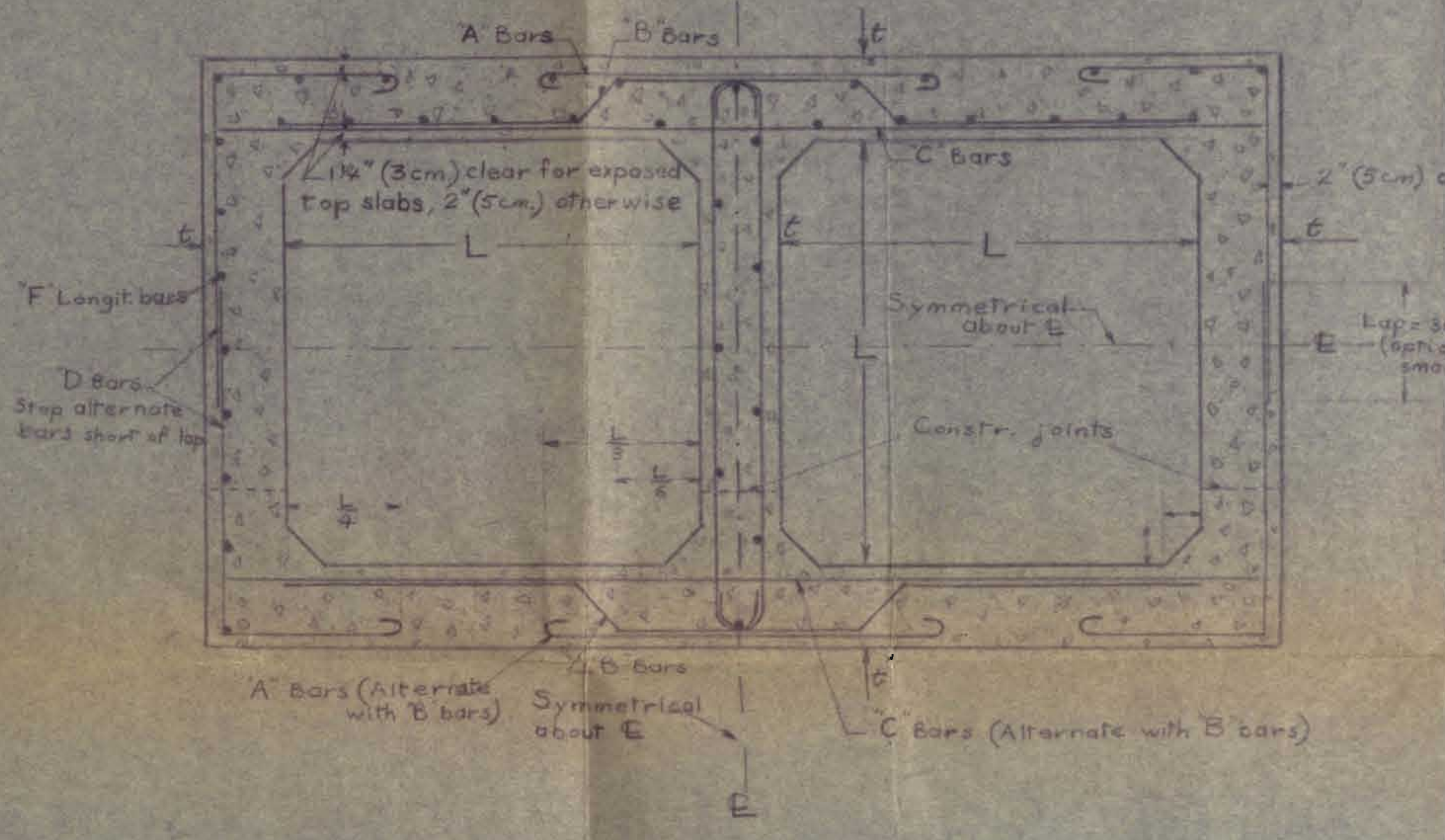
DRAWINGS

STANDARD DESIGNS OF TWO-CELL CULVERTS FOR 10-TON LOADING (SECONDARY HIGHWAYS)

WATER WAY OPENING		DEPTH OF COVER		DIMENSIONS				TRANSVERSE REINFORCEMENT																								LONG. REINF.				VOLUME OF CONCRETE† 7.6(L+t)-t²		APPR. COST PER MR
				L		t		"A" BARS				"B" BARS				"C" BARS				"D" BARS				"E" BARS								"F" BARS						
								Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.						Size		Spac.				
ft²	m²	ft	m	ft	m	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm					in	mm	in	cm	ft³/lin ft	m³/MR	LL or LS
50	4.64	0	0	5	1.50	6	15	1/2	12	12	30	1/2	12	12	30	1/2	12	12	30	9/16	14	6	15	9/16	14	12	30					1/2	12	13	32	17.0	1.76	176.00
		1.5-5	0.50-1.50	5	1.50	6	15	1/2	12	8	20	3/8	10	8	20	3/8	10	8	20	3/8	10	4½	11	3/8	10	16	40					1/2	12	16	40	17.0	1.76	176.00
		5.5-10	1.70-3.00	5	1.50	8	20	1/2	12	8	20	3/8	10	8	20	3/8	10	8	20	3/8	10	4½	11	3/8	10	16	40					1/2	12	12	30	26.0	2.51	251.00
		10.5-15	3.20-4.50	5	1.50	9	23	1/2	12	8	20	1/2	12	8	20	3/8	10	16	40	3/8	10	4	10	3/8	10	16	40					1/2	12	11	28	29.6	2.74	274.00
72	7.75	0	0	6	1.85	6	15	9/16	14	12	30	9/16	14	12	30	9/16	14	12	30	9/16	14	6	15	9/16	14	12	30					1/2	12	11	27	22.5	2.08	208.00
		1.5-5	0.50-1.50	6	1.85	7	18	9/16	14	10	25	1/2	12	10	25	3/8	10	10	25	3/8	10	5	12	3/8	10	20	50					1/2	12	14	35	26.5	2.46	246.00
		5.5-10	1.70-3.00	6	1.85	8	20	5/8	16	11	27	5/8	16	11	27	3/8	10	11	27	1/2	12	5½	13	1/2	12	22	55					1/2	12	12	30	30.7	2.84	284.00
		10.5-15	3.20-4.50	6	1.85	10	25	5/8	16	10	25	5/8	16	10	25	3/8	10	10	25	1/2	12	5	12	1/2	12	20	50					1/2	12	10	25	38.8	3.60	360.00
98	9.10	0	0	7	2.15	6	15	9/16	14	11	27	9/16	14	11	27	9/16	14	11	27	9/16	14	5½	13	9/16	14	11	27					1/2	12	9	22	26.0	2.41	241.00
		1.5-5	0.50-1.50	7	2.15	7	18	5/8	16	9	22	9/16	14	9	22	3/8	10	9	22	3/8	10	4½	11	3/8	10	18	45					9/16	14	17	42	30.6	2.84	284.00
		5.5-10	1.70-3.00	7	2.15	9	23	5/8	16	9	22	5/8	16	9	22	3/8	10	9	22	1/2	12	5	12	1/2	12	18	45					9/16	14	13	32	40.1	3.72	372.00
		10.5-15	3.20-4.50	7	2.15	12	30	3/4	18	10	25	9/16	14	10	25	1/2	12	10	25	1/2	12	5	12	9/16	14	20	50					5/8	16	12	30	55.0	5.10	510.00
128	11.90	0	0	8	2.45	6	15	5/8	16	11	27	5/8	16	11	27	5/8	16	11	27	5/8	16	5½	13	5/8	16	11	27					9/16	14	10	25	29.5	2.74	274.00
		1.5-5	0.50-1.50	8	2.45	8	20	3/4	18	10	25	[illegible]																								40.0	3.71	371.00
		5.5-10	1.70-3.00	8	2.45	10	25	7/8	22	[illegible]																										50.8	4.72	472.00
		10.5-15	3.20-4.50	8	2.45	13	33	7/8	22	11	27	[illegible]																								67.7	6.28	628.00
162	15.00	0	0	9	2.75	6	15	5/8	16	10	25	[illegible]																								33.0	3.06	306.00
		1.5-5	0.50-1.50	9	2.75	9	23	7/8	22	12	30	[illegible]																								50.6	4.70	470.00
		5.5-10	1.70-3.00	9	2.75	11	28	7/8	22	11	27	[illegible]																								62.8	5.83	583.00
		10.5-15	3.20-4.50	9	2.75	14	36	1	25	13	32	[illegible]																								81.7	7.58	758.00
200	18.60	0	0	10	3.00	6½	17	7/8	22	12	30	[illegible]																								37.6	3.47	347.00
		1.5-5	0.50-1.50	10	3.00	9	23	7/8	22	12	30	[illegible]																								55.8	5.18	518.00
		5.5-10	1.70-3.00	10	3.00	12	30	1	25	12	30	[illegible]																								76.0	7.05	705.00
		10.5-15	3.20-4.50	10	3.00	15	38	1	25	11	27	[illegible]																								96.9	8.99	899.00

† Fillet quantities not included.

TYPICAL CROSS-SECTION



STANDARD DESIGNS OF TWO-CELL CULVERTS FOR 15-TON LOADING (PRIMARY HIGHWAYS)

WATER-WAY OPENING		DEPTH OF COVER		DIMENSIONS				TRANSVERSE REINFORCEMENT																				LONG. REINF.				VOLUME OF CONCRETE† 7.6(L+t)-t²		APPR. COST PER M.R.
				L		t		"A" BARS				"B" BARS				"C" BARS				"D" BARS				"E" BARS				"F" BARS						
								Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.				
ft²	m²	ft	m	ft	m	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	ft³/lin ft	m³/MR	LL or LS
50	4.64	0	0	5	1.50	7½	19	7/16	14	12	30	7/16	14	12	30	9/16	14	12	30	5/8	16	6	15	5/8	16	12	30	9/16	14	13	32	24.2	2.25	225.00
		1.5-5	0.50-1.50	5	1.50	7	18	1/2	12	7	18	3/8	10	7	17	3/8	10	7	17	3/8	10	4	10	3/8	10	15	37	1/2	12	15	37	22.4	2.08	208.00
		5.5-10	1.70-3.00	5	1.50	9	23	1/2	12	7	18	3/8	10	7	17	3/8	10	7	17	3/8	10	4	10	3/8	10	15	37	1/2	12	11	27	29.6	2.75	275.00
		10.5-15	3.20-4.50	5	1.50	9	23	1/2	12	8	20	1/2	12	8	20	3/8	10	16	40	3/8	10	4	10	3/8	10	16	40	1/2	12	11	27	29.6	2.78	278.00
72	7.75	0	0	6	1.85	7½	19	5/8	16	12	30	5/8	16	12	30	7/8	16	12	30	5/8	16	6	15	5/8	16	12	30	11/16	14	11	27	28.5	2.65	265.00
		1.5-5	0.50-1.50	6	1.85	8	20	9/16	14	9	23	1/2	12	9	22	3/8	10	9	22	3/8	10	4½	11	3/8	10	18	45	1/2	12	13	32	30.0	2.76	276.00
		5.5-10	1.70-3.00	6	1.85	9	23	5/8	16	10	25	5/8	16	10	25	3/8	10	10	25	1/2	12	5	12	1/2	12	20	50	1/2	12	11	27	34.9	3.24	324.00
		10.5-15	3.20-4.50	6	1.85	10	25	5/8	16	10	25	5/8	16	10	25	3/8	10	10	25	1/2	12	5	12	1/2	12	20	50	1/2	12	10	25	38.8	3.60	360.00
98	9.10	0	0	7	2.15	7½	19	5/8	16	11	27	5/8	16	11	27	5/8	16	11	27	5/8	16	5½	13	5/8	16	11	27	11/16	14	9	22	32.9	3.05	305.00
		1.5-5	0.50-1.50	7	2.15	8	20	5/8	16	8	20	7/16	14	8	20	3/8	10	8	20	3/8	10	4	10	3/8	10	17	42	9/16	14	16	40	35.3	3.28	328.00
		5.5-10	1.70-3.00	7	2.15	10	25	5/8	16	8	20	5/8	16	8	20	3/8	10	8	20	1/2	12	4½	11	1/2	12	17	42	9/16	14	12	30	45.0	4.18	418.00
		10.5-15	3.20-4.50	7	2.15	12	30	3/4	18	10	25	7/16	14	10	25	1/2	12	10	25	1/2	12	5	12	9/16	14	20	50	5/8	16	12	30	55.0	5.10	510.00
128	11.90	0	0	8	2.45	7½	19	3/4	18	11	27	5/8	10	11	27	3/4	18	11	27	3/4	18	5½	13	3/4	18	11	27	5/8	16	10	25	37.3	3.46	346.00
		1.5-5	0.50-1.50	8	2.45	9	23	3/4	18	9	22	7/16	14	9	22	1/2	12	9	22	1/2	12	5½	14	1/2	12	18	45	1/2	12	11	27	45.4	4.22	422.00
		5.5-10	1.70-3.00	8	2.45	11	28	7/8	22	13	32	[illegible]	18	13	32	9/16	14	13	32	9/16	14	6½	16	1/2	12	13	32	9/16	14	11	27	56.3	5.23	523.00
		10.5-15	3.20-4.50	8	2.45	13	33	7/8	22	11	27	5/8	16	11	27	9/16	14	11	27	9/16	14	6	15	5/8	16	22	55	5/8	16	12	30	67.7	6.28	628.00
162	15.00	0	0	9	2.75	7½	19	3/4	18	10	25	3/4	18	10	25	3/4	18	10	25	3/4	18	5	12	3/4	18	10	25	5/8	16	9	22	41.7	3.87	387.00
		1.5-5	0.50-1.50	9	2.75	10	25	7/8	22	11	27	5/8	16	11	27	9/16	14	11	27	1/2	12	5½	14	1/2	12	17	42	7/16	14	12	30	56.7	5.27	527.00
		5.5-10	1.70-3.00	9	2.75	12	30	7/8	22	10	25	5/8	16	10	25	5/8	16	10	25	1/2	12	4½	11	9/16	14	20	50	5/8	16	13	32	64.0	5.83	583.00
		10.5-15	3.20-4.50	9	2.75	14	36	1	25	13	32	3/4	18	13	32	5/8	16	13	32	9/16	14	6	15	1/2	12	15	38	5/8	16	11	27	81.7	7.58	758.00
200	18.60	0	0	10	3.00	8	20	7/8	22	13	32	7/8	20	13	32	7/8	20	13	32	7/8	20	6½	16	7/8	20	13	32	3/4	18	11	27	48.4	6.40	640.00
		1.5-5	0.50-1.50	10	3.00	10	25	7/8	22	11	27	3/4	18	11	27	1/2	12	11	27	9/16	14	5½	14	1/2	12	17	42	9/16	14	11	27	62.5	5.80	580.00
		5.5-10	1.70-3.00	10	3.00	13	33	1	25	11	27	3/4	18	11	27	5/8	16	11	27	9/16	14	5½	14	5/8	16	22	55	3/4	18	11	27	82.8	7.68	768.00
		10.5-15	3.20-4.50	10	3.00	15	38	1	25	11	27	3/4	18	11	27	5/8	16	11	27	9/16	14	5½	13	5/8	16	22	55	5/8	16	15	37	96.9	8.99	899.00

† Fillet quantities not included.

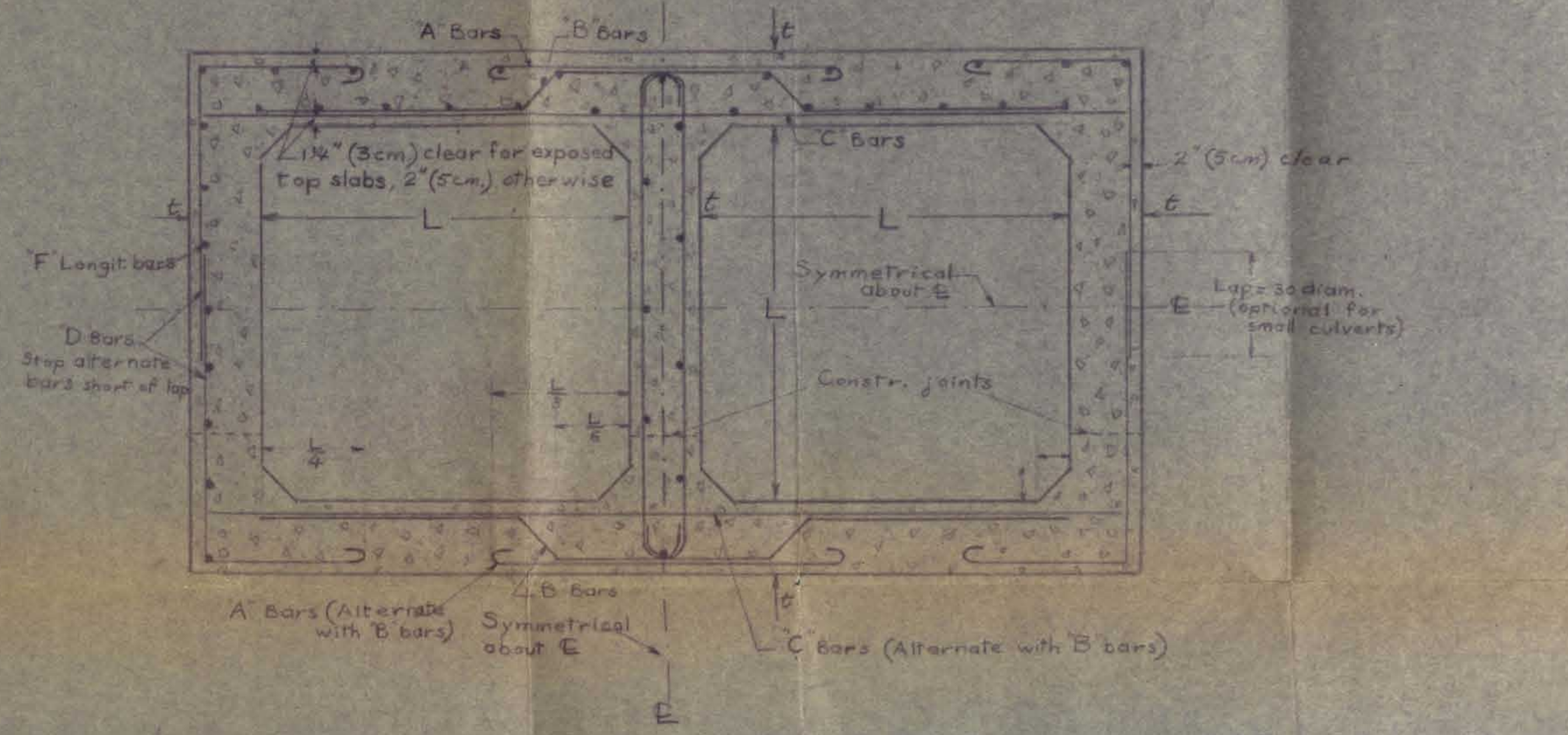
SCHOOL OF ENGIN
PROJECT: HIGHWAY DRA
STANDARD TWO-
DRAWN BY: SADEK
DATE: MAY 20, 1953

DESIGNS OF TWO-CELL CULVERTS FOR 10-TON LOADING (SECONDARY HIGHWAYS)

OF R	DIMENSIONS				TRANSVERSE REINFORCEMENT																				LONG. REINF.				VOLUME OF CONCRETE 7¢(L+t).t²		APPR. COST PER MR
					"A" BARS				"B" BARS				"C" BARS				"D" BARS				"E" BARS				"F" BARS						
	L		t		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.				
m	ft	m	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	ft³/lin.ft	m³/MR	LL. or L.S.
0	5	1.50	6	15	1/2	12	12	30	1/2	12	12	30	1/2	12	12	30	9/16	14	6	15	9/16	14	12	30	1/2	12	13	32	19.0	1.76	176.00
.50-1.50	5	1.50	6	15	1/2	12	8	20	3/8	10	8	20	3/8	10	8	20	3/8	10	4½	11	3/8	10	16	40	1/2	12	16	40	19.0	1.76	176.00
.70-3.00	5	1.50	8	20	1/2	12	8	20	3/8	10	8	20	3/8	10	8	20	3/8	10	4½	11	3/8	10	16	40	1/2	12	12	30	26.0	2.51	251.00
.20-4.50	5	1.50	9	23	1/2	12	8	20	1/2	12	8	20	3/8	10	16	40	3/8	10	4	10	3/8	10	16	40	1/2	12	11	28	29.6	2.74	274.00
0	6	1.85	6	15	9/16	14	12	30	9/16	14	12	30	9/16	14	12	30	9/16	14	6	15	9/16	14	12	30	1/2	12	11	27	22.5	2.08	208.00
.50-1.50	6	1.85	7	18	9/16	14	10	25	1/2	12	10	25	3/8	10	10	25	3/8	10	5	12	3/8	10	20	50	1/2	12	14	35	26.5	2.46	246.00
.70-3.00	6	1.85	8	20	5/8	16	11	27	5/8	16	11	27	3/8	10	11	27	1/2	12	5½	13	1/2	12	22	55	1/2	12	12	30	30.7	2.84	284.00
.20-4.50	6	1.85	10	25	5/8	16	10	25	5/8	16	10	25	[illegible]	10	10	25	1/2	12	5	12	1/2	12	20	50	1/2	12	10	25	38.8	3.60	360.00
0	7	2.15	6	15	9/16	14	11	27	9/16	14	11	27	9/16	14	11	28	9/16	14	5½	13	9/16	14	11	27	1/2	12	9	22	26.0	2.41	241.00
.50-1.50	7	2.15	7	18	5/8	16	9	22	9/16	14	9	22	3/8	10	9	22	3/8	10	4½	11	3/8	10	18	45	9/16	14	17	42	30.6	2.84	284.00
.70-3.00	7	2.15	9	23	5/8	16	9	22	5/8	16	9	22	3/8	10	9	22	1/2	12	5	12	1/2	12	18	45	9/16	14	13	32	40.1	3.72	372.00
.20-4.50	7	2.15	12	30	3/4	18	10	25	9/16	14	10	25	1/2	12	10	25	1/2	12	5	12	9/16	14	20	50	5/8	16	12	30	55.0	5.10	510.00
0	8	2.45	6	15	5/8	16	11	27	5/8	16	11	27	5/8	16	11	27	5/8	16	5½	13	5/8	16	11	27	9/16	14	10	25	29.5	2.74	274.00
.50-1.50	8	2.45	8	20	3/4	18	10	25	9/16	14	10	25	1/2	12	10	25	1/2	12	6	15	1/2	12	20	50	1/2	12	12	30	40.0	3.71	371.00
.70-3.00	8	2.45	10	25	7/8	22	14	35	3/4	18	14	35	9/16	14	14	35	9/16	14	7	17	1/2	12	14	35	9/16	14	12	30	50.8	4.72	472.00
.20-4.50	8	2.45	13	33	7/8	22	11	27	5/8	16	11	27	9/16	14	11	27	9/16	14	6	15	5/8	16	22	55	5/8	16	12	30	67.7	6.28	628.00
0	9	2.75	6	15	5/8	16	10	25	5/8	16	10	25	5/8	16	10	25	5/8	16	5	12	5/8	16	10	25	9/16	14	9	22	33.0	3.06	306.00
.50-1.50	9	2.75	9	23	7/8	22	12	30	5/8	16	12	30	9/16	14	12	30	1/2	12	6	15	1/2	12	18	45	9/16	14	13	32	50.6	4.70	470.00
.70-3.00	9	2.75	11	28	7/8	22	11	27	5/8	16	11	27	5/8	16	11	27	1/2	12	5	12	5/8	16	22	55	5/8	16	14	35	62.8	5.83	583.00
.20-4.50	9	2.75	14	36	1	25	13	32	3/4	18	13	32	5/8	16	13	32	9/16	14	6	15	1/2	12	13	32	5/8	16	11	27	81.7	7.58	758.00
0	10	3.00	6½	17	3/4	18	13	32	3/4	18	13	32	3/4	18	13	32	3/4	18	6½	16	3/4	18	13	32	5/8	16	11	27	39.6	3.67	367.00
.50-1.50	10	3.00	9	23	7/8	22	12	30	3/4	18	12	30	1/2	12	12	30	9/16	14	6	15	1/2	12	18	45	9/16	14	12	30	55.8	5.18	518.00
.70-3.00	10	3.00	12	30	1	25	12	30	3/4	18	12	30	5/8	16	12	30	9/16	14	6	15	5/8	16	24	60	3/4	18	12	30	76.0	7.05	705.00
.20-4.50	10	3.00	15	38	1	25	11	27	3/4	18	11	27	5/8	16	11	27	9/16	14	5½	13	5/8	16	22	55	5/8	16	15	37	96.9	8.99	899.00

not included.

TYPICAL CROSS-SECTION

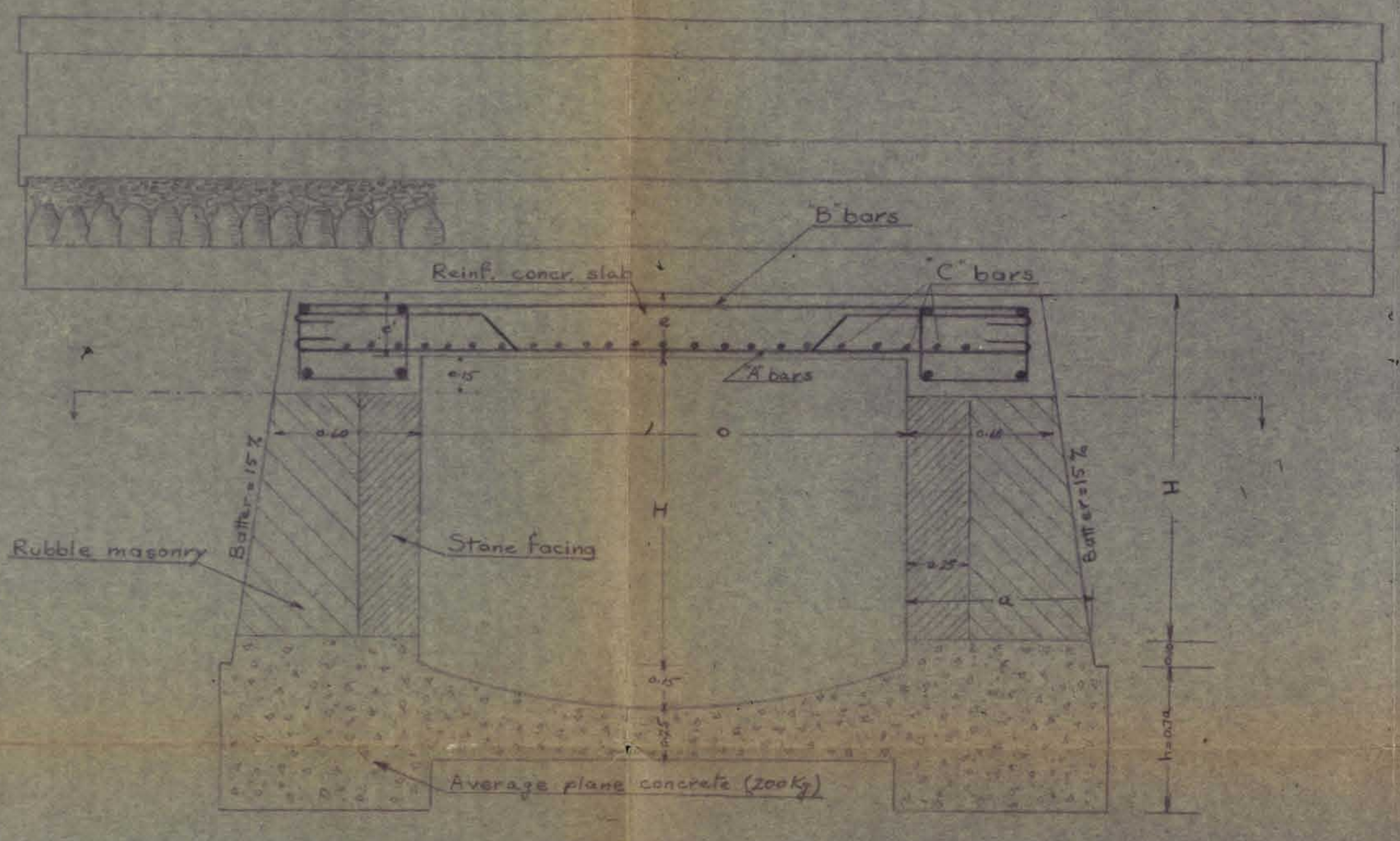


DESIGNS OF TWO-CELL CULVERTS FOR 15-TON LOADING (PRIMARY HIGHWAYS)

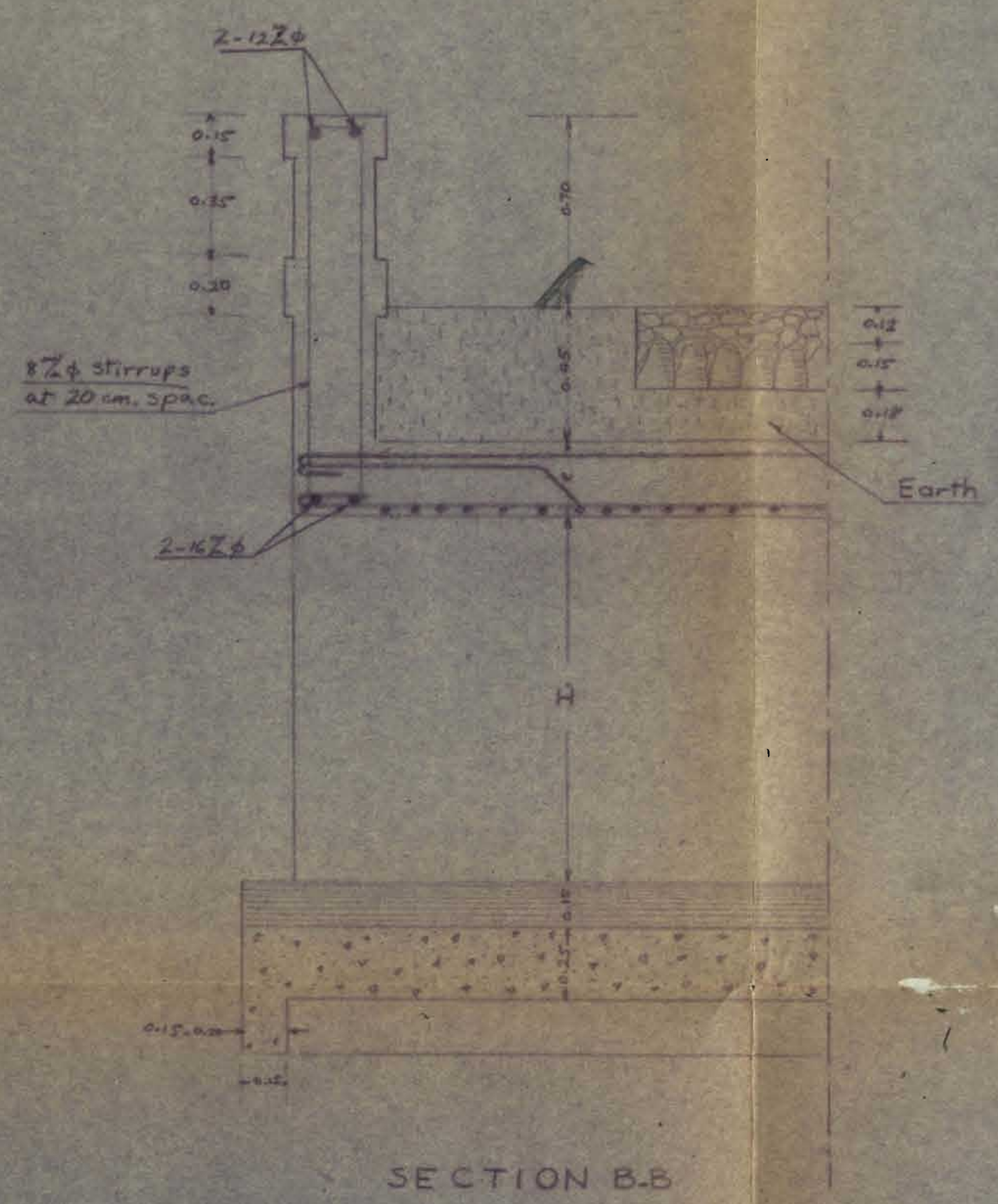
OF R	DIMENSIONS				TRANSVERSE REINFORCEMENT																				LONG. REINF.				VOLUME OF CONCRETE† 7¢(L+t).t²		APPR. COST PER M.R.
					"A" BARS				"B" BARS				"C" BARS				"D" BARS				"E" BARS				"F" BARS						
	L		t		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.				
m	ft	m	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	in	mm	in	cm	ft³/lin.ft	m³/MR	LL. or L.S.
0	5	1.50	7½	19	9/16	14	12	30	9/16	14	12	30	9/16	14	12	30	5/8	16	6	15	5/8	16	12	30	9/16	14	13	32	24.2	2.25	225.00
.50-1.50	5	1.50	7	18	1/2	12	7	18	3/8	10	7	17	3/8	10	7	17	3/8	10	4	10	3/8	10	15	37	1/2	12	15	37	22.4	2.08	208.00
.70-3.00	5	1.50	9	23	1/2	12	7	18	3/8	10	7	17	3/8	10	7	17	3/8	10	4	10	3/8	10	15	37	1/2	12	11	27	29.6	2.75	275.00
.20-4.50	5	1.50	9	23	1/2	12	8	20	1/2	12	8	20	3/8	10	16	40	3/8	10	4	10	3/8	10	16	40	1/2	12	11	27	29.6	2.78	278.00
0	6	1.85	7½	19	5/8	16	12	30	5/8	16	12	30	5/8	16	12	30	5/8	16	6	15	5/8	16	12	30	9/16	14	11	27	28.5	2.65	265.00
.50-1.50	6	1.85	8	20	9/16	14	9	22	1/2	12	9	22	3/8	10	9	22	3/8	10	4½	11	3/8	10	18	45	1/2	12	13	32	30.0	2.76	276.00
.70-3.00	6	1.85	9	23	5/8	16	10	25	5/8	16	10	25	3/8	10	10	25	1/2	12	5	12	1/2	12	20	50	1/2	12	11	27	34.9	3.24	324.00
.20-4.50	6	1.85	10	25	5/8	16	10	25	5/8	16	10	25	3/8	10	10	25	1/2	12	5	12	1/2	12	20	50	1/2	12	10	25	38.8	3.60	360.00
0	7	2.15	7½	19	5/8	16	11	27	5/8	16	11	27	5/8	16	11	27	5/8	16	5½	13	5/8	16	11	27	9/16	14	9	22	32.9	3.05	305.00
.50-1.50	7	2.15	8	20	5/8	16	8	20	9/16	14	8	20	3/8	10	8	20	3/8	10	4	10	3/8	10	17	42	9/16	14	16	40	35.3	3.28	328.00
.70-3.00	7	2.15	10	25	5/8	16	8	20	5/8	16	8	20	3/8	10	8	20	1/2	12	4½	11	1/2	12	17	42	9/16	14	12	30	45.0	4.18	418.00
.20-4.50	7	2.15	12	30	3/4	18	10	25	9/16	14	10	25	1/2	12	10	25	1/2	12	5	12	9/16	14	20	50	5/8	16	12	30	55.0	5.10	510.00
0	8	2.45	7½	19	3/4	18	11	27	3/8	10	11	27	3/4	18	11	27	3/4	18	5½	13	3/4	18	11	27	5/8	16	10	25	37.3	3.46	346.00
.50-1.50	8	2.45	9	23	3/4	18	9	22	9/16	14	9	22	1/2	12	9	22	1/2	12	5½	14	1/2	12	19	48	1/2	12	11	27	45.4	4.22	422.00
.70-3.00	8	2.45	11	28	7/8	22	13	32	3/4	18	13	32	9/16	14	13	32	9/16	14	6½	16	1/2	12	13	32	9/16	14	11	27	56.3	5.23	523.00
.20-4.50	8	2.45	13	33	7/8	22	11	27	5/8	16	11	27	9/16	14	11	27	9/16	14	6	15	5/8	16	22	55	5/8	16	12	30	67.7	6.28	628.00
0	9	2.75	7½	19	3/4	18	10	25	3/4	18	10	25	3/4	18	10	25	3/4	18	5	12	3/4	18	10	25	5/8	16	9	22	41.7	3.87	387.00
.50-1.50	9	2.75	10	25	7/8	22	11	27	5/8	16	11	27	9/16	14	11	27	1/2	12	5½	14	1/2	12	17	42	9/16	14	12	30	56.7	5.27	527.00
.70-3.00	9	2.75	12	30	7/8	22	10	25	5/8	16	10	25	5/8	16	10	25	1/2	12	4½	11	9/16	14	20	50	5/8	16	13	32	63.0	5.83	583.00
.20-4.50	9	2.75	14	36	1	25	13	32	3/4	18	13	32	5/8	16	13	32	9/16	14	6	15	1/2	12	13	32	5/8	16	11	27	81.7	7.58	758.00
0	10	3.00	8	20	7/8	22	13	32	7/8	20	13	32	7/8	20	13	32	7/8	20	6½	16	7/8	20	13	32	3/4	18	11	27	48.4	6.40	640.00
.50-1.50	10	3.00	10	25	7/8	22	11	27	3/4	18	11	27	1/2	12	11	27	9/16	14	5½	14	1/2	12	17	42	9/16	14	11	27	62.5	5.80	580.00
.70-3.00	10	3.00	13	33	1	25	11	27	3/4	18	11	27	5/8	16	11	27	9/16	14	5½	14	5/8	16	22	55	3/4	18	11	27	82.8	7.68	768.00
.20-4.50	10	3.00	15	38	1	25	11	27	3/4	18	11	27	5/8	16	11	27	9/16	14	5½	13	5/8	16	22	55	5/8	16	15	37	96.9	8.99	899.00

s not included.

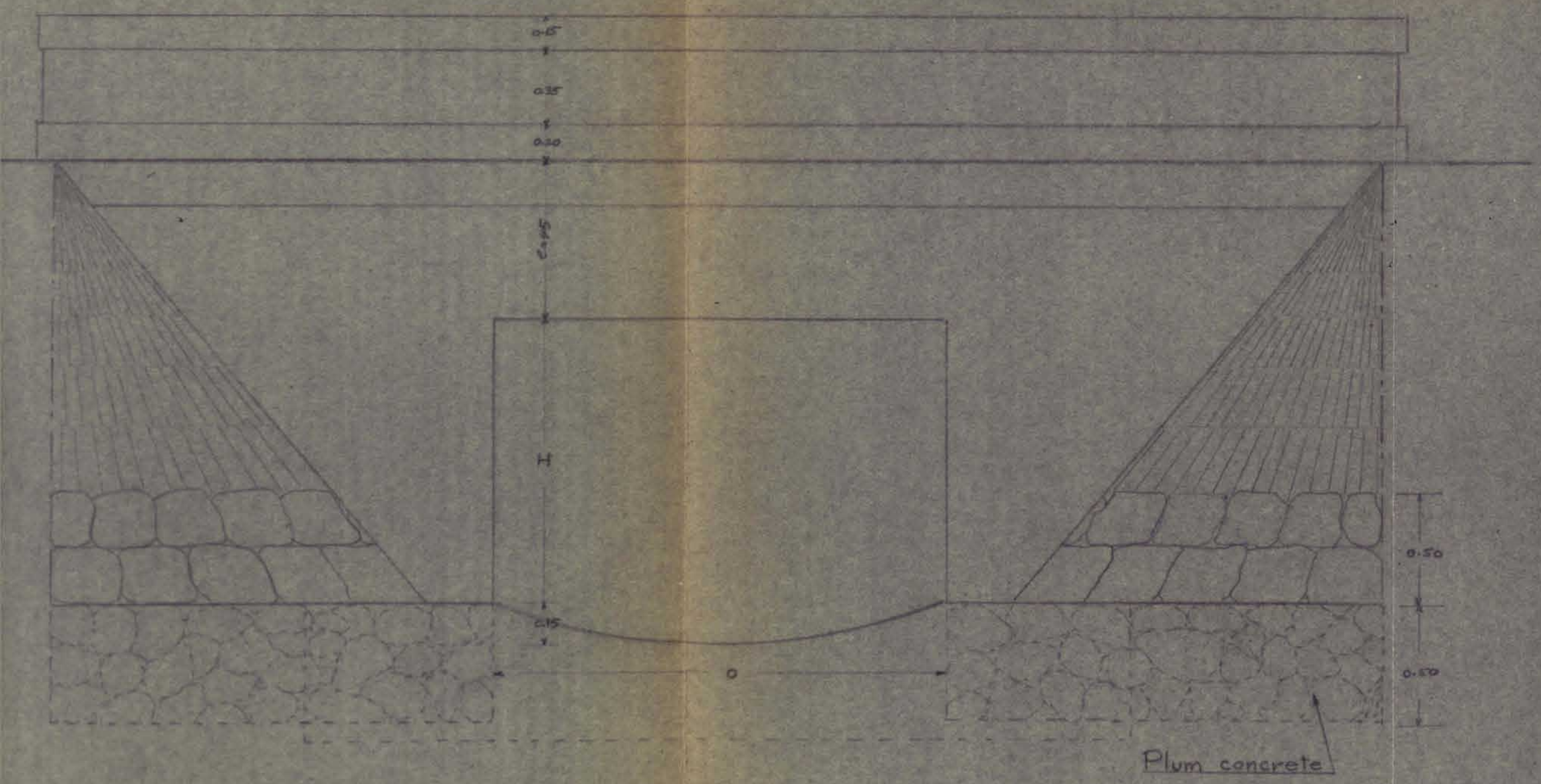
SCHOOL OF ENGINEERING - A.U.B.
PROJECT: HIGHWAY DRAINAGE STRUCTURES
STANDARD TWO-CELL CULVERT
DRAWN BY: SADEK KUWATLY
DATE: MAY 20, 1953 SHEET 2 of 6



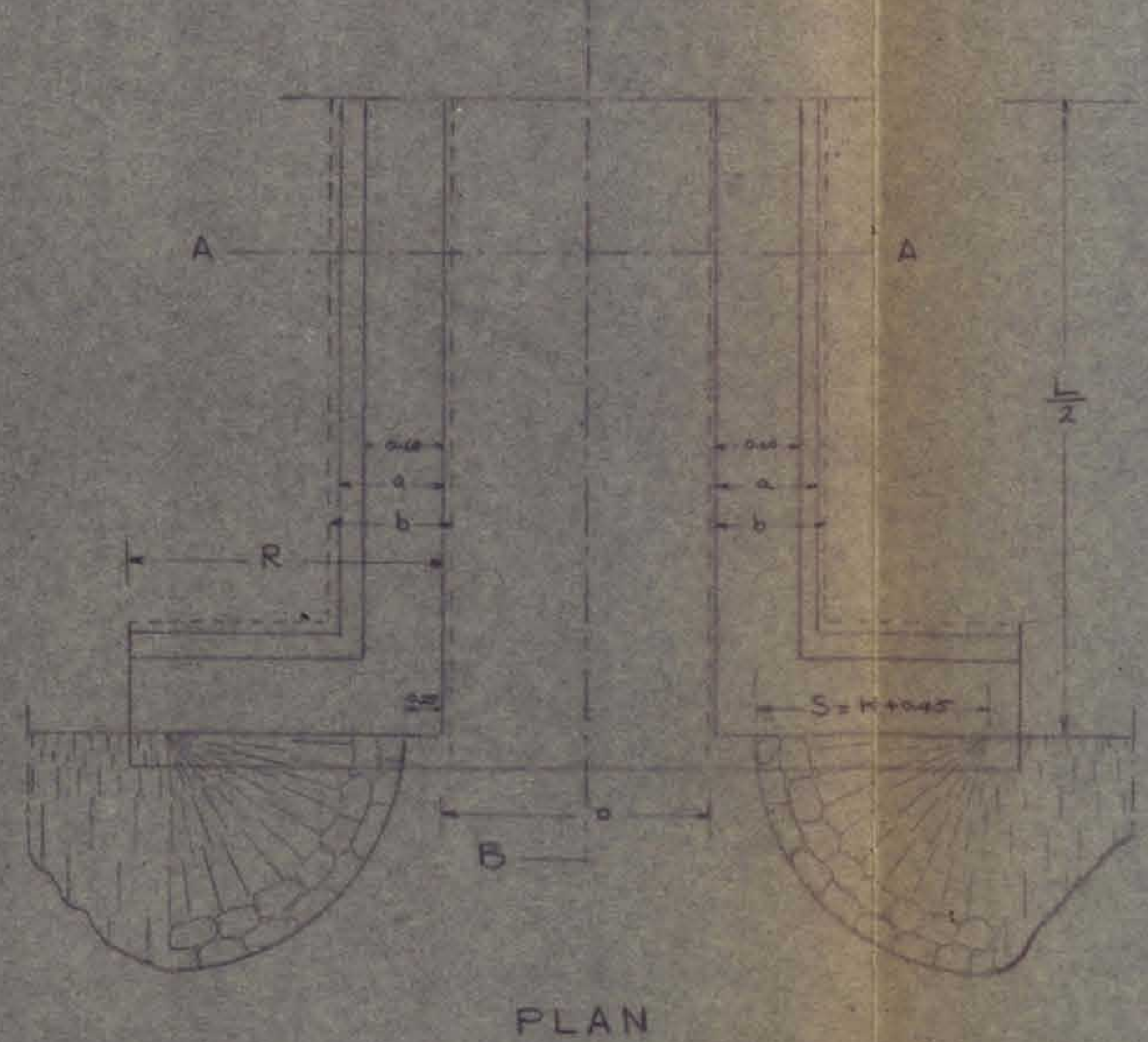
SECTION A-A



SECTION B-B

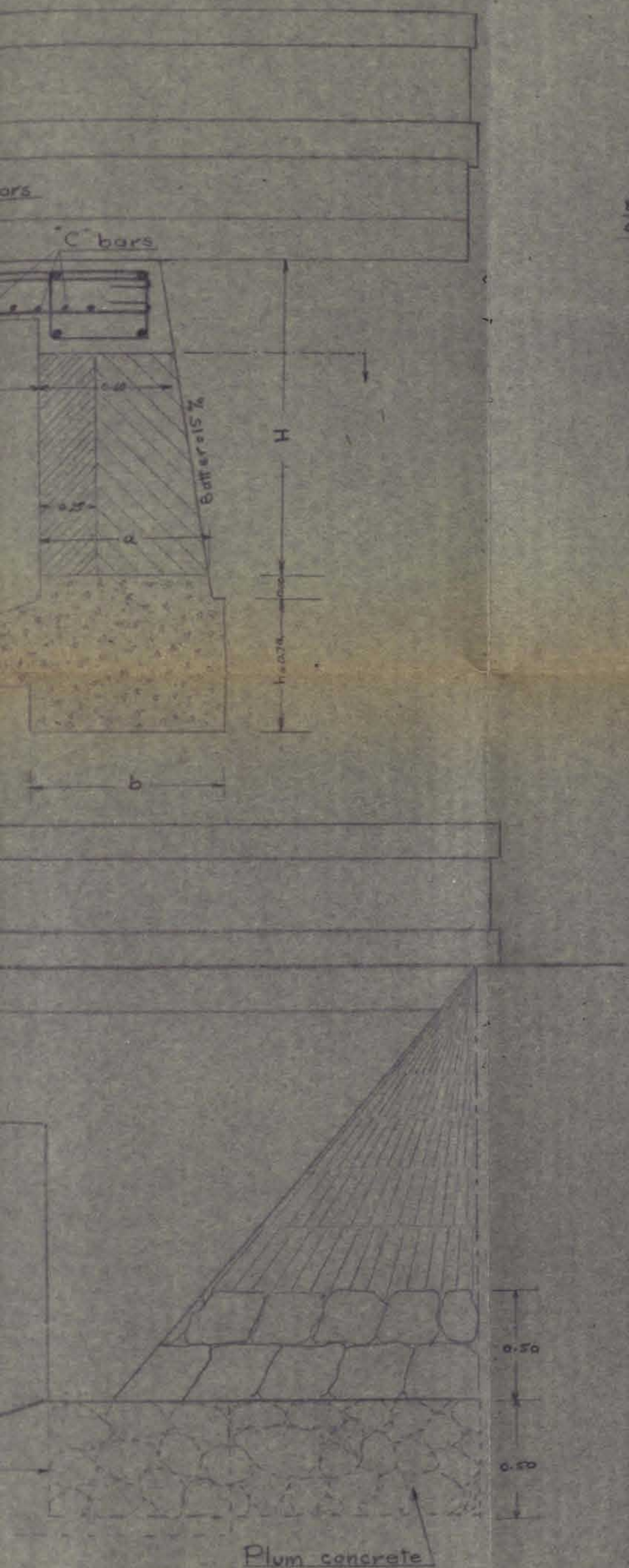


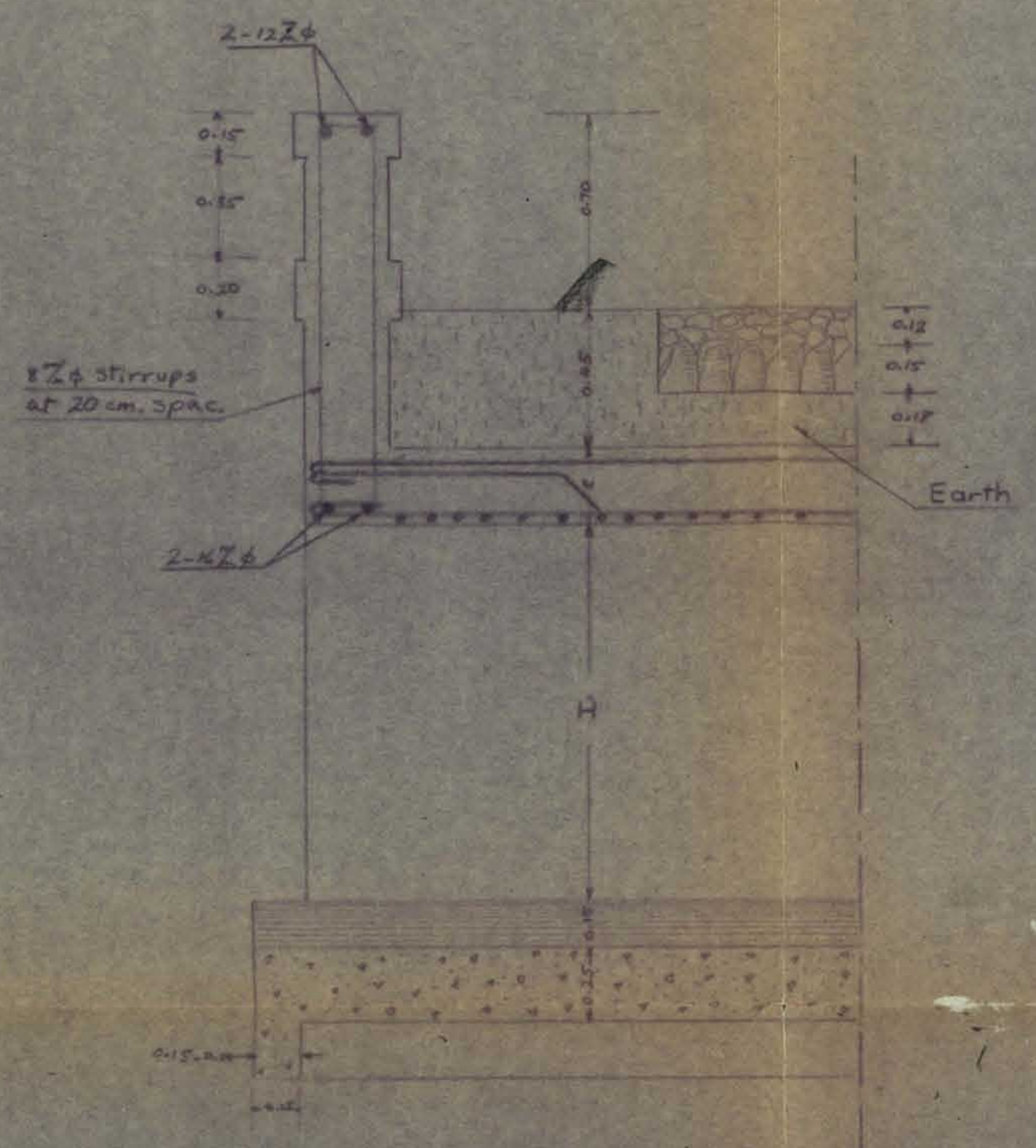
ELEVATION



PLAN
Scale 1:50

HEIGHT OF CULVERT WALL H	WIDTH OF WALL BELOW SLAB h	WIDTH OF WALL ABOVE FOUNDATION a	WIDTH OF FOUNDATION b	LENGTH OF WING R	RADIUS OF CIRCLE FOR WING S
0·75	0·50	0·72	0·75	2·25	1·20
1·00	0·50	0·75	0·80	2·25	1·45
1·25	0·55	0·80	0·85	2·25	1·70
1·50	0·60	0·85	0·90	2·50	1·95
1·75	0·65	0·90	1·00	2·50	2·20
2·00	0·65	0·90	1·00	2·50	2·45
2·50	0·70	1·00	1·10	3·00	2·95
3·00	0·75	1·10	1·20	3·00	3·45
3·50	0·80	1·15	1·25	3·00	3·95
4·00	0·85	1·20	1·30	3·50	4·45



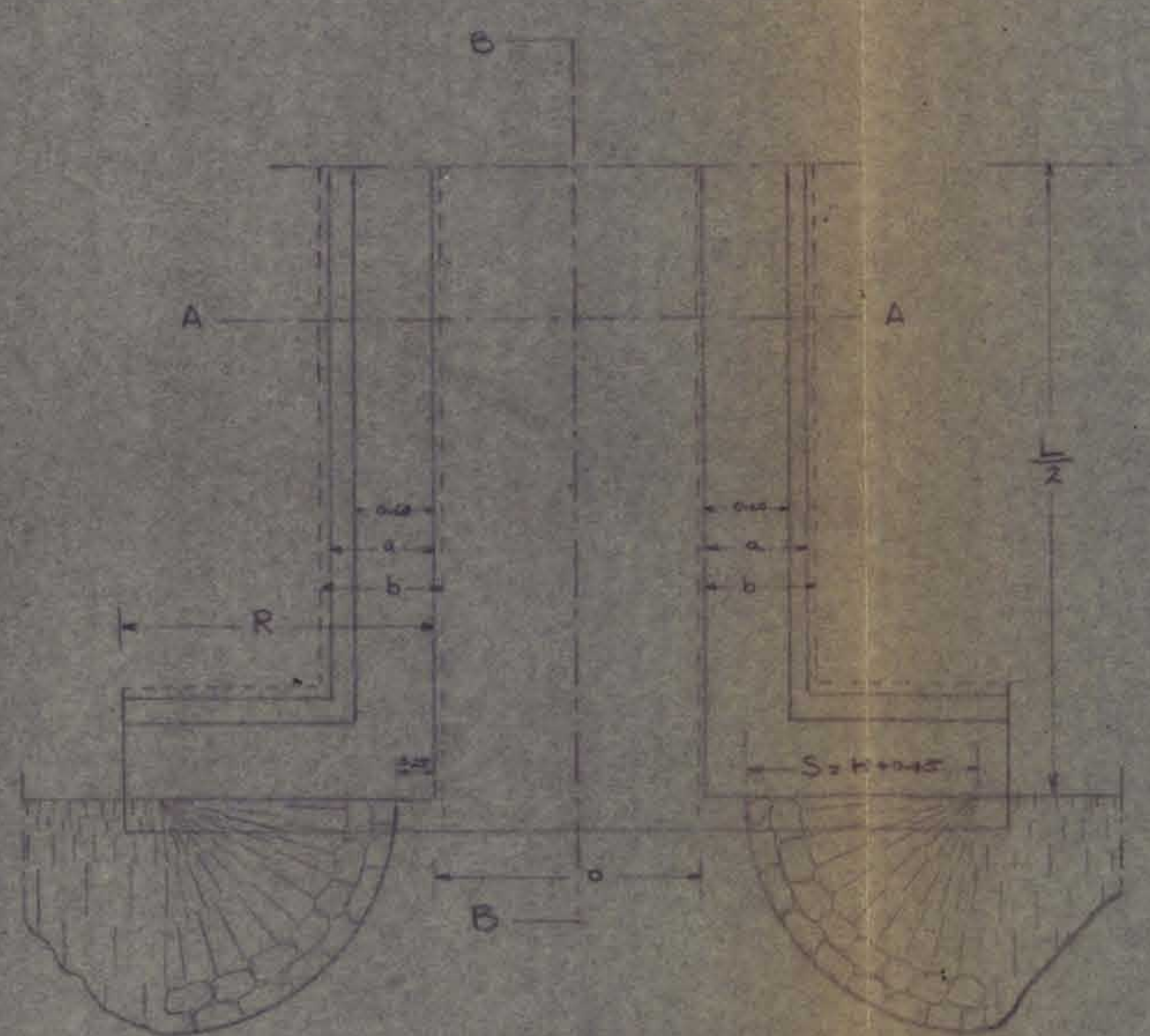


SECTION B-B

HEIGHT OF CULVERT WALL H	WIDTH OF WALL BELOW SLAB h	WIDTH OF WALL ABOVE FOUNDATION a	WIDTH OF FOUNDATION b	LENGTH OF WING R	RADIUS OF CIRCLE FOR WING S
0.75	0.50	0.72	0.75	2.25	1.20
1.00	0.50	0.75	0.80	2.25	1.45
1.25	0.55	0.80	0.85	2.25	1.70
1.50	0.60	0.85	0.90	2.50	1.95
1.75	0.65	0.90	1.00	2.50	2.20
2.00	0.65	0.90	1.00	2.50	2.45
2.50	0.70	1.00	1.10	3.00	2.95
3.00	0.75	1.10	1.20	3.00	3.45
3.50	0.80	1.15	1.25	3.00	3.95
4.00	0.85	1.20	1.30	3.50	4.45

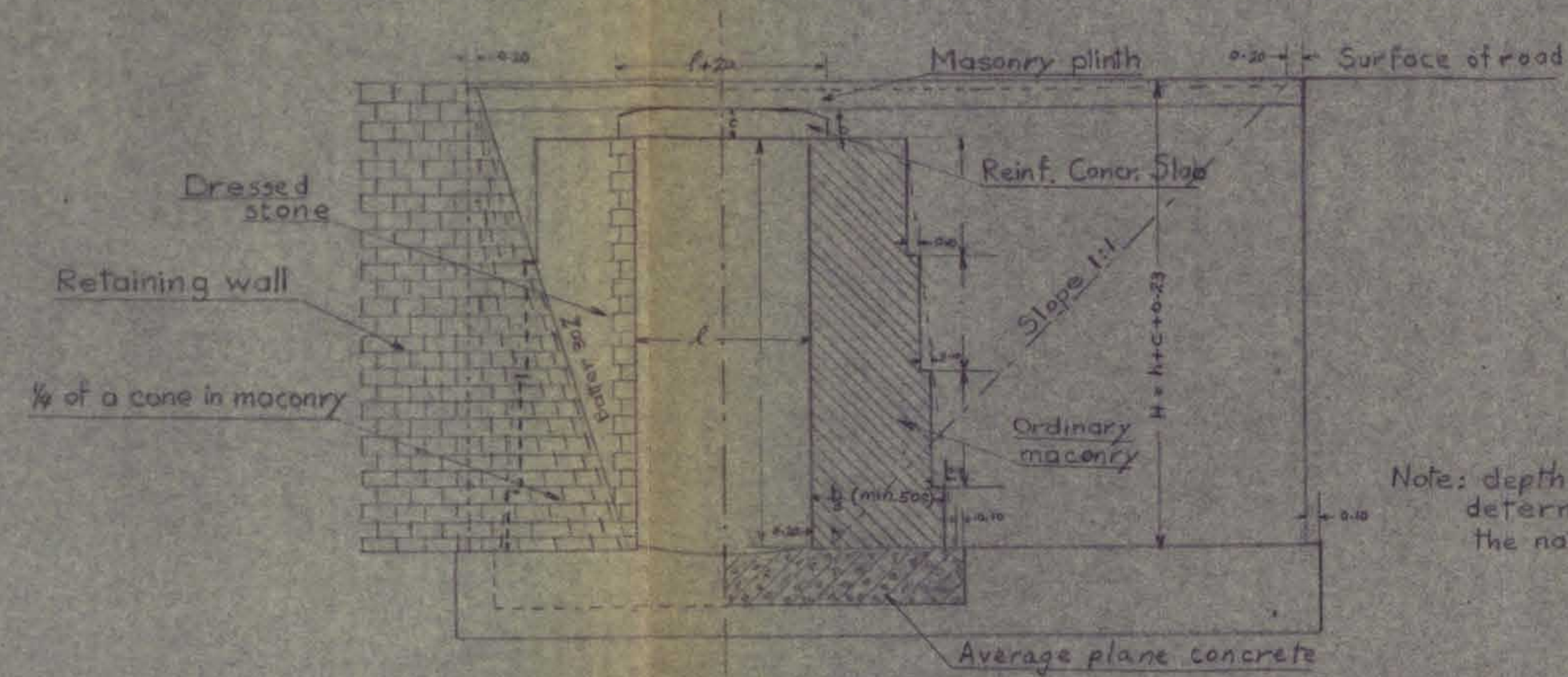
SPAN OF CULVERT O	THICKNESS AT MIDDLE OF SLAB e	THICKNESS AT END OF SLAB e'	"A" BARS	"B" BARS	"C" BARS	APPR. COST (1) PER M.R. in L.L. or L.S.
0.60	15	12	8 ϕ 15 m/m	---	8 ϕ 8 m/m	102.00
0.80	15	12	8 ϕ 10 m/m	---	8 ϕ 8 m/m	115.00
1.00	15	12	10 ϕ 10 m/m	---	8 ϕ 8 m/m	143.00
1.25	16	13	12 ϕ 10 m/m	---	8 ϕ 8 m/m	172.00
1.50	18	15	12 ϕ 12 m/m	8 ϕ 8 m/m	8 ϕ 8 m/m	216.00
1.75	20	17	14 ϕ 12 m/m	8 ϕ 10 m/m	8 ϕ 8 m/m	252.00
2.00	22	19	15 ϕ 12 m/m	8 ϕ 10 m/m	8 ϕ 8 m/m	284.00
2.50	28	25	15 ϕ 14 m/m	8 ϕ 10 m/m	8 ϕ 8 m/m	367.00
3.00	35	32	15 ϕ 14 m/m	8 ϕ 10 m/m	8 ϕ 8 m/m	417.20

(1) Costs are taken for culverts with O = H, except for O = 0.60 & 0.80, H = 0.75.



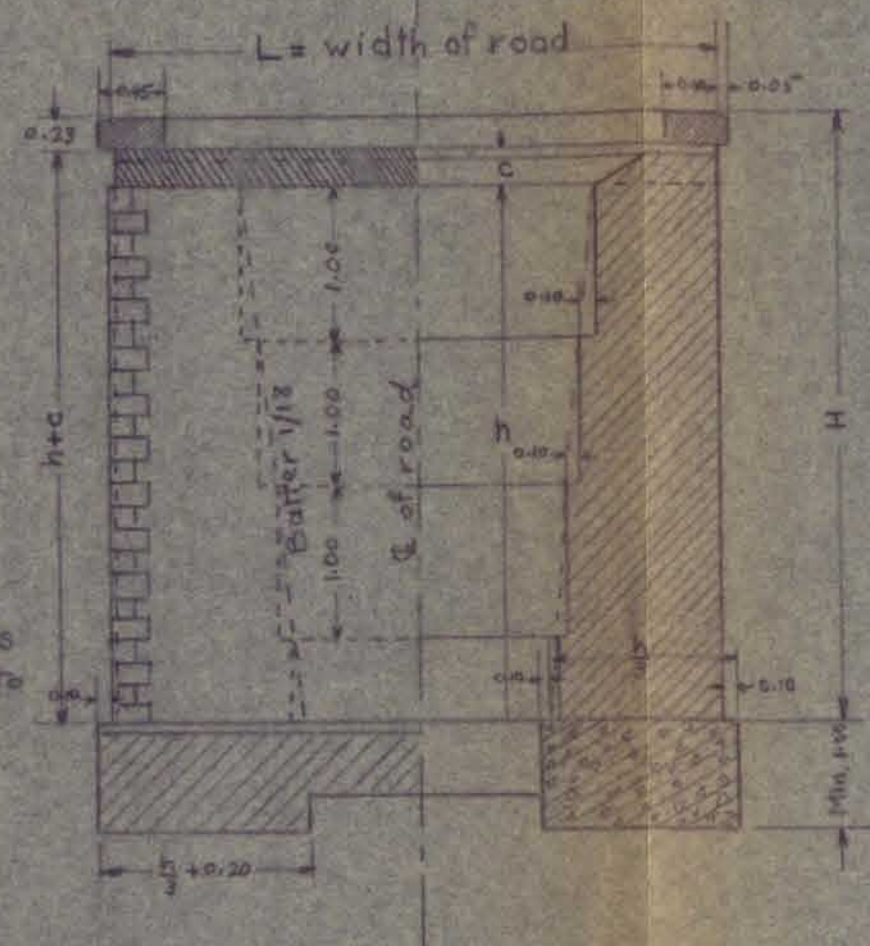
PLAN
Scale 1:50

SCHOOL OF ENGINEERING - A.U.B.
PROJECT: HIGHWAY DRAINAGE STRUCTURES
STANDARD SLAB-TOP CULVERT IN SYRIA
DRAWN BY: SADEK KUWATLY
DATE: MAY 20, 1953
SHEET 3 OF 6



ELEVATION | LONGITUDINAL SECTION

Note: depth of foundations is determined according to the nature of the soil.

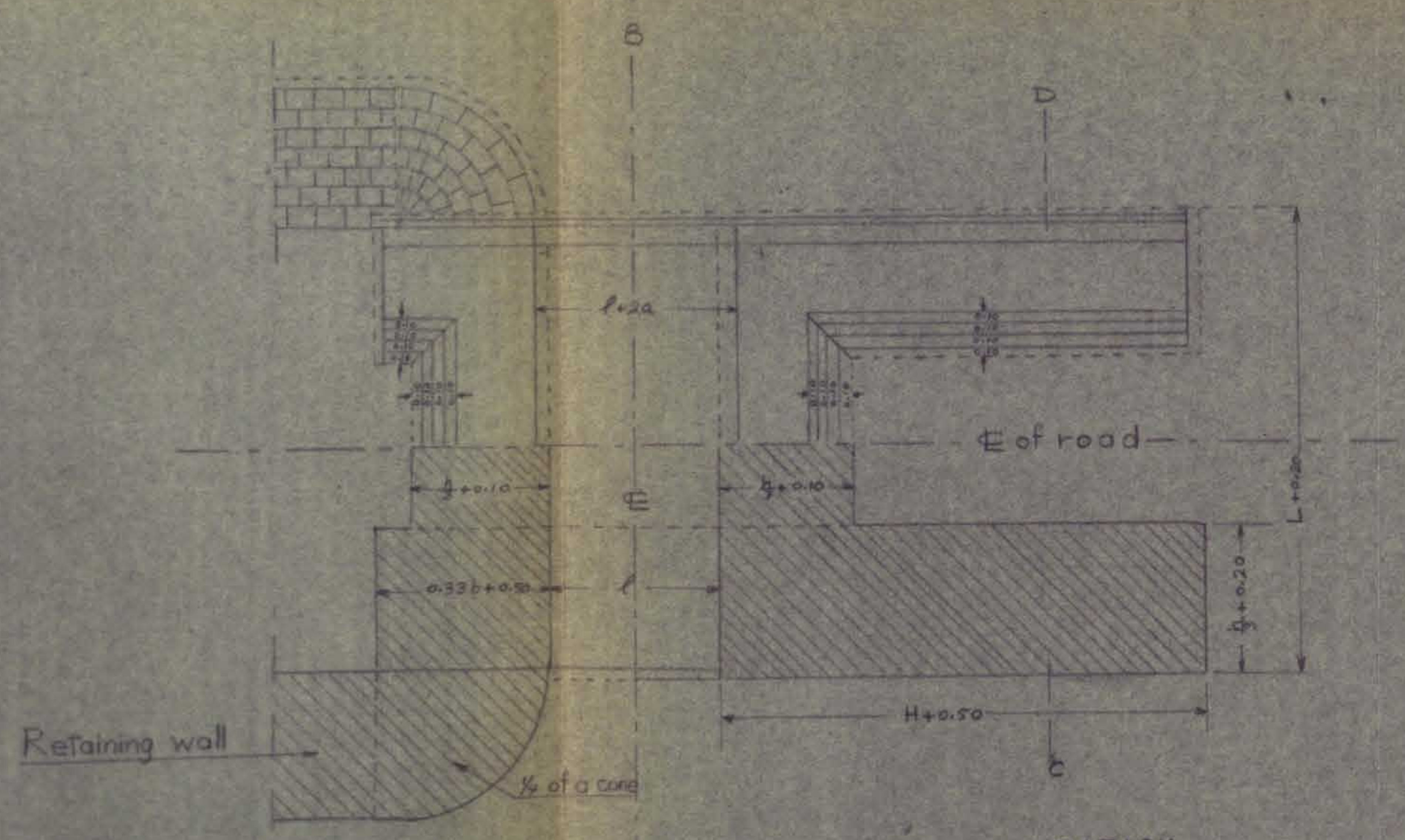


SECTION A-B | SECTION C-D

SPAN ℓ	a	b	c	REINFORCEMENT 'A' bars	REINFORCEMENT 'B' bars	APP… PER …
0.60 m	0.10	0.10	0.13	10 φ 10 m/m	10 φ 8 m/m	6…
1.00	0.15	0.14	0.20	10 φ 14 m/m	13 φ 8 m/m	11…
1.50	0.15	0.16	0.24	11 φ 14 m/m	11 φ 10 m/m	17…
2.00	0.15	0.20	0.28	13 φ 16 m/m	14 φ 10 m/m	21…
2.50	0.20	0.23	0.30	11 φ 16 m/m	14 φ 10 m/m	3…
3.00	0.30	0.25	0.32	13 φ 16 m/m	11 φ 12 m/m	4…

(1) Costs listed above are for square openi…

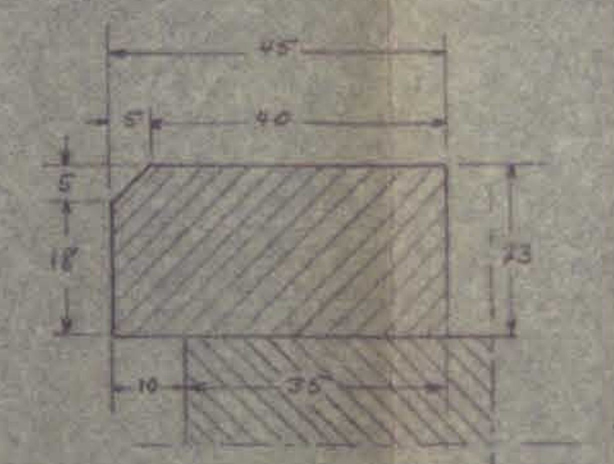
TABLE OF DIMENSIONS FOR …



½ TOP PLAN (EARTH REMOVED) | ½ PLAN OF FOUNDATION

A

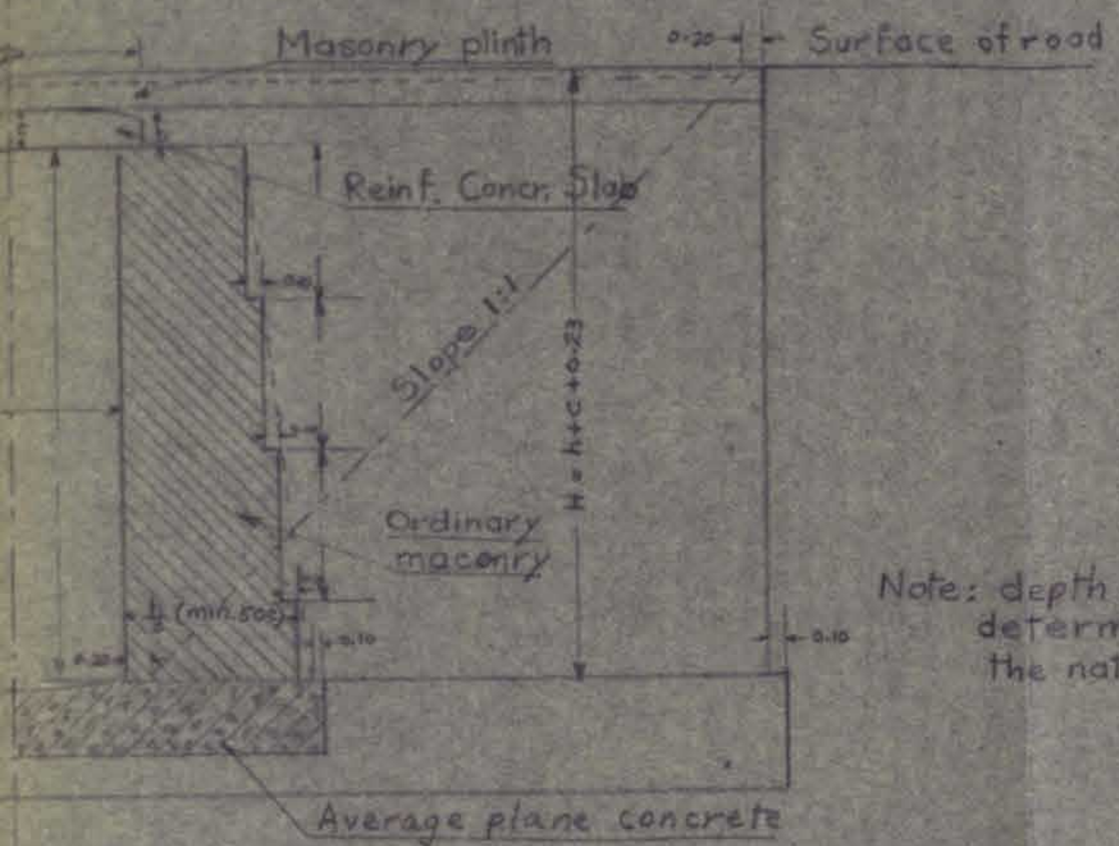
REINFORCED CONCRETE SLAB



DETAIL OF PLINTH

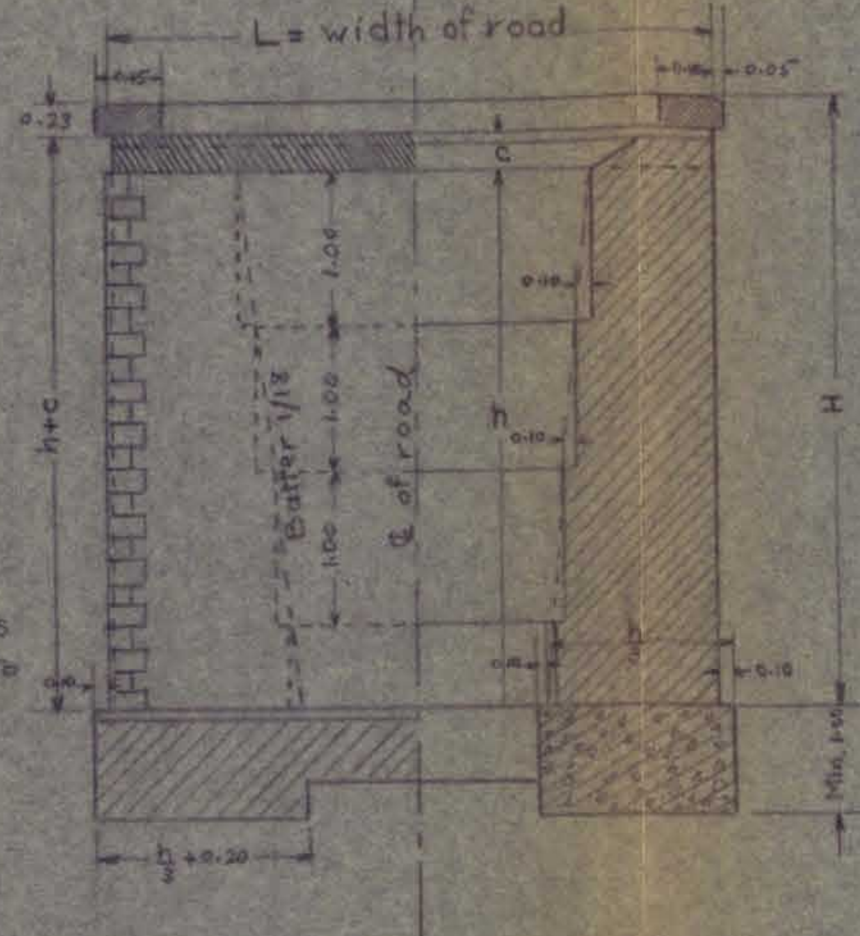
Scale 1:…

PROJ…
STAN…
D…
D…



LONGITUDINAL SECTION

Note: depth of foundations is determined according to the nature of the soil.

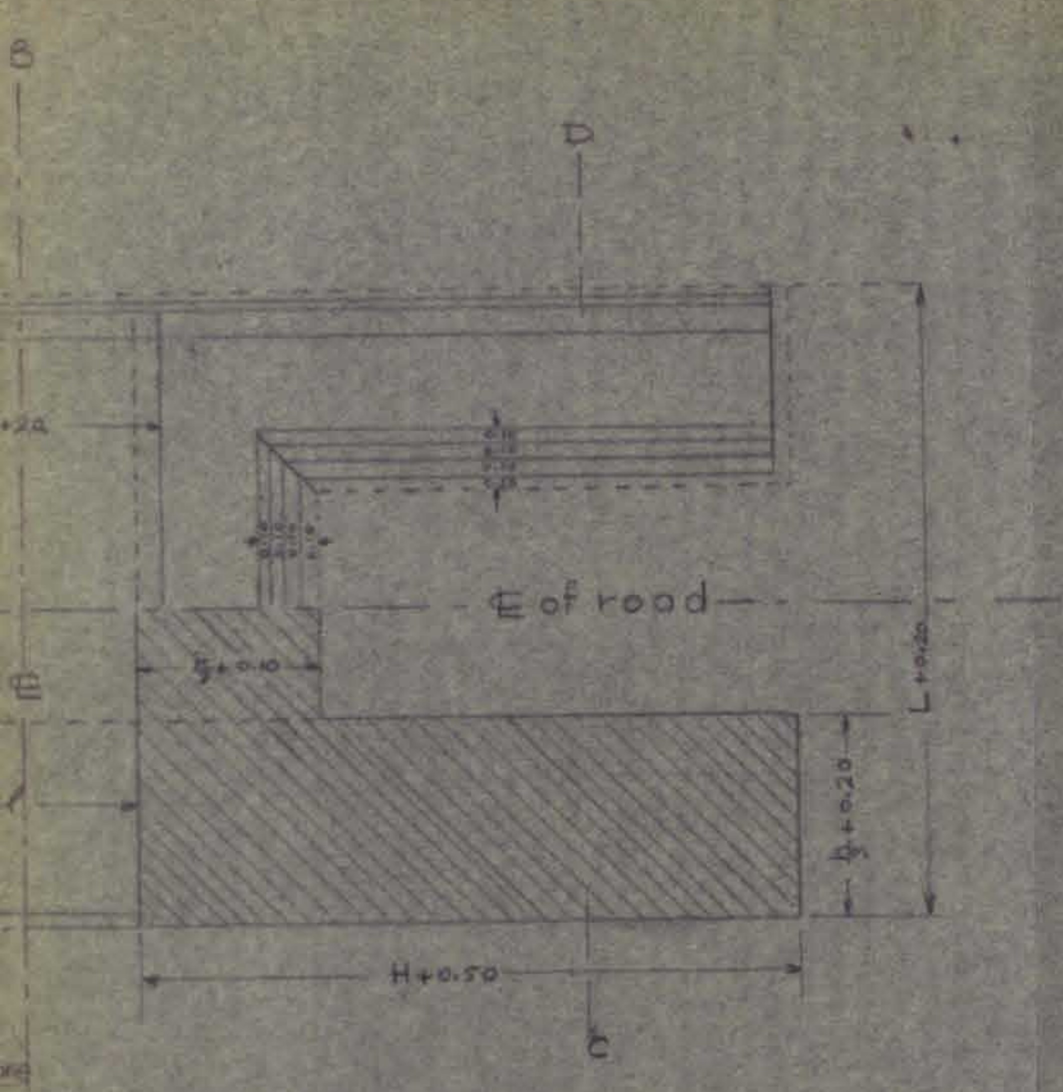


SECTION A-B | SECTION C-D

SPAN ℓ	a	b	c	REINFORCEMENT "A" bars	REINFORCEMENT "B" bars	APPR. COST PER MR in L.L.(1)
0.60 m	0.10	0.10	0.13	10 φ 10 m/m	10 φ 8 m/m	61.00
1.00	0.15	0.14	0.20	10 φ 14 m/m	13 φ 8 m/m	114.00
1.50	0.15	0.16	0.24	11 φ 14 m/m	11 φ 10 m/m	176.00
2.00	0.15	0.20	0.28	13 φ 16 m/m	14 φ 10 m/m	211.00
2.50	0.20	0.23	0.30	11 φ 16 m/m	14 φ 10 m/m	365.00
3.00	0.30	0.25	0.32	13 φ 16 m/m	11 φ 12 m/m	440.00

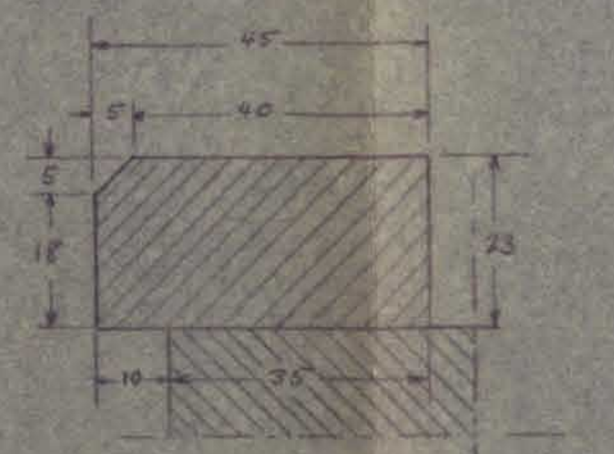
(1) Costs listed above are for square openings.

TABLE OF DIMENSIONS FOR SLAB



½ PLAN OF FOUNDATION

REINFORCED CONCRETE SLAB



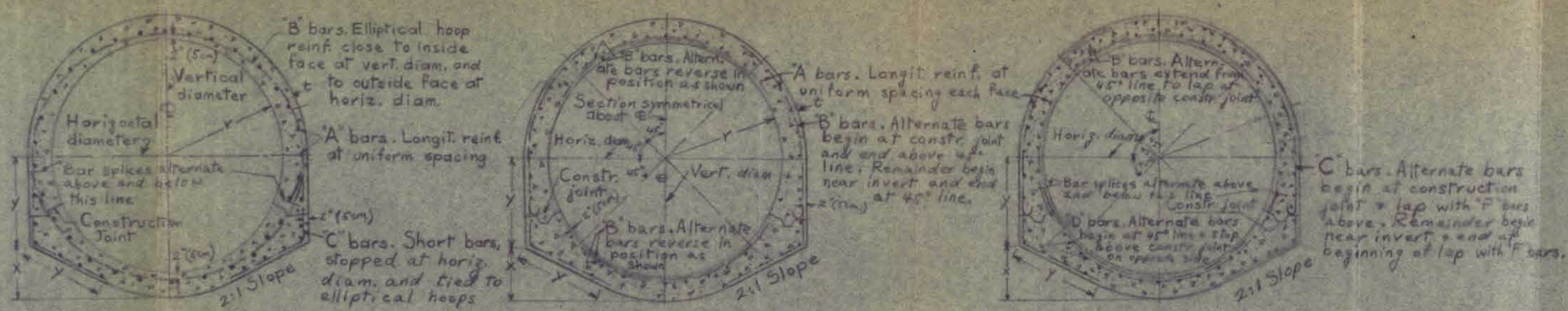
DETAIL OF PLINTH

Scale 1:10

SCHOOL OF ENGINEERING – A.U.B.
PROJECT: HIGHWAY DRAINAGE STRUCTURES
STANDARD SLAB-TOP CULVERTS IN LEBANON
DRAWN BY: SADEK KUWATLY
DATE: MAY 20, 1953 SHEET 4 OF 6

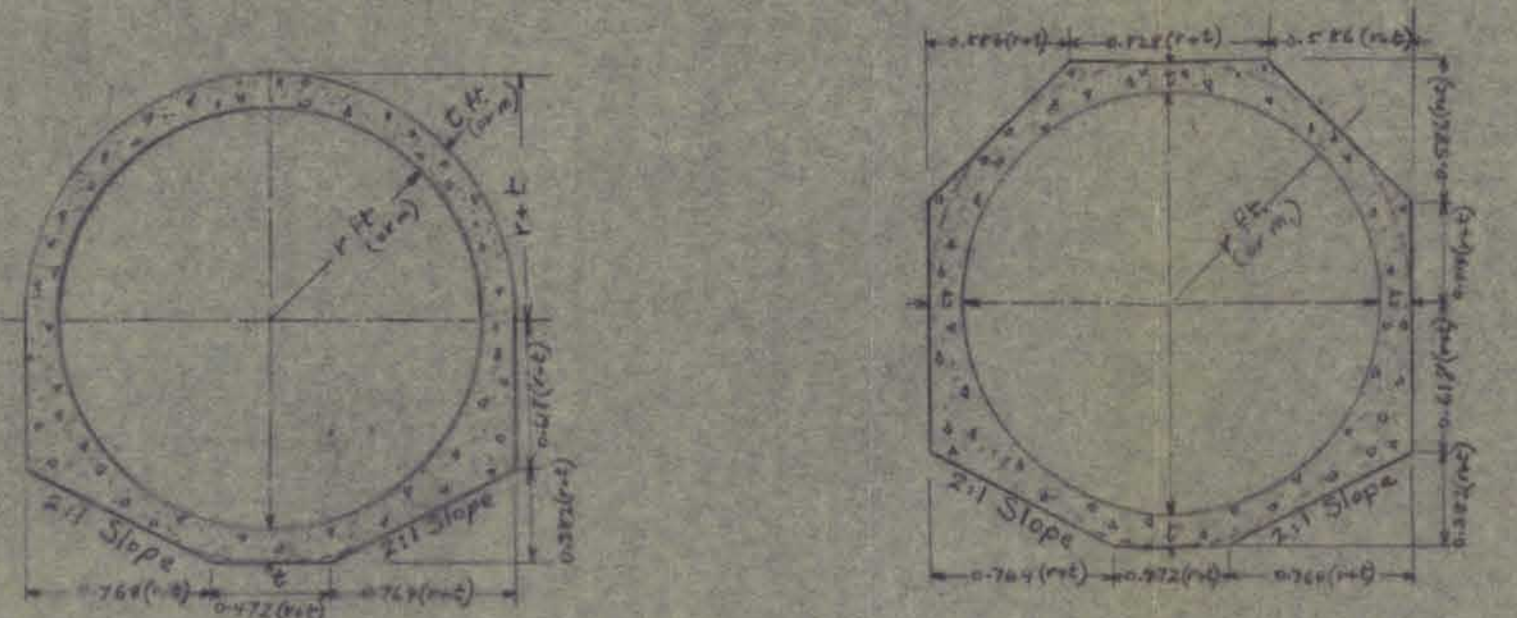
STANDARD DESIGNS OF PIPE CULVERTS FOR 15-TON LOADING

WATERWAY OPENING		DEPTH OF COVER		SECTION TYPE (See Fig.(i))	DIMENSIONS								TRANSVERSE REINFORCEMENT																LONG. REINF.				VOLUME OF CONCRETE		APPROX. COST PER M.R.
					r		t		x		y		"B" BARS				"C" BARS				"D" BARS				"F" BARS				"A" BARS						
													Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.				
ft²	m²	ft	m.		ft	m.	in.	cm.	ft-in	m.	ft-in.	m.	in.	mm	in.	cm.	in.	mm	in.	cm.	in	mm	in	cm	in.	mm	in.	cm	in.	mm	in.	cm	ft³/lin.ft	m³/MR	L.L. or L.S.
28.3	2.63	1.5-5	0.50-1.50	Sec.A	3	0.92	6	15	1-4	0.41	2-2	0.66	1/2	12	6	15	1/2	12	12	30	--	--	--	--	--	--	--	--	1/2	12	15	37	11.8	1.095	137.00
		5.5-10	1.70-3.00	Sec.A	3	0.92	6	15	1-4	0.41	2-2	0.66	1/2	12	5½	13	1/2	12	11	27	--	--	--	--	--	--	--	--	1/2	12	15	37	11.8	1.095	137.00
		10.5-15	3.20-4.50	Sec.A	3	0.92	7	18	1-4½	0.42	2-2½	0.67	9/16	14	6	15	9/16	14	12	30	--	--	--	--	--	--	--	--	1/2	12	12	30	13.7	1.280	160.00
		15.5-20	4.70-6.00	Sec.A	3	0.92	8	20	1-5	0.43	2-3	0.69	9/16	14	5½	13	9/16	14	11	27	--	--	--	--	--	--	--	--	1/2	12	12	30	15.7	1.460	183.00
50.3	4.67	1.5-5	0.50-1.50	Sec.A	4	1.20	7	18	1-9	0.53	2-10	0.86	9/16	14	5½	13	9/16	14	11	27	--	--	--	--	--	--	--	--	1/2	12	12	30	18.4	1.710	214.00
		5.5-10	1.70-3.00	Sec.A	4	1.20	8	20	1-9½	0.55	2-10½	0.87	9/16	14	5½	13	9/16	14	11	27	--	--	--	--	--	--	--	--	1/2	12	12	30	20.9	1.940	243.00
		10.5-15	3.20-4.50	Sec.A	4	1.20	9	23	1-10	0.56	2-11	0.89	5/8	16	6	15	5/8	16	12	30	--	--	--	--	--	--	--	--	9/16	14	14	35	23.5	2.180	272.00
		15.5-20	4.70-6.00	Sec.A	4	1.20	10	25	1-10	0.56	3-0	0.92	5/8	16	5	12	9/16	14	10	25	--	--	--	--	--	--	--	--	9/16	14	12	30	26.1	2.420	303.00
78.5	7.29	1.5-5	0.50-1.50	Sec.A	5	1.50	8	20	2-2	0.66	3-6	1.07	5/8	16	5½	13	9/16	14	11	27	--	--	--	--	--	--	--	--	1/2	12	12	30	26.5	2.460	308.00
		5.5-10	1.70-3.00	Sec.A	5	1.50	9	23	2-2½	0.67	3-6½	1.08	3/4	18	7	17	5/8	16	14	35	--	--	--	--	--	--	--	--	9/16	14	14	35	29.6	2.745	344.00
		10.5-15	3.20-4.50	Sec.A	5	1.50	11	28	2-3	0.69	3-8	1.12	3/4	18	6½	16	5/8	16	13	32	--	--	--	--	--	--	--	--	9/16	14	12	30	36.0	3.340	418.00
		15.5-20	4.70-6.00	Sec.A	5	1.50	12	30	2-3½	0.70	3-8½	1.13	3/4	18	6	15	5/8	16	12	30	--	--	--	--	--	--	--	--	9/16	14	11	27	39.2	3.640	455.00
113.1	10.50	1.5-5	0.50-1.50	Sec.A	6	1.85	9	23	2-7	0.79	4-2	1.27	3/4	18	6	15	5/8	16	12	30	--	--	--	--	--	--	--	--	9/16	14	14	35	35.9	3.330	416.00
		5.5-10	1.70-3.00	Sec.A	6	1.85	10	25	2-7½	0.80	4-2½	1.28	3/4	18	5½	13	5/8	16	11	27	--	--	--	--	--	--	--	--	9/16	14	12	30	39.6	3.680	460.00
		10.5-15	3.20-4.50	Sec.A	6	1.85	12	30	2-8	0.82	4-4	1.32	7/8	22	7	17	3/4	18	14	35	--	--	--	--	--	--	--	--	5/8	16	13	32	47.1	4.370	546.00
		15.5-20	4.70-6.00	Sec.B	6	1.85	13	33	2-8½	0.83	4-4½	1.33	7/8	22	6	15	7/8	22	7	17	7/8	22	6	15	5/8	16	14	35	5/8	16	12	30	51.0	4.730	592.00
153.9	14.30	1.5-5	0.50-1.50	Sec.A	7	2.15	11	28	3-0½	0.93	4-10½	1.49	3/4	18	5½	13	5/8	16	11	27	--	--	--	--	--	--	--	--	9/16	14	12	30	51.0	4.730	592.00
		5.5-10	1.70-3.00	Sec.A	7	2.15	12	30	3-0½	0.93	4-11½	1.51	3/4	18	5	12	5/8	16	10	25	--	--	--	--	--	--	--	--	5/8	16	13	32	55.3	5.130	642.00
		10.5-15	3.20-4.50	Sec.B	7	2.15	14	36	3-1½	0.95	5-0½	1.54	7/8	22	6	15	7/8	22	6½	16	7/8	22	6½	16	5/8	16	13	32	5/8	16	12	30	64.1	5.950	745.00
		15.5-20	4.70-6.00	Sec.B	7	2.15	16	40	3-2	0.97	5-2	1.58	7/8	22	6	15	7/8	22	6	15	7/8	22	6	15	5/8	16	12	30	3/4	18	14	35	73.1	6.790	849.00



(a) SECTION A (b) SECTION A - ALTERNATE (c) SECTION B

Fig.(i). TRANSVERSE SECTIONS



(a) (b)

Fig.(ii). ALTERNATE SECTIONS

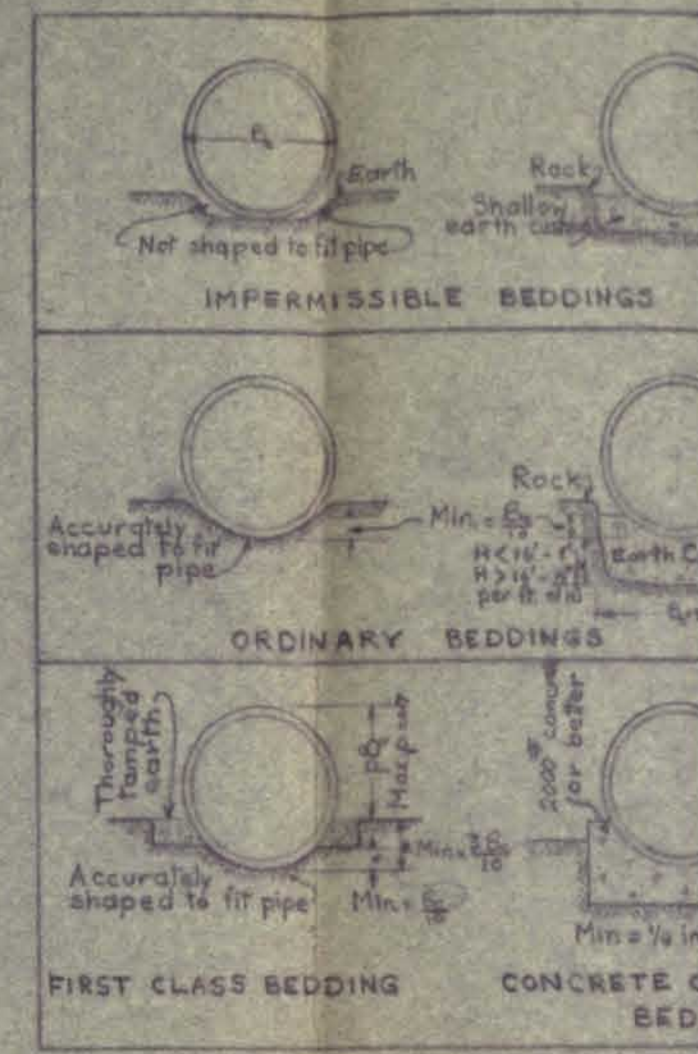


Fig.(iii). TYPES OF PROJECTION B

H = Fill above top of pipe
B_c = Outside diameter of pipe
p = Ratio of vert. height of pipe above embankment subgrade level to B_c

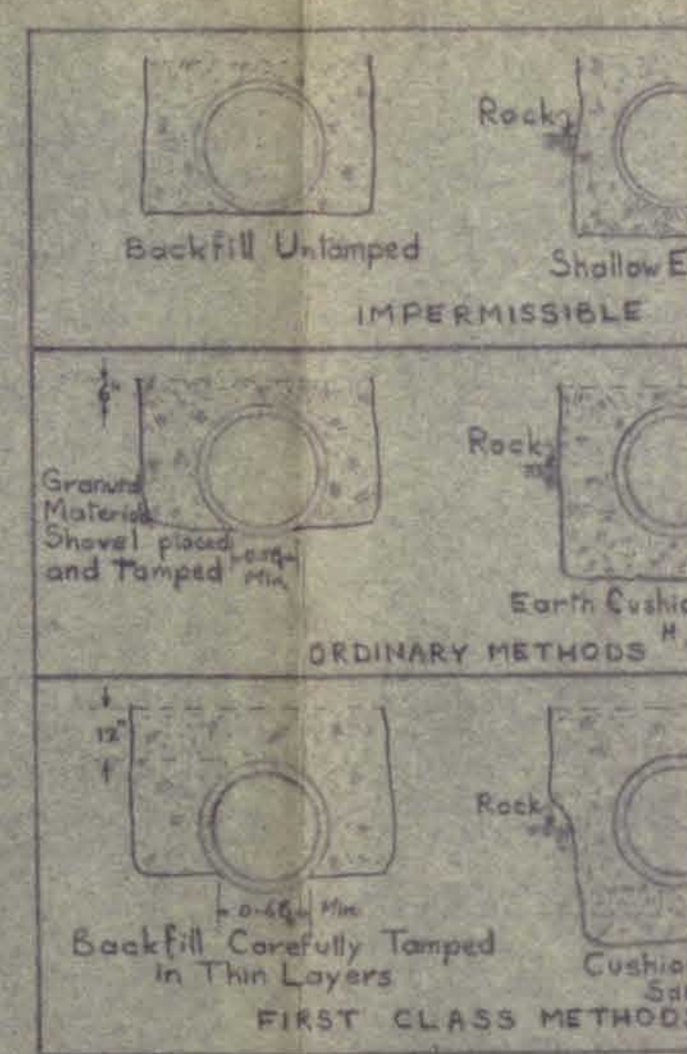


Fig.(iv). TYPES OF PIPE-LAYING M

SCHO
PROJECT: H
STAN
DRAWN
DATE: MAY 2

D DESIGNS OF PIPE CULVERTS FOR 15-TON LOADING

DIMENSIONS							TRANSVERSE REINFORCEMENT																LONG. REINF.				VOLUME OF CONCRETE		APPROX. COST PER M.R.
							"B" BARS				"C" BARS				"D" BARS				"F" BARS				"A" BARS						
r	t		x		y		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.		Size		Spac.				
m.	in.	cm.	ft-in.	m.	ft-in.	m.	in.	mm	in.	cm.	in.	mm	in.	cm	in	mm	in	cm	in.	mm	in.	cm	in	mm	in.	cm	ft³/lin. ft	m³/MR	L.L. or L.S.
0.92	6	15	1-4	0.41	2-2	0.66	1/2	12	6	15	1/2	12	12	30	---	---	---	---	---	---	---	---	1/2	12	15	37	11.8	1.095	137.00
0.92	6	15	1-4	0.41	2-2	0.66	1/2	12	5 1/2	13	1/2	12	11	27	---	--	--	--	--	--	--	--	1/2	12	15	37	11.8	1.095	137.00
0.92	7	18	1-4 1/2	0.42	2-2 1/2	0.67	9/16	14	6	15	9/16	14	12	30	--	--	--	--	--	--	--	--	1/2	12	12	30	13.7	1.280	160.00
0.92	8	20	1-5	0.43	2-3	0.69	9/16	14	5 1/2	13	9/16	14	11	27	--	--	--	--	--	--	--	--	1/2	12	12	30	15.7	1.460	183.00
1.20	7	18	1-9	0.53	2-10	0.86	9/16	14	5 1/2	13	9/16	14	11	27	--	--	--	--	--	--	--	--	1/2	12	12	30	18.4	1.710	214.00
1.20	8	20	1-9 1/2	0.55	2-10 1/2	0.87	9/16	14	5 1/2	13	9/16	14	11	27	--	--	--	--	--	--	--	--	1/2	12	12	30	20.9	1.940	243.00
1.20	9	23	1-10	0.56	2-11	0.89	5/8	16	6	15	5/8	16	12	30	--	--	--	--	--	--	--	--	9/16	14	14	35	23.5	2.180	272.00
1.20	10	25	1-10	0.56	3-0	0.92	5/8	16	5	12	9/16	14	10	25	--	--	--	--	--	--	--	--	9/16	14	12	30	26.1	2.420	303.00
1.50	8	20	2-2	0.66	3-6	1.07	5/8	16	5 1/2	13	9/16	14	11	27	--	--	--	--	--	--	--	--	1/2	12	12	30	26.5	2.460	308.00
1.50	9	23	2-2 1/2	0.67	3-6 1/2	1.08	3/4	18	7	17	5/8	16	14	35	--	--	--	--	--	--	--	--	9/16	14	14	35	29.6	2.745	344.00
1.50	11	28	2-3	0.69	3-8	1.12	3/4	18	6 1/2	16	5/8	16	13	32	--	--	--	--	--	--	--	--	9/16	14	12	30	36.0	3.340	418.00
1.50	12	30	2-3 1/2	0.70	3-8 1/2	1.13	3/4	18	6	15	5/8	16	12	30	--	--	--	--	--	--	--	--	9/16	14	11	27	39.2	3.640	455.00
1.85	9	23	2-7	0.79	4-2	1.27	3/4	18	6	15	5/8	16	12	30	--	--	--	--	--	--	--	--	9/16	14	14	35	35.9	3.330	416.00
1.85	10	25	2-7 1/2	0.80	4-2 1/2	1.28	3/4	18	5 1/2	13	5/8	16	11	27	--	--	--	--	--	--	--	--	9/16	14	12	30	37.6	3.680	460.00
1.85	12	30	2-8	0.82	4-4	1.32	7/8	22	7	17	3/4	18	14	35	--	--	--	--	--	--	--	--	5/8	16	13	32	47.1	4.370	546.00
1.85	13	33	2-8 1/2	0.83	4-4 1/2	1.33	7/8	22	6	15	7/8	22	7	17	7/8	22	6	15	5/8	16	14	35	5/8	16	12	30	51.0	4.730	592.00
2.15	11	28	3-0 1/2	0.93	4-10 1/2	1.49	3/4	18	5 1/2	13	5/8	16	11	27	--	--	--	--	--	--	--	--	9/16	14	12	30	51.0	4.730	592.00
2.15	12	30	3-0 1/2	0.93	4-11 1/2	1.51	3/4	18	5	12	5/8	16	10	25	--	--	--	--	--	--	--	--	5/8	16	13	32	55.3	5.130	642.00
2.15	14	36	3-1 1/2	0.95	5-0 1/2	1.54	7/8	22	6	15	7/8	22	6 1/2	16	7/8	22	6 1/2	16	5/8	16	13	32	5/8	16	12	30	64.1	5.950	745.00
2.15	16	40	3-2	0.97	5-2	1.58	7/8	22	6	15	7/8	22	6	15	7/8	22	6	15	5/8	16	12	30	3/4	18	14	35	73.1	6.790	849.00

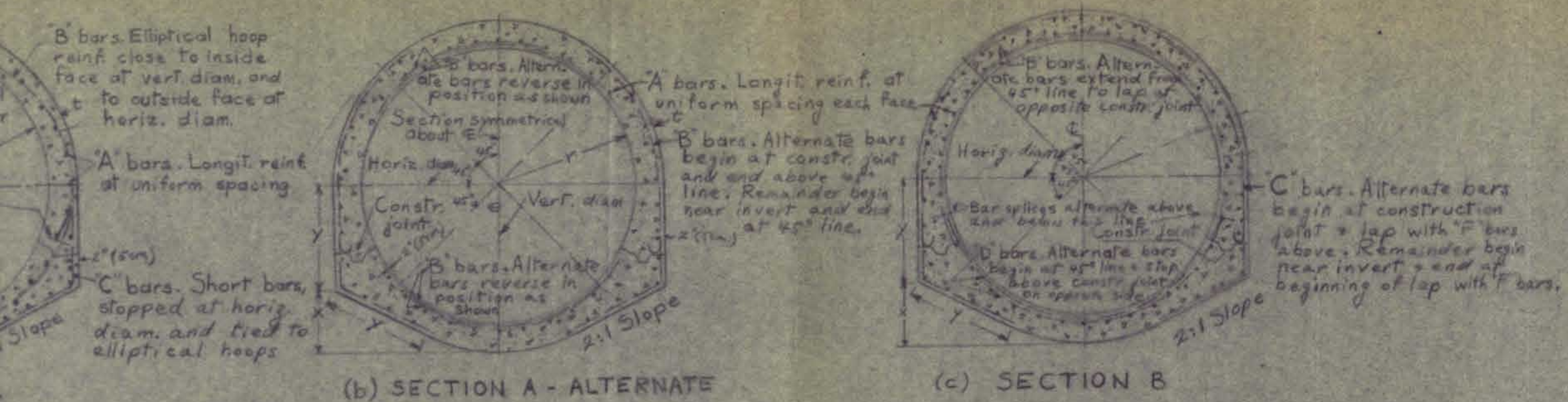


Fig.(i). TRANSVERSE SECTIONS

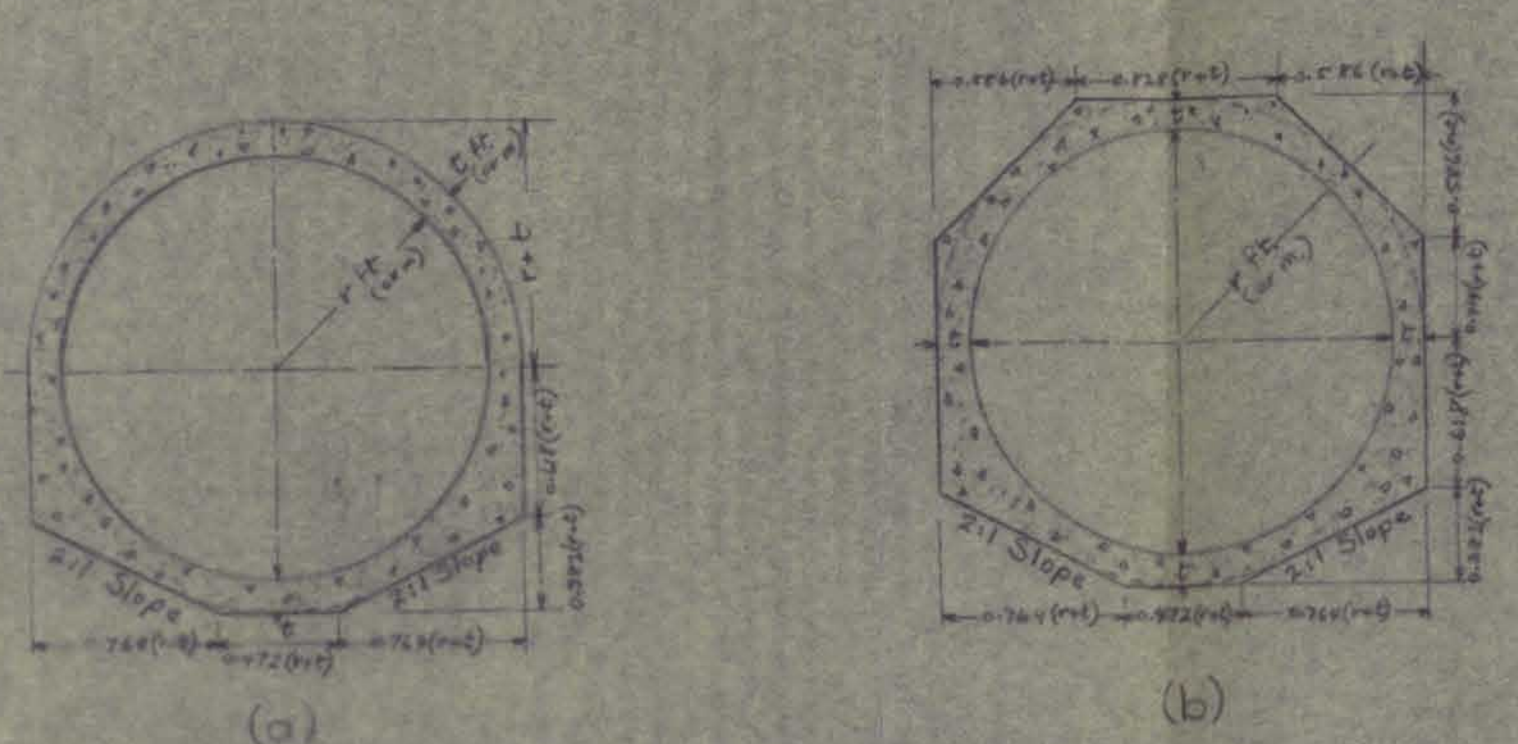


Fig.(ii). ALTERNATE SECTIONS

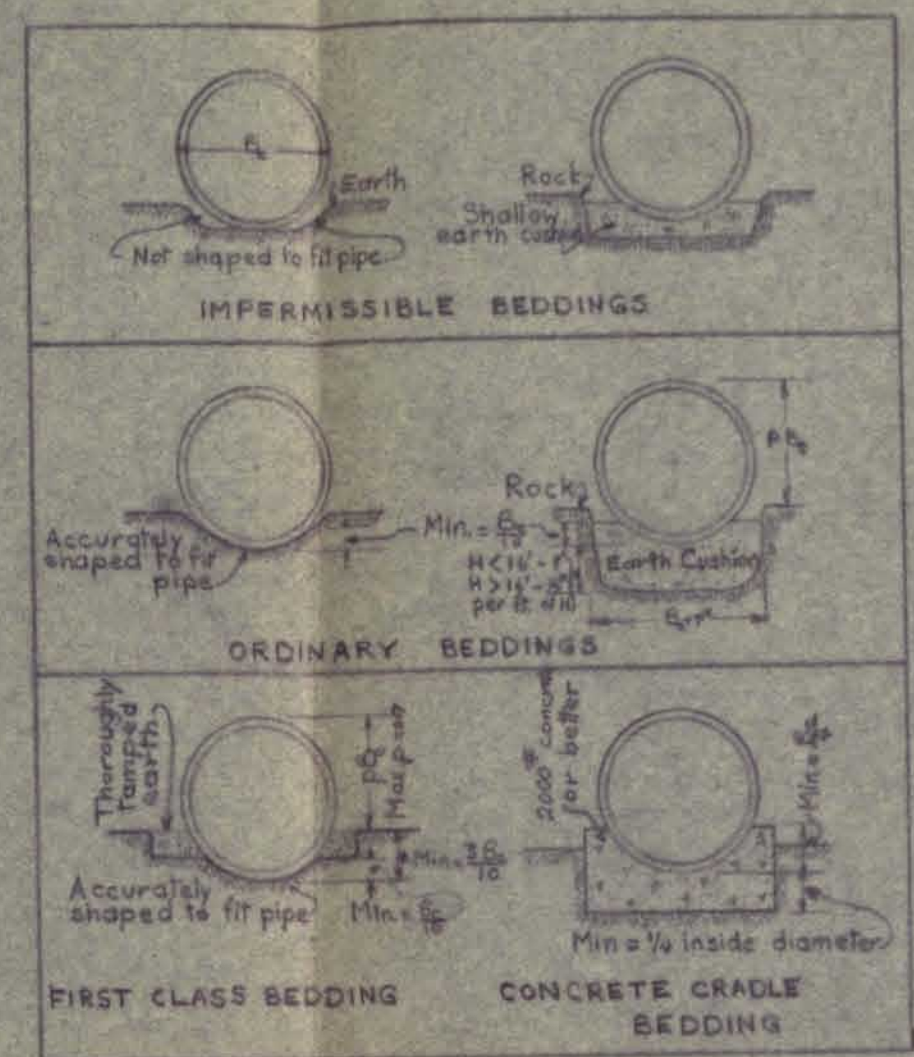


Fig.(iii). TYPES OF PROJECTION BEDDING

H = Fill above top of pipe
B_c = Outside diameter of pipe
p = Ratio of vert. height of pipe above embankment subgrade level to B_c

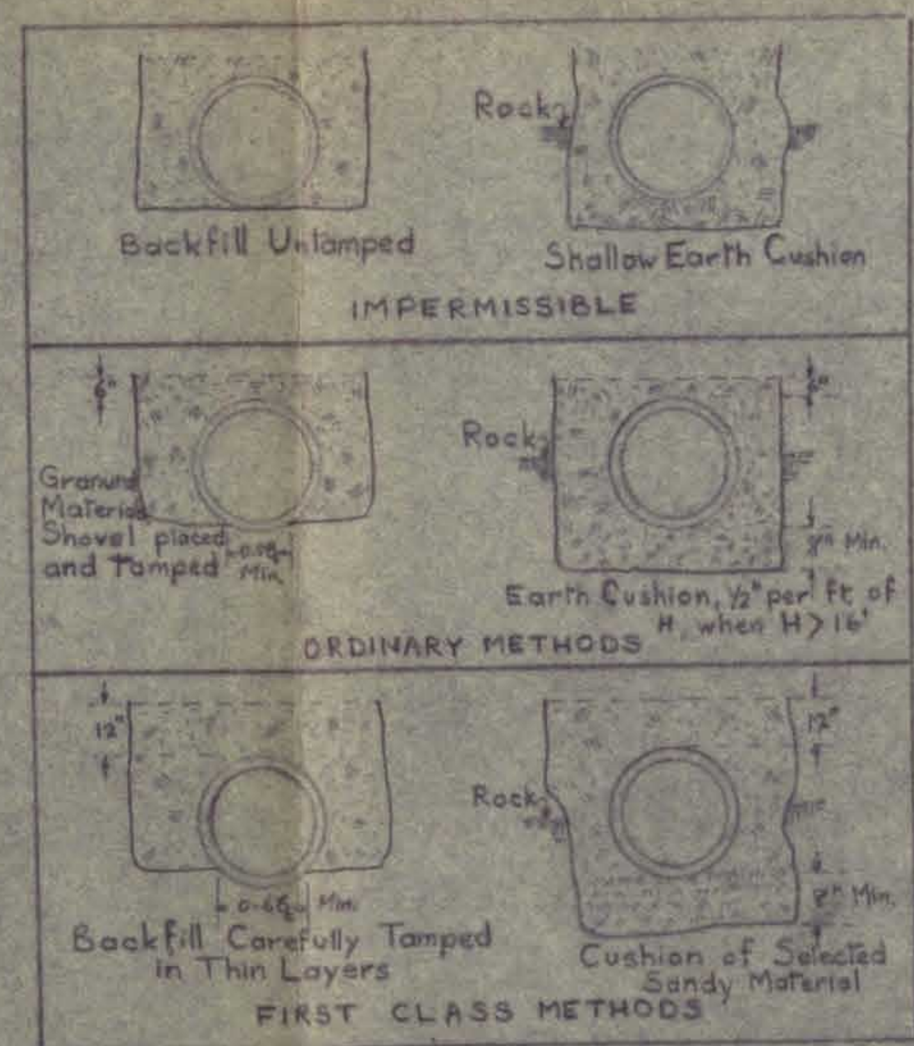


Fig.(iv). TYPES OF PIPE-LAYING METHODS IN DITCHES

SCHOOL OF ENGINEERING_ A.U.B.
PROJECT: HIGHWAY DRAINAGE STRUCTURES
STANDARD PIPE CULVERT
DRAWN BY: SADEK KUWATLY
DATE: MAY 20, 1953 SHEET 5 OF 6