The Design and Evaluation of Hydraulic and Hydrologic Systems in Tafila Area

Mohmd K. SArireh
Civil Engineering Department, Engineering Faculty, Tafila Technical University, Tafila, Jordan
Email: m.sarireh@gmail.com, m.sarireh@ttu.edu.jo

***Abstract*—Jordan Hydraulic and Hydrologic infrastructures (ex. Culverts) specially in Tafila age with increase of failure. The inadequate capacity, blockages, and the non planned construction and maintenance are arising as the major problems that engineers and governors should focus across Tafila area and the whole of country. Culverts' systems are facing many challenges in Tafila area such as the extreme topography with high slopes that make the surface water flow all the time turbulent and critical, transferring large sizes of stones and soil in wet seasons. Also the failure in culverts' systems is the main reason for road failure and damage, as these systems are not suitable for the quality and capacity of the seasonal extreme flow. For these reasons, the cost for rehabilitation, construction, and maintenance will be very high as the governmental agencies (The Municipality of the city, The Ministry of Public Works) are working on emergency basis, in addition, citizens, people and private sector are not affecting the process of construction, maintenance, and rehabilitation positively and they are not motoring government agencies for extra effective work. Also, the reconstruction cost and ineffectiveness in the implementation program (delay and cost overrun) are not considered in cost cycle for the culvert projects or systems. It is recommended to inventor culverts' systems by the responsible governmental agencies mainly the ministry of municipality and the ministry of public works.**

***Index Terms*—pipe culverts, box culverts, hydraulic structures, hydrologic structures**

I. Introduction

A culvert is a conduit under an embankment that transports storm water from one side of the embankment to the other through hydraulic inlet, outlet, or barrel control to convey surface water. The control of flow in a culvert can shift dramatically and unpredictably between inlet control, barrel control, and outlet control, causing relatively sudden rises in headwater [1]. And the following factors should be considered in culvert design: flood frequency, velocity limitations, buoyancy protection, length and slope, debris and siltation control, culvert barrel bends, ice buildup, headwater limitations, tail water conditions, and storage [2].

Many of channels' and culverts sections have failure in Tafila area (erosion, blockage, cracks, and partial demolition and/or full collapse. This put safety of users at risk and delay and interrupt the traffic for many hours or days in some cases, that push responsible agencies to work in emergent conditions considering emergent costs [3]. The purpose of this research is to quantify the design elements and cost of hydraulic and hydrologic structures (culverts), explore the needs for failure safety and cost calculation.

All of the sections detected and visited are made from hydraulic cement concrete for culverts (pipe and box culverts). And it was noticed that there are no records for these projects or infrastructure elements in the formal boards or governmental agencies. And there are no records for the expected life of the structures, and the work for repair and replacement is based on emergency basis and depending on reported sudden failure.

All sections of culverts are rigid section made of reinforced concrete in the shape of pipe or box (single and multi opens) that bore the load directly and specifically as they are rigid structure [4]. Meanwhile the scope of the work has specific objective and clear items, but there is no clear cost for installation of the sections (specially for pipe culvert section), and the price of contract if contracted comes too high and un predictable, so the pipe culverts are most of the time repaired and constructed using the home-in resources of workers and labors of the governmental agency monitoring and responsible for these sections (ministry of municipality and the public works). The high cost of repair and construction is because of the keeping of machine resources (Loader, truck, and compactor) all the time close to the workers and labors compared to the reasonable cost of materials and sections themselves and to the time of the proposed work or project (one day mostly) as the project is critical for the interrupting of traffic. Construction planning and cost estimation are short-term decision for such these projects as the repair and/or construction is needed urgent to stop delay in traffic interruption and in transportation of goods and services. The important question is: what are the procedures and practices and criteria that are employed and implemented by the responsible agencies (municipality and public works ministries) in repair and construction decisions for tracking and monitoring of the inventory and for the selection of the materials, dimensions, shapes and capacity?

II. Literature Review

There is no specific assumption in cost estimation for pipe culvert during the life cycle. This is true because the

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proposed design life for pipe culvert or channel sections is not expected or defined truly. Meanwhile, the design of culvert and channel sections including physical minimum dimensions, materials, and expected design life [5]. After visual inspection, 60% of pipe and box culverts need repair and maintenance, while 40% need reconstruction and replacement. In order to satisfy the design life of infrastructure of 100 years, and the design life of concrete structure of 70-100 years or minimum to 50 years, defined, specific, and serious periodic program for maintenance and repair should be very well planned and implemented without any delay in time or constraints on budget.

In Tafila, and in whole Jordan steel pipes are not used as culverts because they are not suitable for corrosion by soil and at invert and exterior, and with the proper applied coating, the design life may be extended to 50 years. Also, aluminum pipes are not suitable for use because of the high effect of soil corrosion rather than the existence of invert and exterior corrosion, and the design life is not expected to be more than 50 years because of the expected performance rather than the short experience and history with aluminum pipes. Plastic pipes are similar to aluminum pipes, they are not familiar to be used in culvert sections in any shape. Another factor to be considered in the design to have the height of soil embankment above the culvert to the height of culvert concrete ratio (h/Hc), that if increased will make reduction of compression stresses on culvert system [6] as represented in Fig. 1. And the other theory presented by [7] considering the rigid reinforced concrete culvert as two beams supported by elastic springs for developing a simplified design procedure for the culvert system of 1.2 m in diameter and 4 layers of compacted materials each 0.3 m in height and two points of loading at 1.8 m apart of 16 Kips (71 KN) factored by 1.2. and the optimization of section design is considered by [8] and [9].

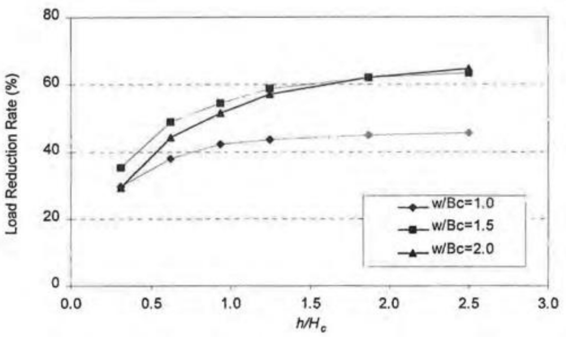

Figure 1. Load reduction on culvert vs. H/Hc ratio [6]

Any work plan for the maintenance, repair, and/or construction and/or replacement should define the cost in terms of: material selection with relation to design service life, considering the design hazards for traffic and people in region, documentation and records for the infrastructures (culverts and channels) should be kept for the use by the responsible or governor agency, considering all costs not only the least or minimum cost, all considerations and constraints should presented and fulfilled in the design, structural and hydraulic considerations should be covered in culvert design for first and repeated cost, failure and damage of surrounding property, safety of traffic and people, environmental considerations, aesthetic considerations, familiar and relevant to existence land use. Also, the delay and hazard (risk) should be evaluated in term of cost and tested by field measurements and readings. So, there is a need for tracking of channels and culverts systems as inventories that should be tracked, examined, and documented in term of existent or current conditions and type and level of failure. And for simplicity, only installation (construction or replacement) and/or maintenance costs are considered.

In the design process, it is necessary to find the case where H_w/L has relation value with discharge coefficient Cr in low $H_w/L < 0.15$), moderate ($H_w/L > 0.15$), and submerged conditions ($H_t/H_w > 0.6$) as it is represented in Fig. 2. Where Hw is the height of water at inlet, and L is the length of section, and H_t is the height of water at outlet, depending on overtopping, soil type, and section slope (constant by design or as in nature for severe slope) [1]. And it is required by the [10] and [11] that the culvert location, length, the waterway area are primary elements in the design process. And it should be avoided to have concentrated stresses on culvert, and it is preferable to have uniform distributed load on culverts' base. [12] stated that the design of culvert and drainage systems is from point of view a key issue in road construction and improvement of road projects.

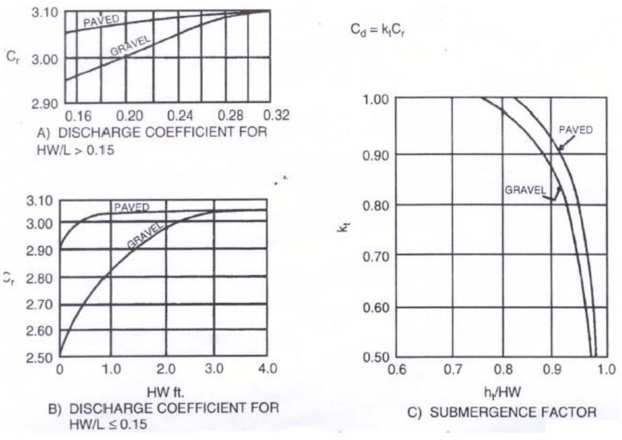

Figure 2. Design parameters a) discharge coeff. For Hw/L > 0.15, b) discharge coeff. For Hw/L < 0.15, c) submergence factor [1]

And the procedure for the hydraulic design of culvert can be summarized by the following steps according to Ref. [1]:

1) Get the design data and parameters that include Q (discharge, cfs), L (culvert length, ft), S (culvert slope, ft/ft), K_e (inlet loss coefficient), V (velocity, ft/s), T_W (tailwater depth, ft), H_W (allowable headwater depth for the design storm, ft).
2) Determine trial culvert size by assuming a trial velocity 3-5 ft/s and computing the culvert area, A = Q/V. Determine the culvert diameter (inches).
3) Find the actual H_W for the trial-size culvert for inlet and outlet control. Also the critical depth can be found from Fig. 3, Fig. 4, and Fig. 5 for pipe

culvert considering the discharge volume and the selected diameter of the pipe culvert, and from Fig. 6, and Fig. 7.

For inlet control, enter inlet-control nomograph with D and Q and find H_W/D for the proper entrance type [13] and [14]. Compute H_W, and, if too large or too small, try another culvert size before computing H_W for outlet control. For outlet control, enter the outlet-control nomograph with the culvert length, entrance loss coefficient, and trial culvert diameter. To compute H_W, connect the length of the scale for the type of entrance condition and culvert diameter scale with a straight line, pivot on the turning line, and draw a straight line from the design discharge through the turning point to the head loss scale H. Compute the headwater elevation H_W from the following equation: $H_W = H + h_o - LS$, where $h_o = ½$ (critical depth + D), or tailwater depth, whichever is greater. Fig. 3 represents the design for pipe culvert considering critical depth (ft) [15] and discharge of the range of 0-100 cfs. And the designed diameter selected will be in the range of 1-4 ft, and the critical depth ratio will be of 0.4-0.9 of selected diameter.

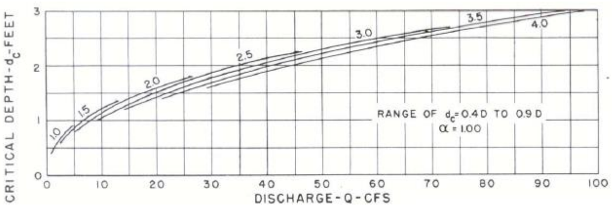

Figure 3. Critical depth, Circular Pipe Discharge = 0 - 100 cfs [1]

Fig. 4 represents the design for pipe culvert considering critical depth (ft) and discharge comes in two sets of ranges; one of 0-500 cfs, and the second of 500-600 cfs. And the designed diameter selected will be in the range of 4-7 ft and 7-9 ft respectively, and the critical depth ratio will be of 0.4-0.9 of selected diameter, also.

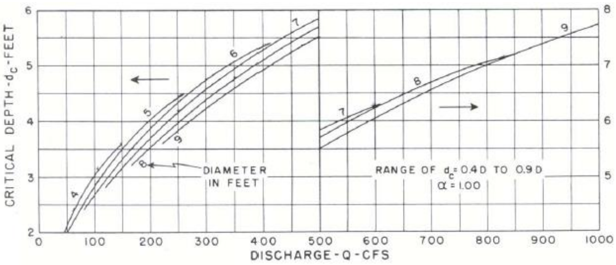

Figure 4. Critical depth, circular pipe, Discharge = 0 - 1000 cfs [1]

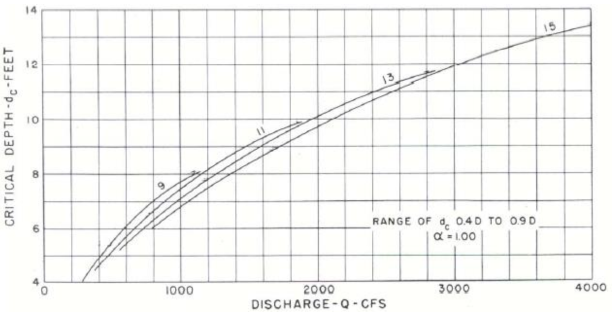

Figure 5. Critical depth, circular pipe, Discharge = 0 - 4000 cfs [1]

Fig. 5 represents the design for pipe culvert considering critical depth (ft) and discharge of the range of 0-4,000 cfs. And the designed diameter selected will be in the range of 9-15 ft, and the critical depth ratio will be of 0.4-0.9 of selected diameter.

Fig. 6 represents the design for Box culvert considering critical depth (ft) and discharge to width ratio of the range of 0-60 cfs/m. And the critical depth will be in the range of 1-5 ft, so the depth of box culvert should be greater than or exceeding critical depth found.

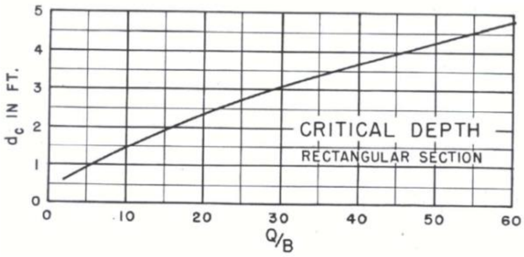

Figure 6. Critical depth, box culvert, Q/B = 0 60 cfs [1]

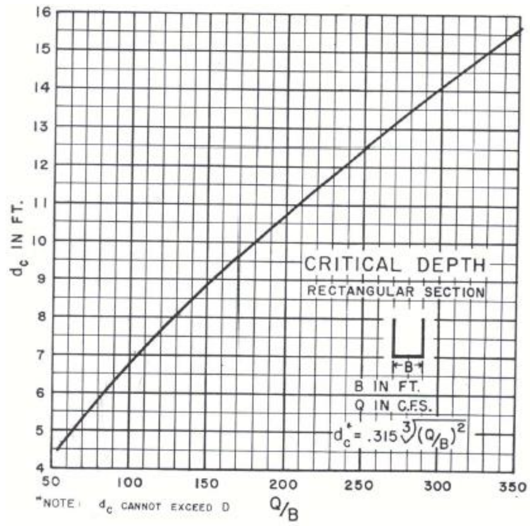

Figure 7. Critical depth, box culvert, Q/B = 50 - 350 cfs [1]

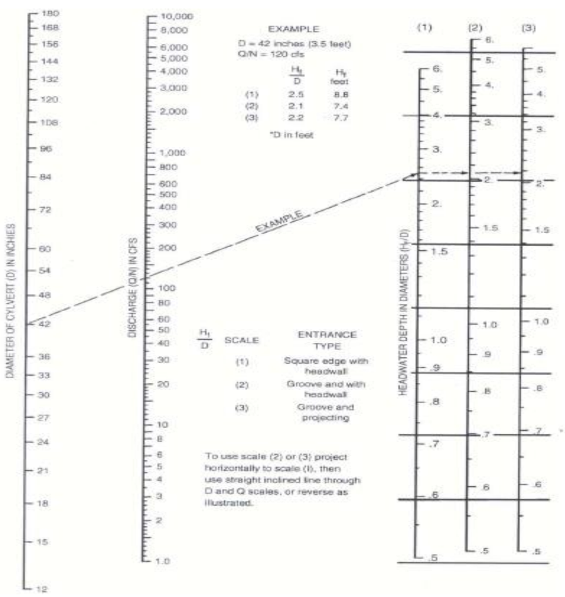

Figure 8. Inlet control nomograph, Q = 1-10,000 cfs [1]

Fig. 7 represents the design for Box culvert considering critical depth (ft) and discharge to width ratio of the range of 0-350 cfs/m. And the critical depth will be in the range of 4-16 ft, so the depth of box culvert should be greater than or exceeding critical depth found.

Compare the computed headwaters and use the higher H_W nomograph to determine if the culvert is under inlet (Fig. 8) or outlet control. If outlet control governs and the H_W is unacceptable, select a larger trial size and find another H_W with the outlet control nomographs. Because the smaller size of culvert had been selected for allowable H_W by the inlet control nomographs, the inlet control for the larger pipe need not be checked. Fig. 8 and Fig. 9 can be used for inlet control to get Hw considering discharge volume, and Fig. 10 for outlet control also.

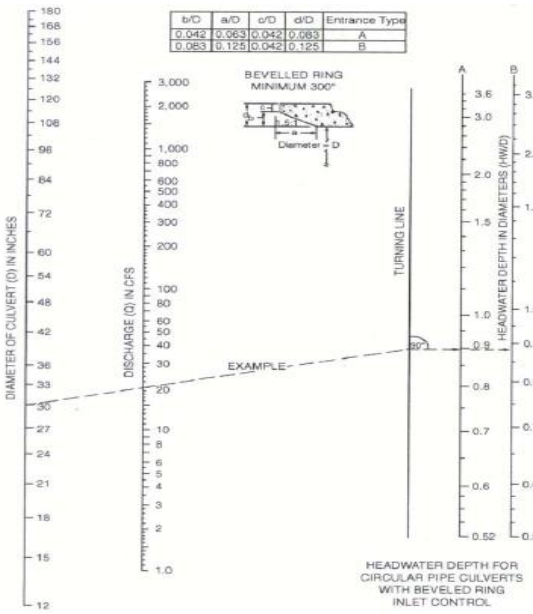

Figure 9. Inlet control nomograph, Q = 1-3,000 cfs [1]

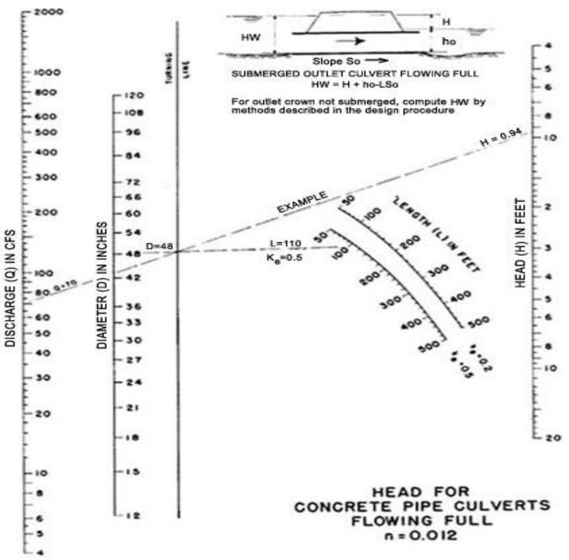

Figure 10. Outlet control nomograph, Q = 2-2,000 cfs, K_e = 0.2 and 0.5 [1]

Calculate exit velocity and expected streambed scour to determine if an energy dissipater is needed. The stream degradation may be a pre-existing condition, and the reasons and rate of degradation need to be determined. The culvert cross-sectional area may need to be increased and culvert invert initially buried if stream degradation is probable. A performance curve for any culvert can be obtained from the nomographs by repeating the steps outlined above for a range of discharges that are of interest for that particular culvert design. A graph is then plotted of headwater versus discharge with sufficient points so that a curve can be drawn through the range of interest. These curves are applicable through a range of headwater, velocities, and scour depths versus discharges for a length and type of culvert. Curves with length intervals of 25-50 feet are usually satisfactory for design purposes. Such computations are made much easier by available computer programs.

Fig. 11 illustrates the outlet control for pipe culvert for Discharge Q = 2-2,000 cfs to get the expected head of water through the pipe culvert that takes the values of 0.4 – 20 ft with inlet loss coefficient of 0.25, 0.5, and 0.9, and length of culvert of 50-500 ft.

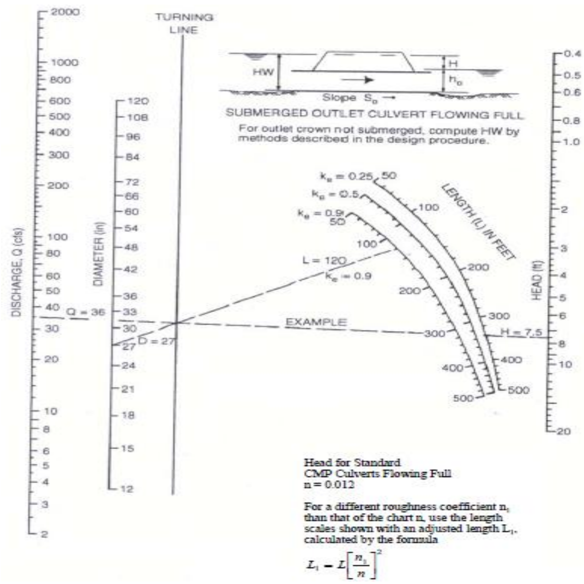

Figure 11. Outlet control nomograph, Q = 2-2,000 cfs, Ke = 0.25, 0.5, and 0.5 [1]

Fig. 12 illustrates the outlet control for box culvert for Discharge Q = 5-5,000 cfs to get the expected head of water through the pipe culvert that takes the values of 0.4 – 20 ft with inlet loss coefficient of 0.25, 0.5, and 0.7, and length of culvert of 50-500 ft.

III. Real Data for Culvert Design in Tafila Area

The target area of the study doesn't have the efficient hydraulic and hydrologic system (Culverts) as part of the infrastructure in the city that includes streets and roads and culverts and channels. The design of culverts' system is the target of this research. The current system of culverts has many problems including the inefficient design (diameter, depth of backfill and embankment, thickness of elements, required steel reinforcement, blockage and unsuitable level between inlet and outlet, and unsuitable level for the streets and channels) [16]. Table I illustrates the designed pipe and box culverts from the sections 1 to 10 considering discharge rate, length, critical depth and water depth.

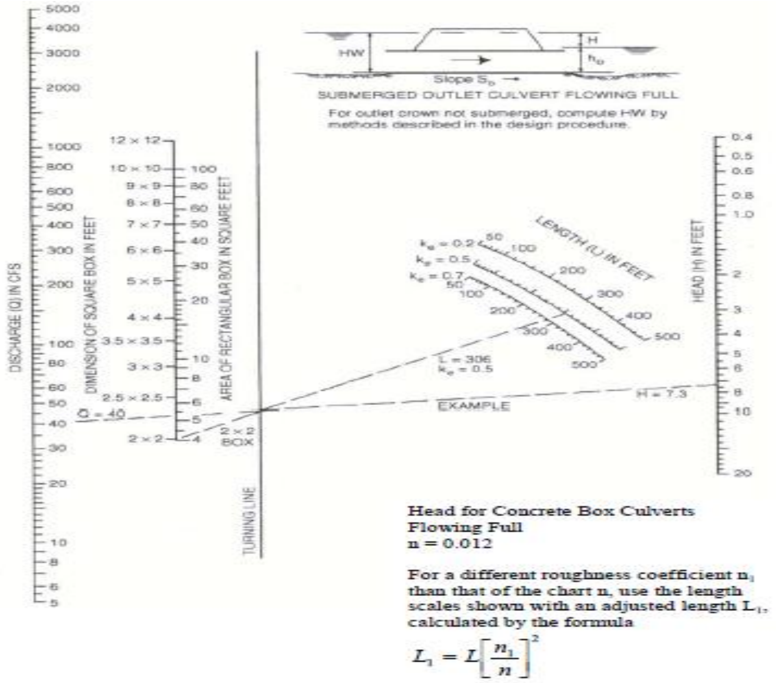

Figure 12. Outlet control nomograph, Q = 5-5,000, K_e = 0.2, 0.5, and 0.7 [1]

TABLE I. THE DESIGN PARAMETERS FOR CULVERT SYSTEM IN TAFILA AREA

Sec #	Discharge (cfs)	Length (ft)	Velocity ft/s	Diameter or Height (ft)	Critical Depth (ft)	H_w (ft)	H_w (ft)	Culvert Type
1	5.9	50	5	3	1	0.1	1	Pipe
2	26.62	75	5	3	1.8	0.75	2.8	Pipe
3	101.5	75	5	4	3	2.8	2.6	Pipe
4	143.17	100	5	4	3.4	1.7	3	Pipe
5	219.8	125	5	6	3.4	0.95	1.4	Box
6	370.24	160	5	6	4.8	1.4	1.8	Box
7	499.84	180	5	8	4.8	0.92	0.8	Box
8	558.71	210	5	8	5.4	1.05	0.9	Box
9	597.913	240	5	8	5.6	1.2	1	Box
10	818.03	240	5	8	6.8	1.5	1.2	Box

In details, Table II illustrates the design (dimensions of working area at each section) for pipe culverts, and the required items for work construction that includes excavation, number of elements required in each section, lining, shoulders of culvert required to protect inlet and outlet and the floor areas of inlet and outlet required before and after section. Prices for items of work were obtained considering the home-in resources and prices considered by the directory of public works and housing in Tafila governorate. The total cost of pipe culvert projects is JD16,940, and the cost per foot is JD59.44/ft.

TABLE II. PIPE CULVERT DESIGN AND ESTIMATION OF COST OF CONSTRUCTION

Section	Type	Dimension (ft)			Excavation (Yrd^3)	Piece	Lining	Shoulder (ft^2)	Inlet / Out (ft^2)	
1	Pipe	60	7	8	124.5	20	250	106.7	170	
2		75	7	8	155.6	24		128.0	223	
3		75	8	8	155.6	24		128.0	223	
4		75	8	8	436	24		362.7	616	
Unit Cost (JD)					3	75		1.5	1.5	
Sub Total (JD)					1744	5100		910	1232	11
Backfill Cost (Thousands JD)										.55
Subbase Cost (Thousands JD)										0.84
Base Coarse (Thousands JD)										1.26
Prime Coat Cost (Thousands JD)										0.32
HMA Cost (Thousands JD)										2.94
Total (Thousands JD)										16.9

Table III illustrates the design of working area, estimation of construction cost for box culverts' systems in Tafila area, the total cost for the project is JD184,066 the cost per linear ft is 395.84 JD/ft.

TABLE III. THE ESTIMATION FOR THE COST OF CONSTRUCTION OF BOX CULVERT

Section	Type	Dimensions			Excav. (Yrd^3)	Concrete	Lining	Shoulders (ft^2)	Inlet / Outlet (ft^2)	Steel
5	Box	60	10	10	222	54		150	40	94
5										
6		60	12	12	320	69		240	80	
7		75	12	12	400	74		240	80	
8		90	12	12	480	91		240	80	
9		90	12	12	480	104		240	80	
10		90	12	12	480	104		240	80	
Unit Cost (JD)					3	90		1.5	1.5	
Sub Total 1 (Thousands JD)					7.15	44.64	0.4	2.025	0.66	54.9
Backfill Cost (JD)										6.7
Subbase Cost (Thousands JD)										5.6
Base Coarse Cost (Thousands JD)										7.5
Prime Coat Cost (Thousands JD)										1.4
HMA Cost (Thousands JD)										14
Sub Total 2 (Thousands JD)										91
Total (Thousands JD)										184

IV. DISCUSSION AND RECOMMENDATION

Infrastructures such as the hydrologic and hydraulic structures (culvers as examples) need for complete, continuous, planned monitoring program for inspection and repairs. The program will be useful for avoiding the failure of culvert system as transfering and safety structure. The failure may have the level of cracks, blockage, overflow, and/or collapse.

The studied ssystems (culverts) are all under public roads, that needs reasonable monitoring and inspection program to avoid failure in the form of collapse or overflow in wet seasons that will interrupt traffic systems and put safety of public and properties at critical siyuation.

The current study investigated the redesign and reconstruction of 4 sites for pipe culverts, and 6 sites for box culver, in addition to the calculation of cost. The design included the required diameter or dimension of culvert, the critical depth of culvert, the expected or allowed hieght of water in culvert, also the hieght of water at inlet and outlet control nomographs.

The expected total cost for the studied pipe culverts is JD16,940, and the rate cost is JD59.44 per feet. While the expected total cost for the box culvert system is JD184,066, at the rate cost JD395.84 per feet.

It is recommended that responsible agencies (Municipality of city, and directorate of public works) should share the responsibility and take actions on plan-basis and not on emergent-basis. The monitoring and inspection program will help in avoiding sudden collapse and failure, and wil help in reduction of maintenance and repair cost in future.

V. LIMITATIONS ON RESEARCH

The current research focused on the adjacent sections for pipe and box culvert, but not all sections in the governorate of Tafila city and other villages belong to the directorate of the city because of transportation dificulties and lack of support for the reserach. The lack of local and international studies on the subject is other difficulty that faced the research conduction. Future studies are required to widden the study area and to have the chance to have different sections design and aspects for design of flow in valleyes in the country areas in the city.

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Mohmd Kh. Sarireh is an assistant professor in Civil Engineering Department, Tafila Technical University. He received his B.Sc. in civil engineering from Mu'ta University, Jordan, and he received his M.Sc. in Civil Engineering from The University of Jordan, Jordan. He got his Ph.D. in Construction Engineering from Civil Engineering Department at The University of Texas at Arlington in August 2011, Arlington, Texas, USA. His Ph.D. Thesis was in modeling of productivity for horizontal directional drilling and factors affecting HDD productivity. The author had published his researches and papers in the HDD Productivity and Analysis and Market Statistics, Usage, and Applications and affecting Factors. Also, in concrete mixes, and Project Safety, and Deterioration of Pavement on Highways in Jordan. Another interest is in the volcanic tuff aggregate for block construction for slabs and walls for its properties. Other researches are under revision in cost overrun, HDD time of drilling, and the application of solar and wind energy in Kuwait, and administration of wind energy also, and in high strength concrete.