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Modifying Standard Design and Construction Procedure for Culverts

Dr. Bassam A. Ghulman

Ass. Professor, Civil Engineering Department, Umm Al-Qura University
P.O.Box 9125, Makkah 21955, Saudi Arabia
E-Mail: ghulman@hotmail.com

تطوير أسلوب قياسي لتصميم عبارات تصريف مياه الأمطار و السيول وتشييدها

يهتم مخططو المدن و مديرو المشاريع فيها و منفذو برامجها التطويرية بكل ما مـن شـأنه تقـديم الخدمات الضرورية لقاطنيها و توفير سبل الراحة لهم عن طريق تنفيذ مشاريع المتطلبات الأساسية و البنـى التحتية إضافة إلى ما يرتبط بتلك المشاريع من أعمال تضمن حمايتها و حماية أرواح مستخدميها و الممتلكات المرتبطة بها في مواجهة ما قد يعترضها من مخاطر جراء بعض الظواهر الطبيعية.

و تعتبر المخاطر الناجمة عن تدفق مياه الأمطار و السيول من أكثر ما يثير اهتمـام المـسئولين و بالأخص في المناطق و المدن ذات الطبيعة الجغرافية و التضاريس السطحية و الظروف المناخية المـساعدة على تجمع تلك المياه و تدفقها بمعدلات و سرعات و كميات كبيرة، و ذلك لما لها من آثار مدمرة على ما قد يعترض مسارها من منشآت و مرافق ، وعلى وجه التحديد شبكات الطرق و خطوط النقل و المواصـلات، الأمر الذي دعا المسئولين و المختصين إلى التفكير بجدية في حماية تلك المشاريع و مستخدميها و خصوصا الطرق من خلال إنشاء عبارات (مجاري) تصريف تضمن تجميع مياه الأمطار و السيول و تأمين مـسارات مناسبة لها تحت الطرق و خطوط النقل، بحيث يتحقق هدف حماية تلك الطـرق و عـدم تـأثر أجزاءهـا و مكوناتها من جراء تدفق المياه إضافة إلى حماية مرتادي تلك الطرق و مستخدميها.

و يتناول هذا البحث موضوع عبارات التصريف من جوانب عدة ابتداءا من التعريـف بـدورها و وظيفتها و أهميتها و أنواعها المختلفة، مرورا بإيضاح الأجزاء الرئيسية المكونة لها و دور كل جزء فيهـا، انتهاءا بتطوير خطوات و آلية تصميم و تشييد قياسية (نموذجية) لتلك العبارات بأجزائها و مكوناتها المختلفة و التي كان من أهمها: الفرشة الخرسانية، الأنابيب الخرسانية، التغطية الخرسانية للأنابيب، الحوائط الساندة، و حجار (صخور) الحماية و التجميل. و لغرض تطبيق المعادلات الرياضية ذات العلاقة و إتمام العمليـات الحسابية، فلقد تم اعتماد عدة فرضيات من مصادر مختلفة تمت الإشارة لها في مواقع استخدامها بحيث يمكن

لمستخدم تلك العلاقات أو النموذج الذي تم التوصل إليه في هذا البحث أن يجري عليها التعـديل أو التغييـر المناسب (إن لزم الأمر) بما يتوافق مع وضع المنطقة المراد تطبيق الآلية و النموذج فيها.

Abstract

City planners, project managers, and development program executers usually pay attention to the top necessities and classify them in accordance with a priority scale. Among the top priority subjects in today's world is to have an extensive system to reduce the risk of floods produced by rainwater, especially in areas and locations with terrains and surfaces that help in cumulating them in the form of floods. A part of this system of draining water and reducing floods effects is to drain water through culverts (channel pipes, open channels …etc.) and make the roads pass above them.

Culverts are considered to be means used to avoid the damages of the floods on the roads. Because of the risk of floods and rainwater against the roads and the infrastructure in cities, the paper aims to help avoid these risks by modifying a standard design procedure for different parts of culverts. In other words, the main objective of the paper is to define culverts, forms, types, and their main parts and segments; and modify a standard design and construction procedure for each major part or segment in the culvert.

For the sake of the correct usage and application of the related mathematical equations and formulas, several assumptions are made. These assumptions are obtained and achieved from different mentioned sources to enable the user to alter them in such a way that suits the situation of the location for which the procedure is to be applied.

Key words: Construction, Culverts, Concrete Pipes, Blinding Concrete, Retaining Walls, Riprap Stones.

INTRODUCTION

People who are in charge of city management usually pay attention to the top necessities and classify them in accordance with a priority scale. Among the top priority subjects in today's world is to have an extensive system to reduce the risk of floods produced from the gathered rainwater in the bottom of valleys. A part of this system of draining water and reducing floods effects is to drain water through culverts (channel pipes…etc.) and make the roads pass above them.

Culverts are considered to be means used to avoid the damages of the floods on the roads, see figure 1.

(Figure 1) Effect of floods on roads
(Location: Makkah – Arafat road no.2)

Culverts may face some problems that affect their operation and the purposes for which they were designed and constructed. These problems arise from two reasons:

First: Error in Design:

Lack of comprehensive studies and experience results in errors in estimating the required size of culverts. Errors in determining the size of the water drainage pipes are the most noticed and committed errors by designers, which lessen the benefit of these culverts. When the size of water drainage pipes are smaller than what is required, they do not effectively drain the flowing water, which may cause flood on the surface of the road and consequently leads to scratch embankment under the road. This makes the layers of asphalt fall and may also cause complete or partial settlement of the road, see figure 2.

(Figure 2) Effect of size of culvert
(Location: Makkah – Arafat road no.2)

Second: Error in Execution:

These errors often take place during the execution of culverts projects. This kind of errors occurs as a result of little experience and competency of the execution team (contractor), lack of supervision, or unqualified workforce in executing this kind of project.

Executing the level of culvert over or below the level of the ground surface is one the most common errors of this type of construction. Executing culverts with a level higher than the ground surface may cause digging under the blinding concrete that receives water, and this leads to the collapse of the culvert, see figure 3.

(Figure 3) A level of culvert higher than the level of ground surface.
(Location: Makkah – Arafat road no.2)

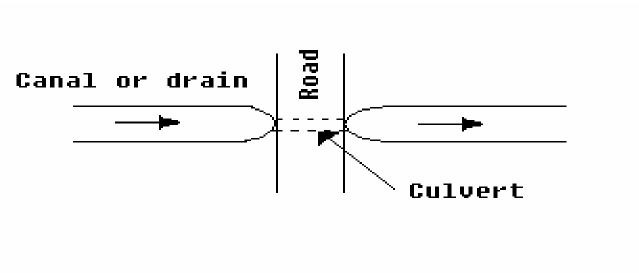
OBJECTIVES

Because of the risk of floods and rainwater against roads and the infrastructure in cities, this paper is prepared to help in avoiding these risks by modifying a standard design procedure for different parts of culverts. In other words, the main objectives of the paper are:

1- Defining culverts, forms, types, and their main parts and segments.
2- Modifying a standard design procedure for each major part or segment in the culvert.

CULVERTS

A **"Culvert"** is simply defined as the construction that carries water under roadways or railways, (see figure 4).



(Figure 4) Culvert position on road.

The major criteria in choosing the type and size of culverts are: the quantity of flowing water through these culverts, the loads above these culverts, and the circumstances of the place in which these culverts are going to serve.

Culverts may be rectangular, circular, trapezoidal, arch or otherwise in shape. They may be made of masonry, metal, concrete, wood or other materials. They may be single or multiple barrel structures, depending on loads to be carried, depth of water in connecting canal and other factors.

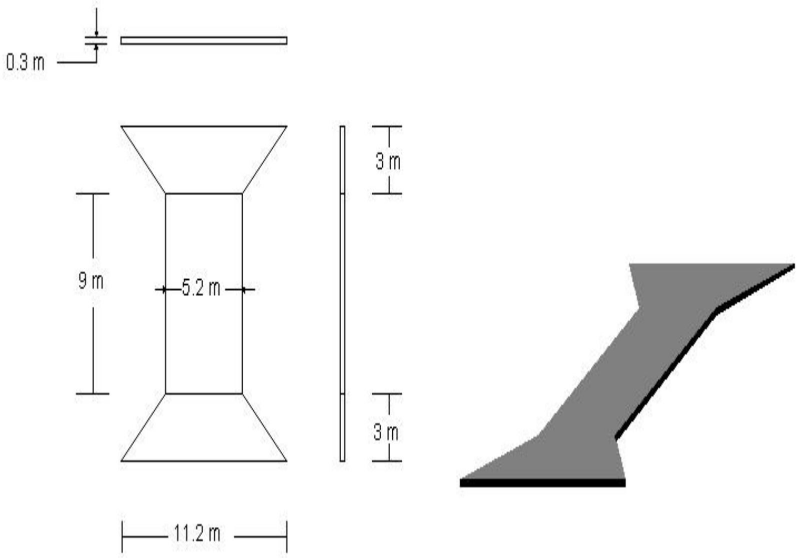
Frequently used metal culverts are usually made of corrugated metal or plate steel monolithic concrete of rectangular shape. Precast concrete of circular shape has the most extended usage for these structures. [Wright, 1996]

ANALYSIS AND DESIGN

1- Blinding Concrete.

It is the plain concrete cast after leveling the site to:

- Isolate the constructed structure against what could affect it, like damaging materials existed in soil (salts, sulfate, …etc.)
- Protect the structure from partial settlement. See figure 5.



(Figure 5) Blinding concrete.

Blinding concrete to be coated with average slope (0.4 - 1)cm/m
The total length of blinding concrete (15m) and the selected slope is (0.7 cm) / m.
The final slope will be:
Slope of blinding concrete = 15 x 0.7 = 10.5 cm.

2- Concrete Pipes.

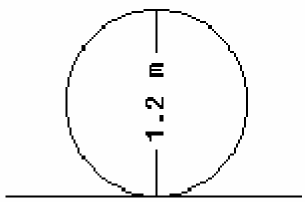
They are pipes made of reinforced concrete, used to drain floods and rainwater, and manufactured with certain specifications such as dimensions, diameters, reinforcement, thickness, and the section shape (circular, rectangular.. etc.). They are available from pipes manufacturing factories.

Assume: $Q_{max} = 6.0\ m^3/sec$
Note: Always
$0.8\ m/sec < V_{culvert} < 2.0\ m/sec$
Use velocity through the culvert = 1.9 m/sec
⟹ Water - area through culvert = $Q_{max} / V_{culvert}$
Area = $(6.0\ m^3/sec) / (1.9\ m/sec)$
Area = $3.16\ m^2$

Try 2 pipes :
$A_{for\ 1pipe} = 3.16 / 2 = 1.6\ m^2$
$D_{for\ 1pipe} = 2.24$ m Not OK

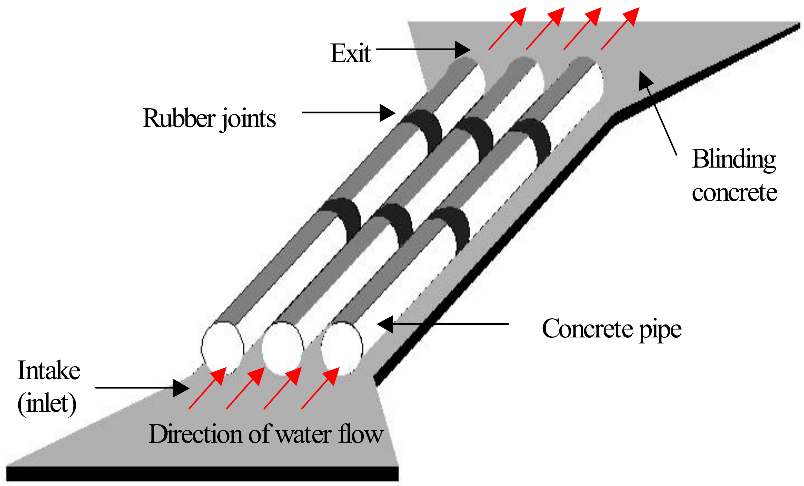
Try 3 pipes :
$A_{for\ 1pipe} = 3.16 / 3 = 1.05\ m^2$
$D_{for\ 1pipe} = 1.16$ m OK Use 1.20 m diameter.

We can choose 3 concrete pipes each diameter 1.2 m
Actual area of pipes = $\pi * (1.2)^2 * 3 / 4 = 3.39\ m^2$
Actual velocity through culvert ($V_{culvert}$) = 6 / 3.39 = 1.77 m/s OK
So, we use 3 pipes , each pipe is as in (figure 6) in size.



(Figure 6) Culvert pipe.

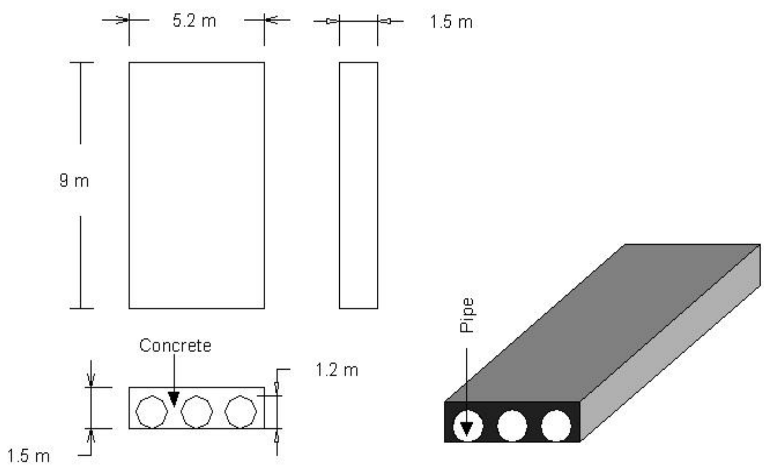
The laying down of pipes above blinding concrete is shown in (figure 7).



(Figure 7) Laying down of pipes above blinding concrete.

3- Covering Pipes with Concrete.

Figure 8 shows pipes when covered with plain concrete in order to protect them against applied stresses.



(Figure 8) Covering pipes of culvert by concrete.

4- Retaining Walls.

Retaining walls are structures at both sides of culvert, which are capable to resist the horizontal stresses and prevent fall of soil at the intake and exit of culvert.

For design purposes, retaining walls can be grouped as follows:

(a) Gravity walls which rely on the mass of the structure to resist overturning.
(b) Cantilever walls, which rely on the bending strength of the cantilevered slab above the base.
(c) Counter-fort walls, which are restrained from overturning by the fort exerted by the mass of the earth behind the wall.
(d) Buttressed walls, which transmit their thrust to the soil through buttresses projecting from the front of the wall.
(e) Tied-back walls, which are restrained from overturning by anchors at one or more levels.
(f) Contiguous bored-pile walls.

The choice of retaining wall is based on the materials available, appearance, the space required, the acting force, and finally cost. Walls used in conjunction with stone-faced buildings or in residential areas and parks are often of brick or stone masonry. Walls in industrial areas or adjacent to bridges and dams are usually concrete. Plain concrete is relatively easy to form and requires no steel but may use excessively large quantities of concrete; reinforced concrete is economical for large structures.

A satisfactory retaining wall must meet the following requirements:

1. The wall must be structurally capable of withstanding the applied earth pressure.
2. The foundation of the wall must be capable of supporting both the weight of the wall and the force resulting from earth pressure acting upon it without:
   a. Overturning or soil failure.
   b. Sliding of the wall and foundation.
   c. Undue settlement. [Wright, 1996]

There are assumptions used to design retaining walls:

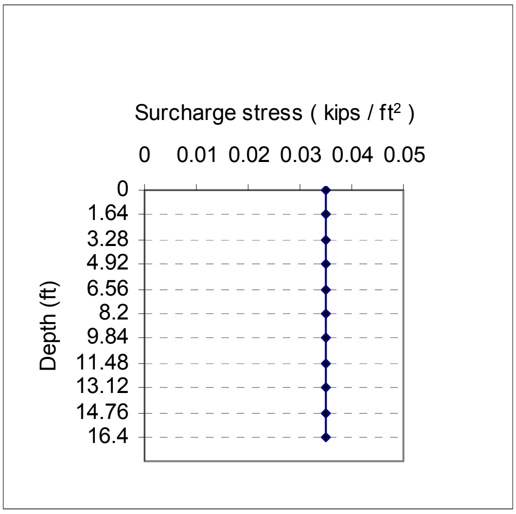
-Unit weight of soil = γ_{soil} = 1.8 ton/m^3 (0.1142 kips/ft^3)
-Depth of retaining walls = 5 m (16.4 ft)
-q = 500 kg/m^2 (0.104 kips/ft^2)

To design retaining walls, we must first find the total stress effect on the wall. Total stress can be estimated by summing:

1- Surcharge stress.
2- Earth stress.
3- Truck wheels stress.

Total stress = Surcharge stress+ Earth stress +Truck wheels stress

Estimating surcharge stress:
Surcharge stress = q . k = 0.104 X 1/3 = 0.0346 kips/ft^2
Where: k = Earth pressure coefficient = 1/3
Note: Surcharge stress is constant at all depths (see figure 9)



(Figure 9) Surcharge stress.

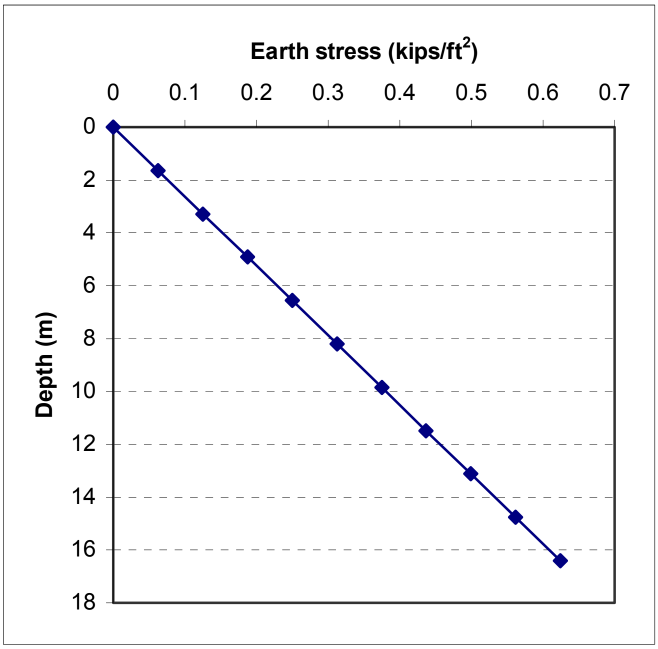
Estimating earth stress:
Earth stress = γ_{soil} . h . k
Where h : the required depth of retaining wall
For example : at depth 1.64 ft (1m)

Earth stress = (0.1142 kips/ft^3) (1.64 ft) (1/3)
= 0.0625 kips/ft^2

Table 1 and figure 10 show the earth stresses at multi depths.

Depth (ft)	**Earth stress (kips/ ft^2)**
0	0
1.64	0.062429
3.28	0.124859
4.92	0.187288
6.56	0.249717
8.2	0.312147
9.84	0.374576
11.48	0.437005
13.12	0.499435
14.76	0.561864
16.4	0.624293

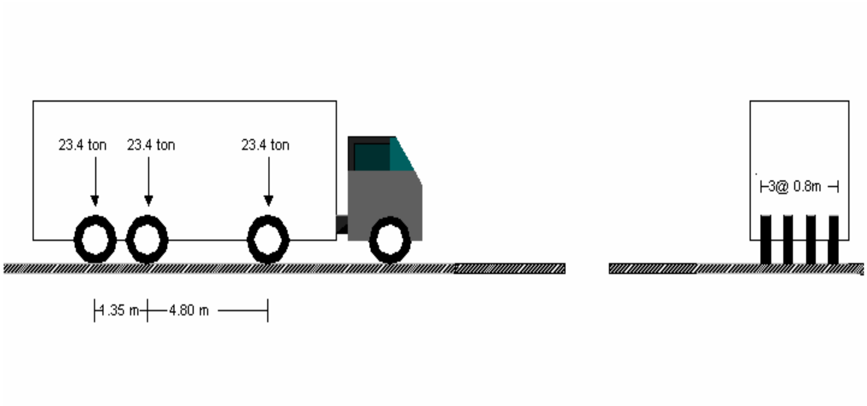
(Table 1) Earth stresses at multi depths.



(Figure 10) Earth stress.

Estimating truck wheels stresses:
Before estimating stress due to truck wheels, we must know the type of truck used in design and its loads and dimensions. [Owais, 1983]

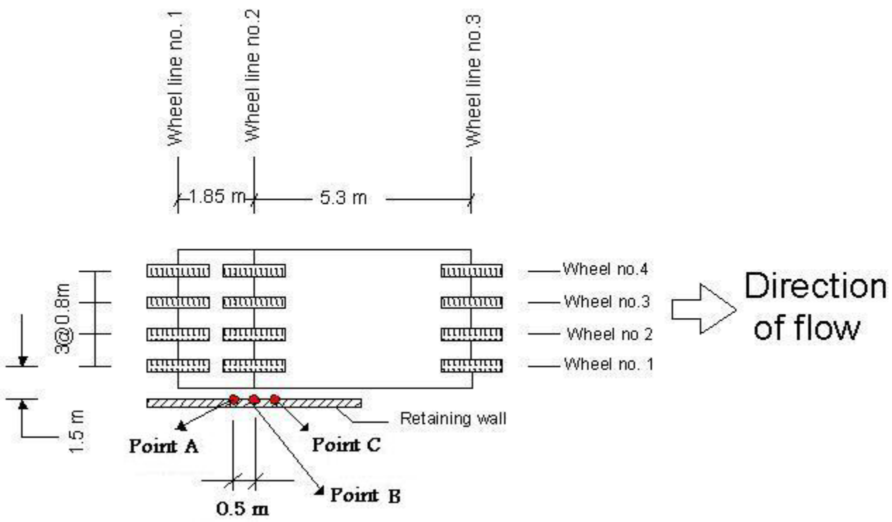
Figure 11 shows the standard lorry truck used in design.



(Figure 11) Standard lorry truck. [Owais, 1983]

To calculate the stress caused by truck wheels, there are many steps taken to calculate this stress:

1- Dividing the rows of wheels in three lines (line 1, line 2 and line 3), see figure 12.



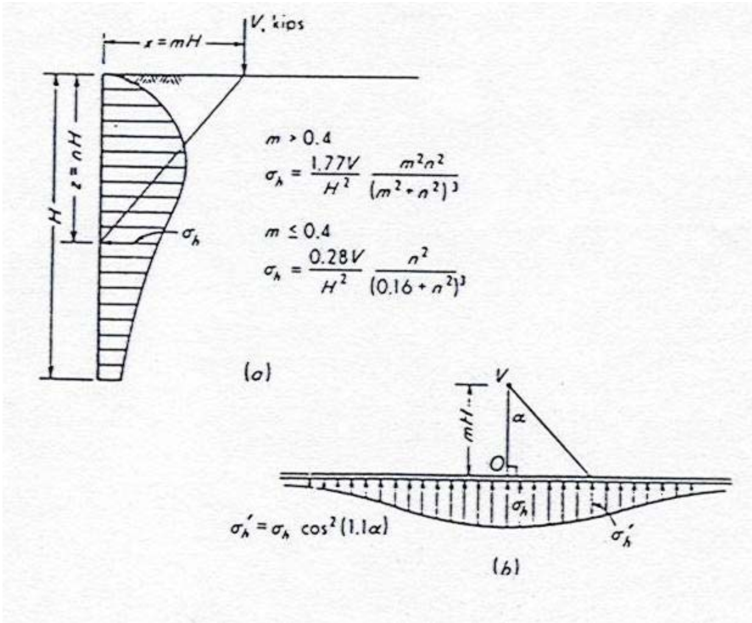
(Figure 12) Distribution of truck wheels.

2- Numbering the wheels for every line (1, 2, 3 and 4).

3- Choose three points A, B and C between the rows of wheels because at this area there is maximum stress. At point A, B and C, we calculate the stress caused by all truck wheels (12 wheels) at multi depths of wall (1.64, 3.25, 4.92, 6.56, 8.20, 9.84, 11.48, 13.12, 14.76 and 16.40 ft).

So, stress at point A, B or C caused by wheel no. 1, 2, 3 or 4 and at any depth, can be calculated by using this method:

a- Calculate the value of σ_h as:



(Figure 13) Distribution of stress due to depths. [Bowles, 1988]

If $m > 0.4$ *then* $\sigma_h = [\,(1.77\,V/H^2)\,.\,\{m^2\,.\,n^2/(m^2+n^2)^3\}\,]$ <u>eq. 1</u>

If $m \leq 0.4$ *then* $\sigma_h = [\,(0.28\,V/H^2)\,.\,\{n^2/(0.16+n^2)^3\}\,]$ <u>eq. 2</u>

Where : $n = z/H$ and $m = x/H$ (See figure 13)

b- *Calculate* $\sigma'_h = \sigma_h\,.\,\cos^2(1.1\alpha)$

Where : $\alpha = \tan^{-1}(y/x)$ [Bowles, 1988]

For point A:

Depth (ft)	∑Effective stress by wheel pressure (kips/ft^2)	Effective stress by surcharge pressure (kips/ft^2)	Effective stress by earth pressure (kips/ft^2)	**ACCUMULATIVE** stresses (kips/ft^2)
0	0	0	0	0
1.64	0.07046	0.034696	0.062429	0.167585
3.28	0.1908	0.034696	0.124859	0.350355
4.92	0.232773	0.034696	0.187288	0.454757
6.56	0.25154	0.034696	0.249717	0.535953
8.2	0.21829	0.034696	0.312147	0.565133
9.84	0.17634	0.034696	0.374576	0.585612
11.48	0.14243	0.034696	0.437005	0.614131
13.12	0.11208	0.034696	0.499435	0.646211
14.76	0.08792	0.034696	0.561864	0.684480
16.4	0.06906	0.034696	0.624293	0.728049

(Table 2) Accumulative stresses by wheels, surcharge and earth pressure at point A.

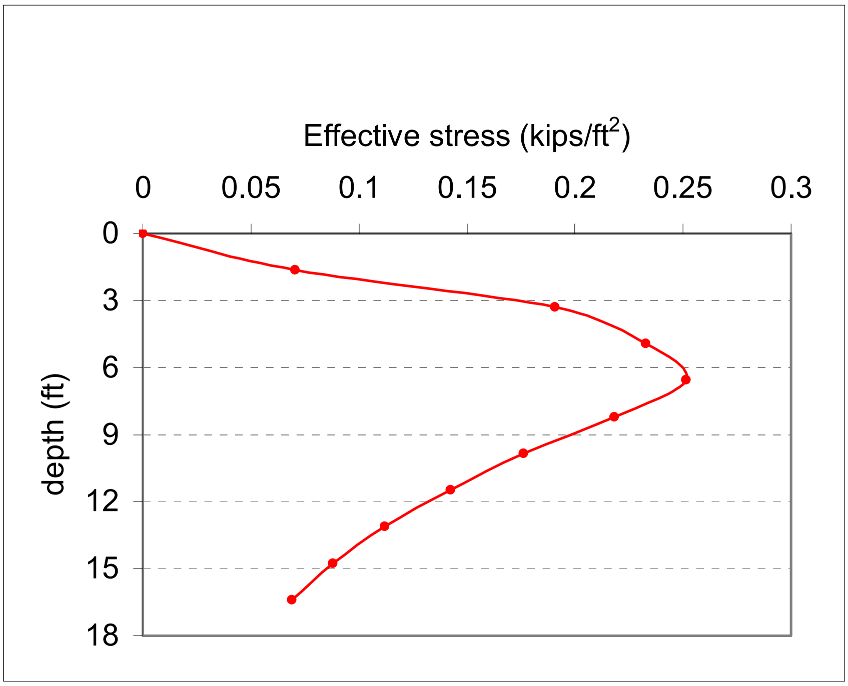
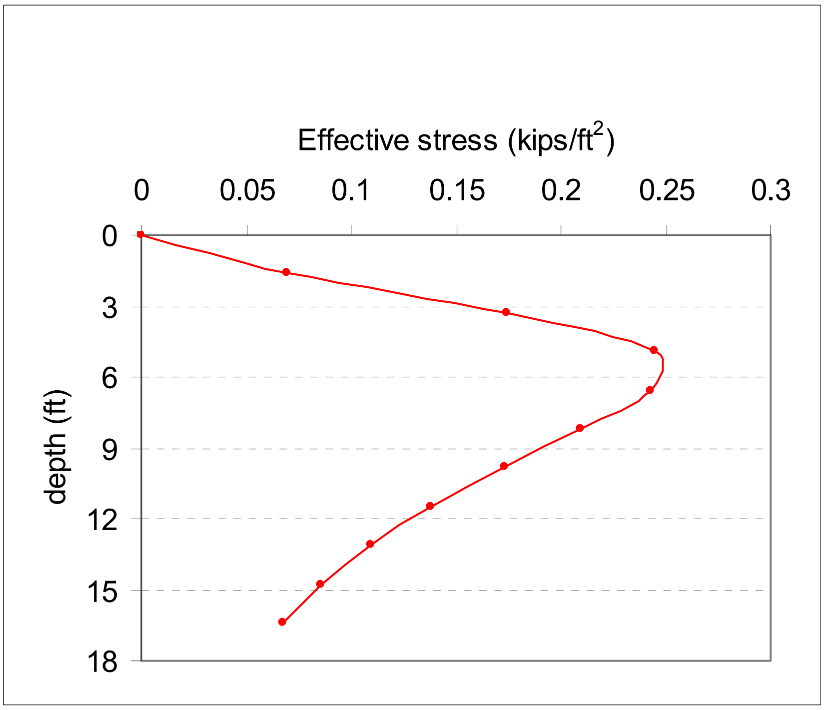


Figure 14 Lateral pressure on wall at point A.

For point B:

Depth (ft)	∑Effective stress by wheel pressure (kips/ft^2)	Effective stress by surcharge pressure (kips/ft^2)	Effective stress by earth pressure (kips/ft^2)	**ACCUMULATIVE** stresses (kips/ft^2)
0	0	0	0	0
1.64	0.06997	0.034696	0.062429	0.167095
3.28	0.17443	0.034696	0.124859	0.333985
4.92	0.24449	0.034696	0.187288	0.466474
6.56	0.24287	0.034696	0.249717	0.527283
8.2	0.20986	0.034696	0.312147	0.556703
9.84	0.17369	0.034696	0.374576	0.582962
11.48	0.137884	0.034696	0.437005	0.609585
13.12	0.10906	0.034696	0.499435	0.643191
14.76	0.08562	0.034696	0.561864	0.68218
16.4	0.06729	0.034696	0.624293	0.726279

(Table 3) Accumulative stresses by wheels, surcharge and earth pressure at point B.

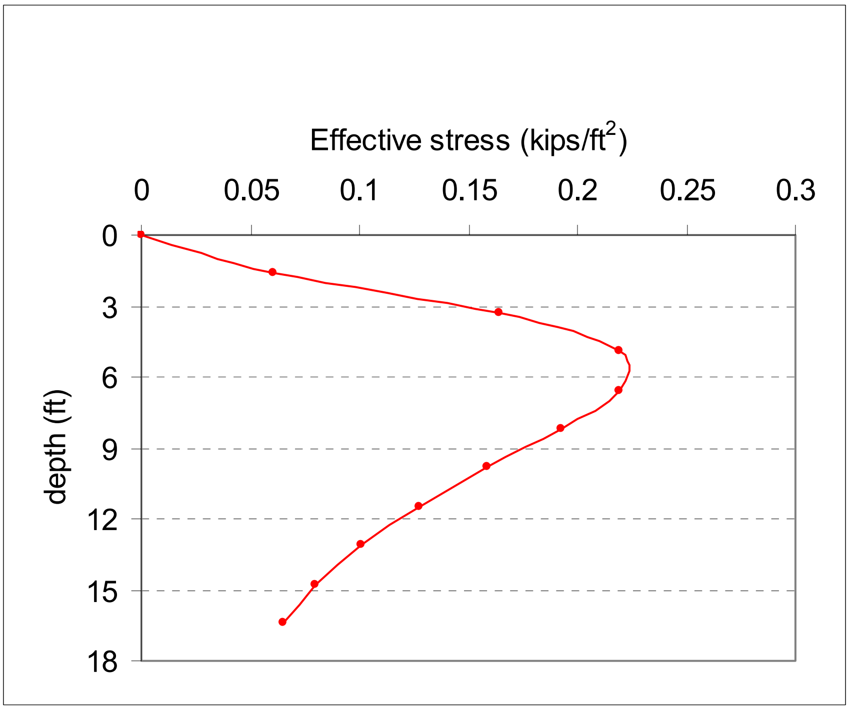


(Figure 15) Lateral pressure on wall at point B.

For point C:

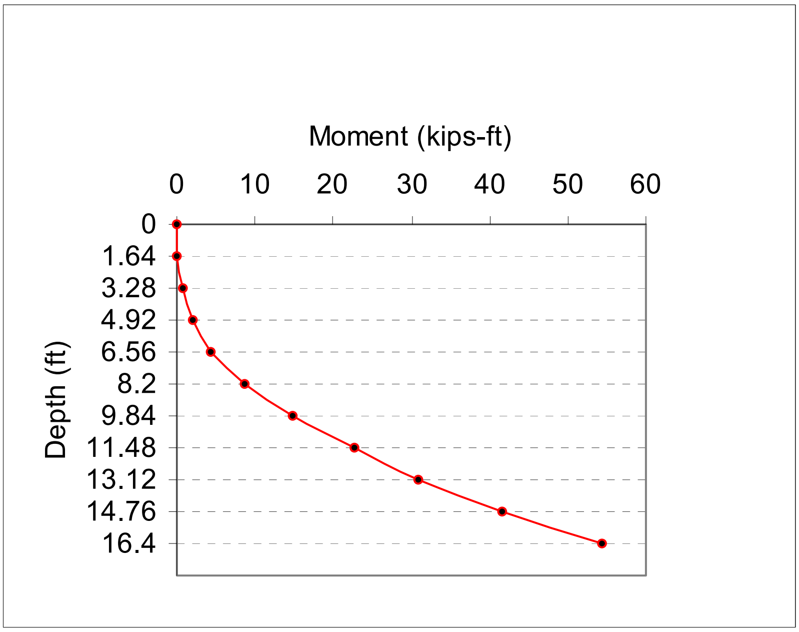
Depth (ft)	∑Effective stress by wheel pressure (kips/ft^2)	Effective stress by surcharge pressure (kips/ft^2)	Effective stress by earth pressure (kips/ft^2)	**ACCUMULATIVE** stresses (kips/ft^2)
0	0	0	0	0
1.64	0.06032	0.034696	0.062429	0.157445
3.28	0.16428	0.034696	0.124859	0.323835
4.92	0.21916	0.034696	0.187288	0.441144
6.56	0.21949	0.034696	0.249717	0.503903
8.2	0.192814	0.034696	0.312147	0.539657
9.84	0.15917	0.034696	0.374576	0.568442
11.48	0.12754	0.034696	0.437005	0.599241
13.12	0.1009	0.034696	0.499435	0.635031
14.76	0.07948	0.034696	0.561864	0.676040
16.4	0.06505	0.034696	0.624293	0.724039

(Table 4) Accumulative stresses by wheels, surcharge and earth pressure at point C.



(Figure 16) Lateral pressure on wall at point C.

From these figures we choose the point that has maximum stress *(point A)* and calculate moments at each depth, See figure 17.



(Figure 17) Moment affected on the wall at point A.

After estimating moment we design the retaining wall as follows:

At depth 9.84 ft (3 m) :

Moment = 15 kips – ft

= 15 x 416.7 x 30.48 = 190515 ≈ 200,000 kg -cm

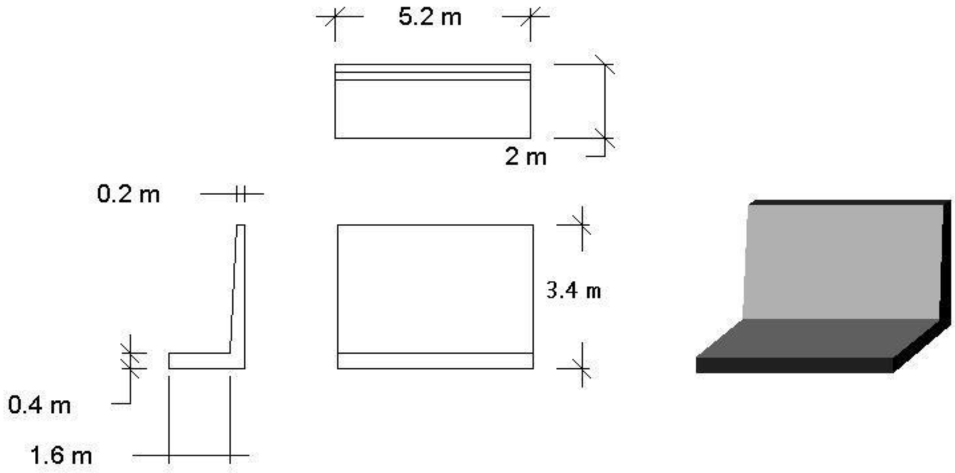
d = k1 √ (M/b) [El-Behairy, 1975]

where M = 200,000 kg –cm, b = 100 cm, k1 = 0.5 cm / √ kg

d = 0.5 x √ (200,000 / 100) = 23 cm use d = 25 cm

t = (cover) + d

= 5 + 25 = 30 cm use t = 40 cm



(Figure 18) Retaining wall dimensions.

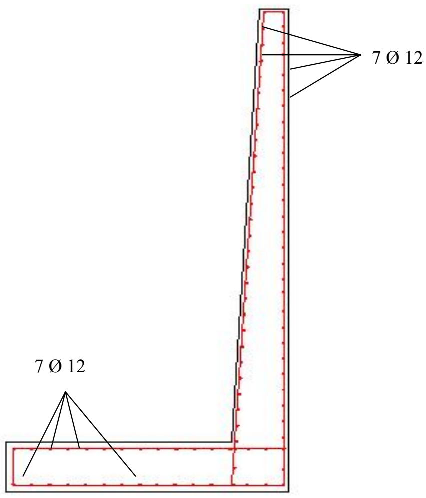
Retaining Wall Reinforcement:

A_s (areas of steel bars in cm^2) = M / (k_2 x d) ; k_2 = 1200 kg / cm^2 [El-Behairy, 1975]

$A_s = (2 \times 10^5) / (1200 \times 25) = 6.6 \ cm^2$

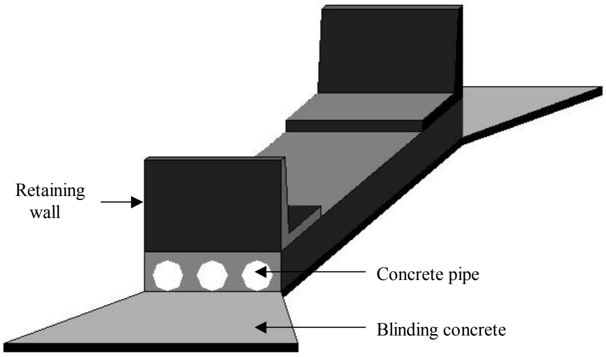
From steel table: use 7 Ø 12 / m steel bar

The distribution of steel bars for retaining walls will be done as shown in figure 19



(Figure 19) Distribution of steel bars in the retaining wall.

Finally, the laying of retaining walls will be done as shown in figure 20.

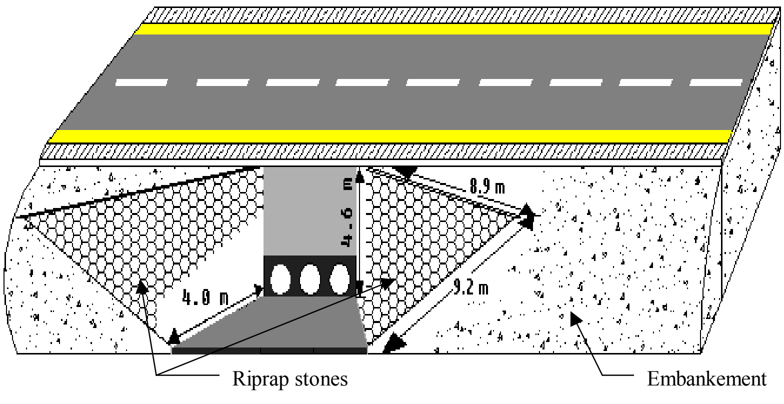


(Figure 20) Laying of retaining wall in the culvert.

5- Riprap Stones.

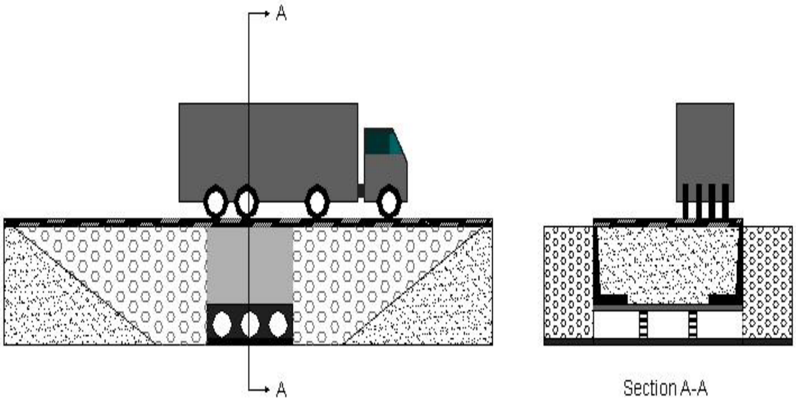
These stones usually come with a hexagonal shape, and with an average diameter of 20 cm, usually fixed on the slope part of culvert sides to protect soil against crumbling under the effect of the flowing water at the entrance and exit.

The gaps and spaces between stones to be filled with mortar (cement, sand, and water) to increase stones bonding. Usually the soil average slope angle (30º) and fixed as shown in figure 21.

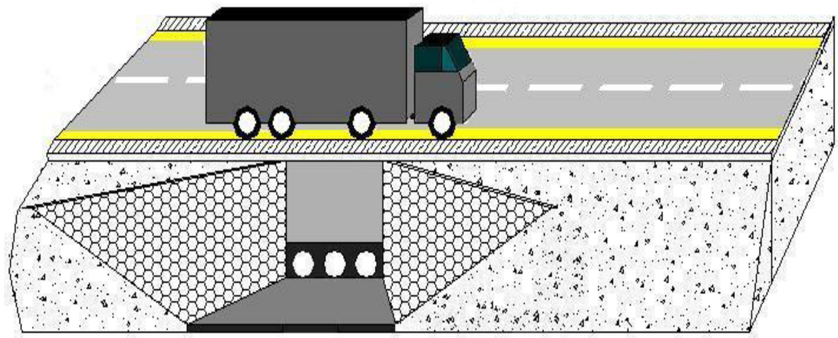


(Figure 21) Placing of riprap at intake and exit.

The general ideal views of culvert are shown in figures 22 and 23.



(Figure 22) Side view for culvert.



(Figure 23) 3-Dimension view for culvert.

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