DE GRUYTER Open Engineering 2022; 12: 808–816

Research Article

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Optimum hydraulic investigation of pipe aqueduct by MATLAB software and Newton–Raphson method

https://doi.org/10.1515/eng-2022-0369
received April 12, 2022; accepted August 09, 2022

Abstract: An aqueducts are a water source (the channel that a flowing body of water follows) designed to transport water from a specified point to a point where the designer aims to distribute the water within it. To enhance the hydraulic properties of pipe aqueducts, a workable, efficacious, and convenient method for the optimal design of an aqueduct has been determined in this research article to study the optimum design of pipe aqueduct (finding optimum diameter) and study the effect of design parameters on safe span length by MATLAB Software R2017b and Newton–Raphson method and check the effects of the parameters of design such as the span length (L), discharge (Q), overhead loss (H), inlet and outlet coefficient ($K1$ & $K2$), etc. Also, this article studies the safe span (L) depending on the optimum value of pipe diameter.

Keywords: pipe aqueduct, safe span, optimum design, AppDesigner MATLAB, hydraulic design

1 Introduction

In water resources engineering, achieving optimal design is such a challenging task. Most of the time, rigorous iterative processes take place to obtain the most suitable solution regarding prescribed engineering objectives associated with design constraints. In the past years, the software tools used for optimization have been widely used in various fields of water resources engineering. Although the benefits of these technics, these tools are not efficiently integrated into practicing engineers' design workflow. This article intends to show the benefits of using optimization software integrated with an analysis tool.

An aqueduct is a water conveyance system built to carry water across a canal or valley. The term aqueduct refers to ditches, pipes, tunnels, canals, and supporting structures utilized in modern engineering. To transport water from a source location to the location where it will be distributed. The primary purpose of this system is to supply daily population uses and agricultural lands with water. The benefit of the aqueduct is revealed particularly in the development of lands with a restricted gain of freshwater. There are different sizes and shapes of aqueduct, and it is specified depending on the primary purpose and the amount of water carried by it; it can take a range of shapes from the small trench that excavates into the earth to wide channels, and the essential factor that effect on the size is its gradient as by increasing the gradient will allow a smaller channel to have the potential to transport the same (as much as possible) magnitude of fluid as a more extended canal with a minimal gradient, but by employing this principle, the water's ability to deteriorate the aqueduct's structure is increased.

Currently, pipe aqueducts are used widely to transport water over long distances when it must run through high ground or where canals are inappropriate because of issues about freezing, pollution, and freezing [1] (Figure 1).

The authors of ref. [3] created a novel approach to constructing main drinking water lines, including the possible hydroelectric generation as a pipeline advantage. He also aimed to acquire the optimal design of water pipelines and micro-hydro turbines via an evolutionary algorithm.

The authors of ref. [4] studied the optimum design of the pipeline system by using the genetic algorithm, and they found the following point:

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Figure 1: The Los Angeles aqueduct carries water from the Owens Valley to Los Angeles, California [2].

- A genetic algorithm is an excellent tool as it decreases the total cost by 45%.
- They are producing outstanding results in a reasonable amount of time, making this technique a valuable tool for quickly identifying solutions.

The author of ref. [5] improved the genetic algorithm to improve its search capability. The outcome demonstrates that the new algorithm is viable and effective and can be used to develop comparable projects in the future.

In ref. [6], a genetic algorithm has been used in this research to determine the optimal design plan for the Sha-He aqueduct, and the results show that U-sectioned aqueducts are superior to rectangle-sectioned aqueducts in terms of cost and safety. Genetic algorithms (GA) is an effective optimal design method worth applying and disseminating.

In ref. [7], the aqueduct from the point of view of seismic response analysis and seismic design has been studied, and they use the dynamic characteristics of an aqueduct structure, which were calculated and analyzed using the ANSYS finite element analysis program. The research results provide the basis for the seismic design and protection of the aqueduct.

In ref. [8], a development of optimum hydraulic design is achieved for a case study of the executed project to stock a cost-effective aqueduct structure. This led to 29% conservation in substantial quantity.

In ref. [9], by taking into account different applicable theories, the development of the hydraulic design of the aqueduct is achieved by STAAD Pro software. It was noted that the researchers discuss the aqueduct parameters from a structural point of view, not hydraulic.

The authors of ref. [10] present the hydraulic design of the aqueduct and use optimization theory in the design by choosing the best cross-section of the canal (trapezoidal shape). It was noted that this study does not take various values for hydraulic elements and is content with only one value for each hydraulic element.

In ref. [11], a model (one-dimensional flow) is constructed to quantify, project, and simulate the future effect of subsidence on the aqueduct; this is achieved by using Hydrologic Engineering Center's River Analysis System (HEC-RAS).

The authors of ref. [12] aim to assess the aqueduct's structural safety, and the research's outcome is to raise lateral cashiers to 0.60 m. This will result in a 19.1% increase in hydraulic capacity while keeping the overall weight increase below 10%.

In ref. [13], the HEC-RAS model calibration process was used to assess the hydraulic behavior of the Eastern National Water Carrier. The mean Manning's roughness coefficients in the three water carrier sections were n = 0.099, 0.124, 0.028, and 0.038 in canal, respectively. When contrasted to the roughness condition, n = 0.015 of concrete-lined aqueducts, it may be deduced that the aqueduct's hydraulic state is undesired. As a result, solid aqueduct operating and maintenance plans are essential.

The authors of ref. [14] use ABAQUS to construct a model (finite element model) of composite aqueduct to study the structural performance of this type of hydraulic structure. Many parametric analyses use finite elements to find the suitable formula for effective width. The accuracy used in this formula in several national codes with stress error is usually less than 10.

The authors of ref. [15] focus on their working on avoiding the problem that comes from the sewage inverted siphon intersection with immovable infrastructures while simultaneously specifying this type of structure's optimum and safety design. The outcome of this study showed that the optimum design for discharges ranging from 0.38 m^3/s to 0.95 m^3/s was poly vinyl chloride siphon. For the discharge, the optimum solution is specified by applying the reinforced concrete type. From the point of view of the cost, a significant cost reduction is achieved by using the optimum solutions.

2 Types of aqueduct

The authors of ref. [16] moreover, ref. [2] specified that aqueducts could be classified into different categories as follows:

(1) Materials
  (a) Stone blocks

   (b) Concrete
   (c) Tiles
   (d) Bricks
   (e) Mortar
   (f) Steel
(2) Shape
   (a) Pipes
   (b) Ditches or small ditches cut into the earth
   (c) Canals
   (d) Tunnels
   (e) Bridge on an artificial watercourse
(3) Purpose of construction
   (a) Irrigate crops
   (b) Supply large cities with drinking water.

3 Cases to be solved and parameters used

The main equations used in the study are follows [17]:

$$\Delta H = \left[K_1 + K_2 + \frac{124.6 \times n^2 \times L}{D^{4/3}}\right] \times \frac{V^2}{2\,g} \tag{1}$$

$$L = 0.91\left[\frac{f_s \times D}{30 + \frac{D}{t}}\right]^{\frac{1}{2}}, \tag{2}$$

where:

ΔH = total overhead loss (m)
K^1 = inlet coefficient
K^2 = outlet coefficient
n = manning coefficient
L = safe span length (m)
D = pipe diameter (m)
V = canal velocity
f_s = steel stress for mild steel (Kn/m^2)
t = pipe thickness (mm).

Parametric values are used in this inquiry to analyze and build the pipe aqueduct. Table 1 presents a description of these scenarios.

4 Methodology and problem-solving

A digital foam is used to evaluate the model created to check the percentage of effect of the design parameter on the pipe aqueduct diameter and its safe span length with an initial coefficient value shown in Table 2. To achieve that, the Matlab program associated with Newton–Raphson method is used to calculate the best hydraulic design for a pipe aqueduct (Figure 2).

Table 1: Parameters used for designing and analysis

Hydraulic elements value	Description
Design discharge	1.00:2:12.00 (m^3/s)
Inlet coefficient	0.1:0.5:5.00
Outlet coefficient	0.25:0.5:5.00
Manning roughness coefficient	0.005:0.005:0.04
Length of pipe	25:25:200 (m)
Total headwater lost	0.25:0.5:2.50 (m)
Steel stress for mild steel	50:50:250 (MPa)
pipe thickness	5.00:5:30.00 (mm)

4.1 Input data

The parameters included in the current study (initial analysis and design) are specified in Table 2.

4.1.1 Approach steps

(1) Discharge parameters
   (a) The design discharge and number of opening
   (b) Total discharge
   (c) Down and up stream W.L.
   (d) Length of culvert
(2) Calculations of loads
   (a) Bottom and top loads
      (i) Soil thickness above Culvert
      (ii) Road thickness
   (b) Side loads

Table 2: Initial coefficient value

Design discharge	1.8 (m^3/s)
Inlet coefficient	0.5
Outlet coefficient	1.00
U/S stream W.L.	1.00 m
D/S stream W.L.	0.79 m
Manning roughness coefficient	0.01
Length of culvert	28 m
Total headwater lost	0.21 m
Steel stress for mild steel	93 MPa
Pipe thickness	9.50 mm

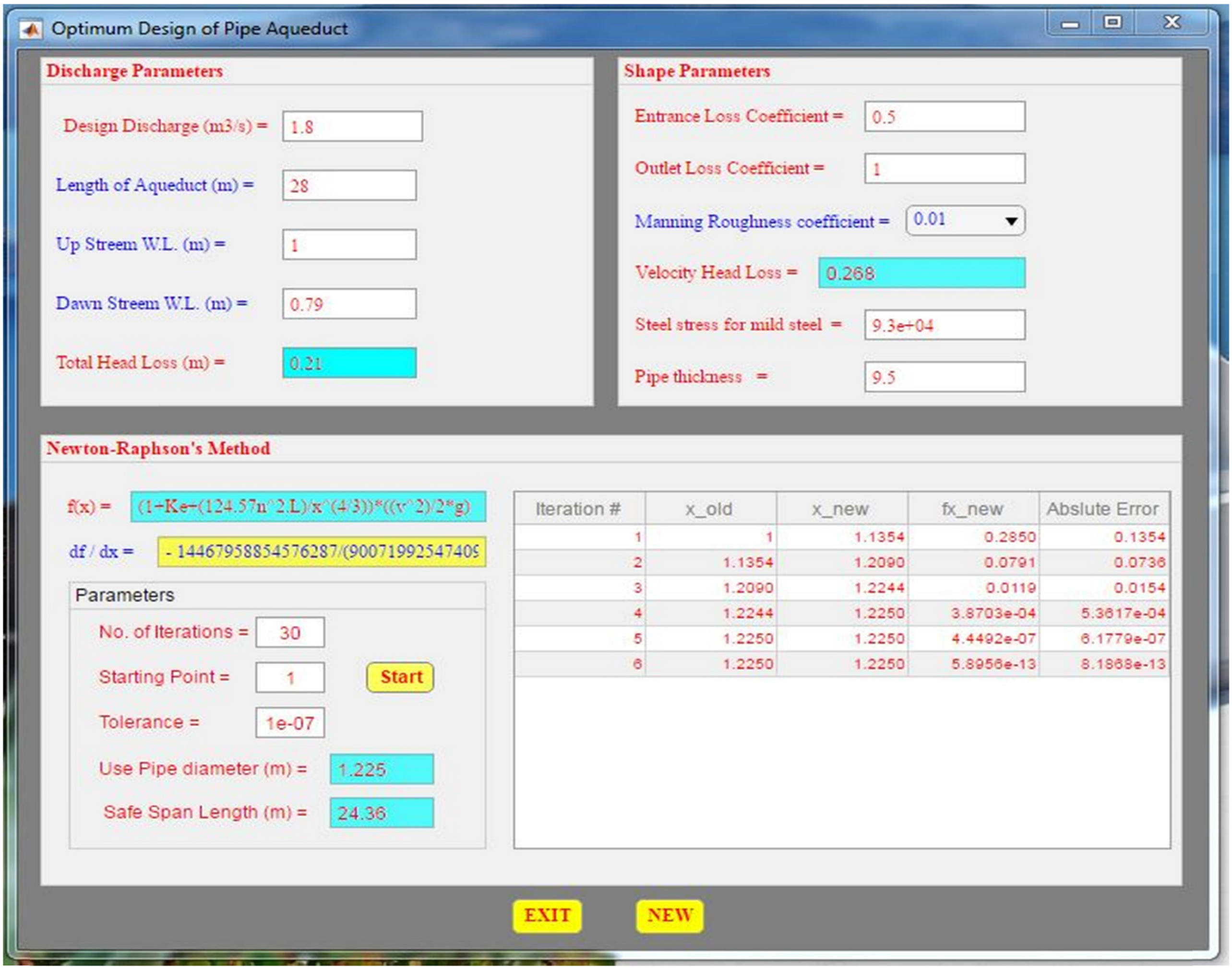

Figure 2: Shows the MATLAB application we developed to determine the best hydraulic design for the pipe aqueduct.

(3) Newton–Raphson's method
 (a) Calculate optimum top and bottom slab thickness
 (b) Calculate optimum clear span and height
(4) Shape parameters
 (a) Manning the roughness coefficient
 (b) Entrance shaped and wing walls.

Table 3: Value of optimum diameter and optimum span length vs discharge

Q (m^3/s)	1.00	3.00	5.00	7.00	10.00	12.00
D (m)	0.928	1.565	2.004	2.361	2.811	3.075
Lo (m)	23.66	24.88	25.31	25.55	25.77	25.88

5 Result of applying parameters

5.1 Design discharge vs optimum diameter and safe span length

To investigate the effect of design discharge on the optimum diameter and safe span length, a discharge of range 1–12 m^3/s shown in Table 3 is used. After applying these values within the program created by using graphical user interface design environment (GUIDE) within Matlab, the result is presented in Figures 3 and 4.

5.2 Pipe length vs optimum diameter and safe span length

To investigate the effect of the pipe length on the optimum diameter and safe span length, a pipe length of range 25–200 m shown in Table 4 is used. After applying these

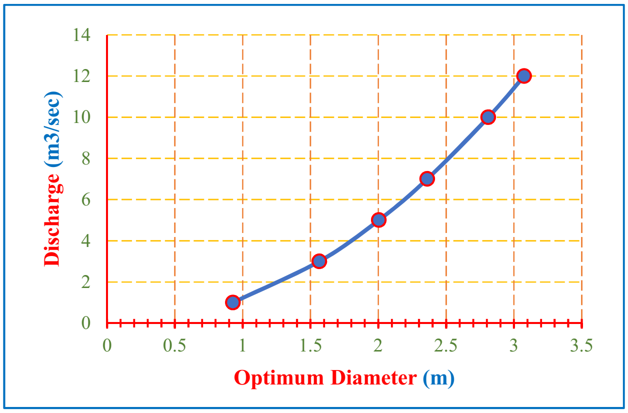

Figure 3: Optimum diameter vs discharge.

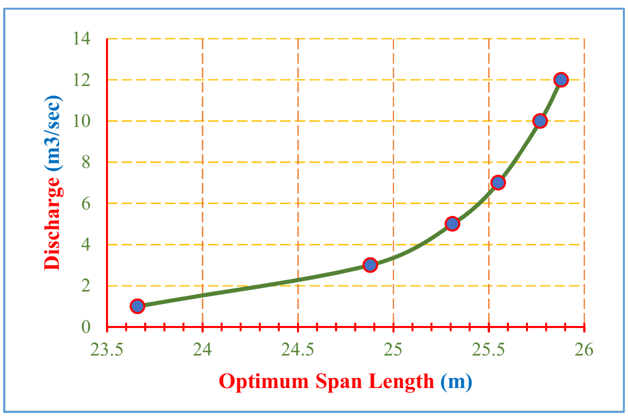

Figure 4: Optimum span length vs discharge.

values within the program created by using GUIDE within Matlab, the result is presented in Figures 5 and 6.

5.3 Inlet and outlet coefficient vs optimum diameter and safe span length

To investigate the effect of inlet and outlet coefficient on the optimum diameter and safe span length, a pipe length of range 1.5–5.0 shown in Table 5 is used. After

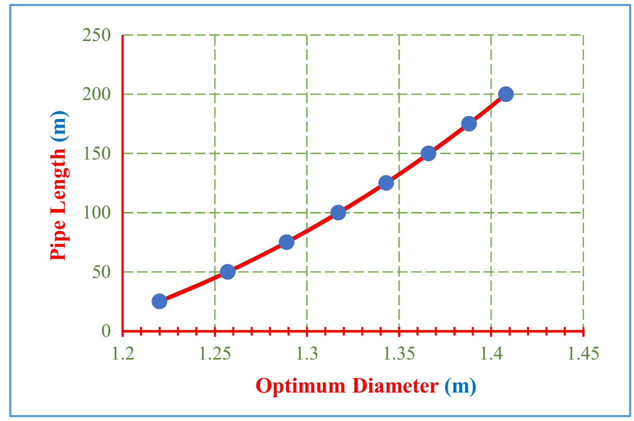

Figure 5: Optimum diameter vs pipe length.

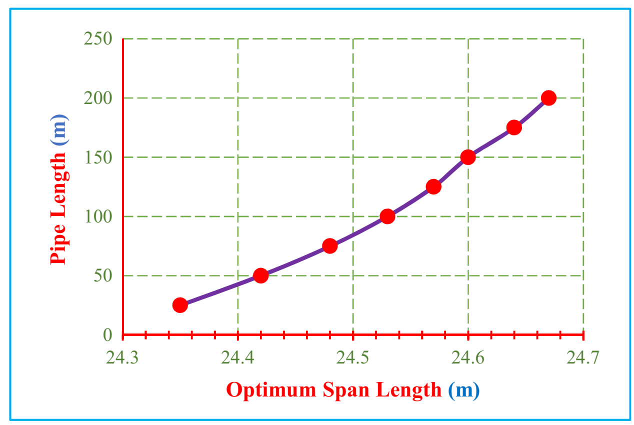

Figure 6: Optimum span length vs pipe length.

applying these values within the program created by using GUIDE within Matlab, the result is presented in Figures 7 and 8.

5.4 Manning coefficient vs optimum diameter and safe span length

To investigate the effect of Manning coefficient on the optimum diameter and safe span length, a pipe length

Table 4: Value of optimum diameter and optimum span length vs pipe length

L (m)	25	50	75	100	125	150	175	200
D (m)	1.22	1.26	1.29	1.32	1.34	1.37	1.39	1.41
Lo (m)	24.35	24.42	24.48	24.53	24.57	24.6	24.64	24.67

Table 5: Value of optimum diameter and optimum span length vs inlet and outlet coefficients

K	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
D (m)	1.225	1.301	1.366	1.423	1.474	1.521	1.564	1.603
Lo (m)	24.36	24.5	24.6	24.69	24.76	24.82	24.88	24.92

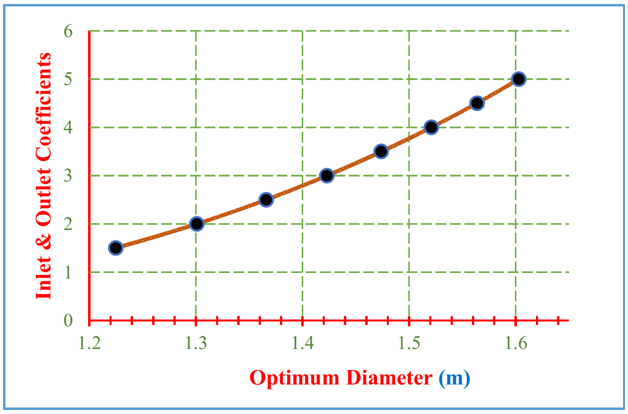

Figure 7: Optimum diameter vs inlet and outlet coefficients.

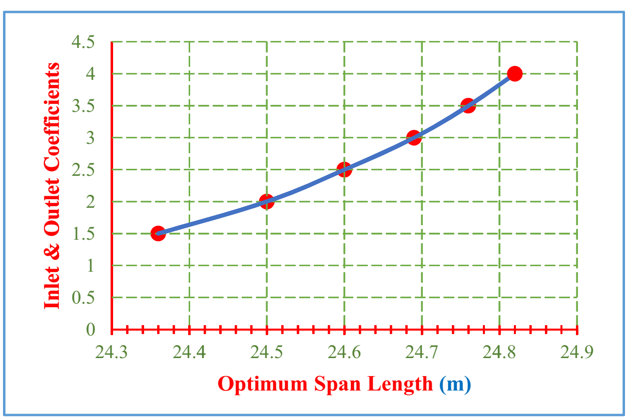

Figure 8: Optimum span length vs inlet and outlet coefficients.

of range 0.005–0.04 shown in Table 6 is used. After applying these values within the program created by using GUIDE within Matlab, the result is presented in Figures 9 and 10.

5.5 Total head lost vs optimum diameter and safe span length

To investigate the effect of total head lost on the optimum diameter and safe span length, a pipe length of range 0.5–2.50 m shown in Table 7 is used. After applying these values within the program created by using GUIDE within Matlab, the result is presented in Figures 11 and 12.

5.6 Steel stress vs optimum diameter and safe span length

To investigate the effect of steel stress on the optimum diameter and safe span length, a pipe length of range 50–250 MPa shown in Table 8 is used. After applying these values within the program created by using GUIDE within Matlab, the result is presented in Figures 13 and 14.

5.7 Pipe thickness vs optimum diameter and safe span length

To investigate the effect of pipe thickness on the optimum diameter and safe span length, a pipe length of range 5–30 mm shown in Table 9 is used. After applying these values within the program created by using GUIDE within Matlab, the result is presented in Figures 15 and 16.

6 Conclusion and discussion

(1) The application we created using App designer in MATLAB software approved it was a helpful tool.

Table 6: Manning coefficient vs optimum diameter and safe span length

n	0.005	0.01	0.015	0.02	0.025	0.03	0.035	0.04
D (m)	1.189	1.225	1.274	1.33	1.388	1.556	1.501	1.556
Lo (m)	24.29	24.36	24.45	24.55	24.64	24.87	24.8	24.87

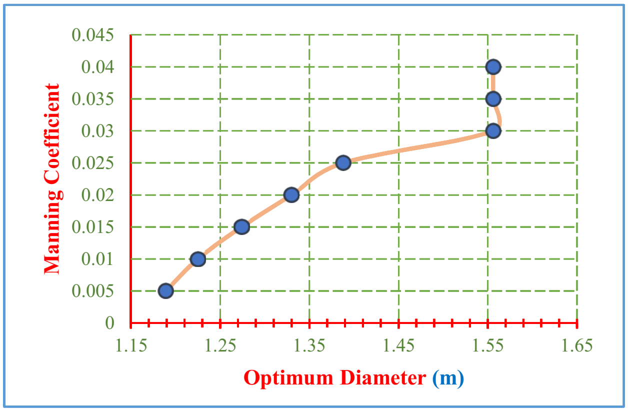

Figure 9: Manning coefficient vs optimum diameter.

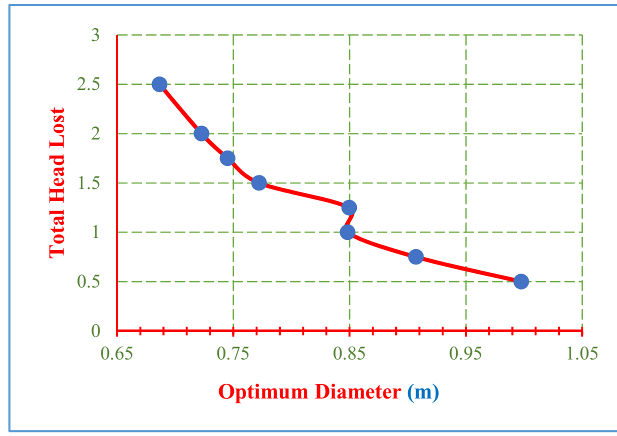

Figure 11: Total head lost vs optimum diameter.

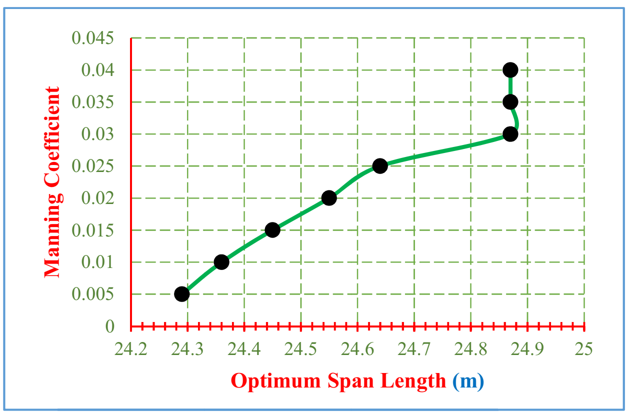

Figure 10: Manning coefficient vs safe span length.

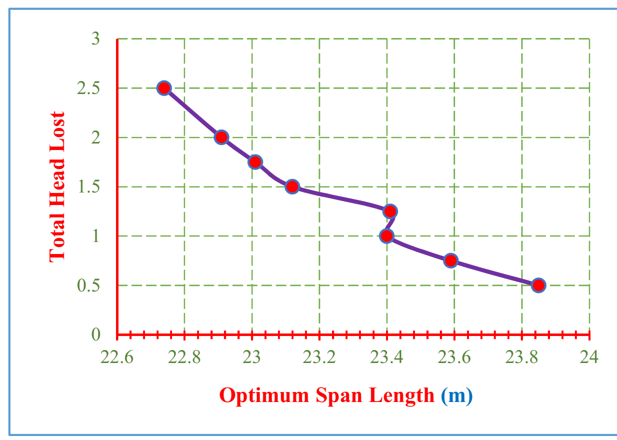

Figure 12: Total head lost vs safe span length.

Table 2 presents the parameters utilized in the initial design and study of the pipe aqueduct to determine the best hydraulic design.

(2) We used the description to apply several types of loading scenarios. Tables 8 and 9 note that pipe thickness and steel stress do not affect the ideal hydraulic pipe diameter value magnitude. On the other hand, according to ref. [14], an increase in the thickness of steel plates can effectively reduce the longitudinal deflection and section curvature. Also, the authors of ref. [14] mention that increasing the thickness or the width of the concrete flange decreases the longitudinal deflection and the longitudinal compressive stress of concrete. As a result, this two-parameter does not affect the hydraulic performance of the aqueduct.

(3) The investigation of the discharge value effect on the optimum diameter and safe span length shows that there are a few changes in the pipe diameter and almost no change in the safe span, as shown in Figures 3 and 4. The reason for this increase is that it is directly proportional to flow velocity, so the value of impact load will increase in the case of increased discharge.

Table 7: Total head lost vs optimum diameter and safe span length

Head lost (m)	0.5	0.75	1.00	1.25	1.50	1.75	2.00	2.50
D (m)	0.997	0.907	0.848	0.849	0.772	0.745	0.722	0.686
Lo (m)	23.85	23.59	23.40	23.41	23.12	23.01	22.91	22.74

Table 8: Steel stress vs optimum diameter and safe span length

Fs (MPa)	50	75	100	125	150	175	200	250
D (m)	1.225	1.225	1.225	1.225	1.225	1.225	1.225	1.225
Lo (m)	17.86	21.88	25.26	28.24	30.94	33.42	35.73	39.94

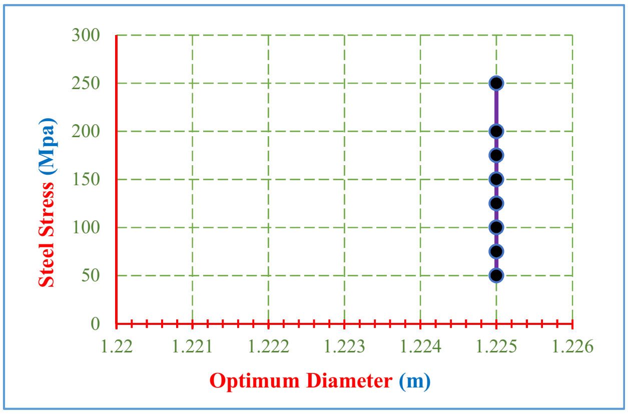

Figure 13: Steel stress vs optimum diameter.

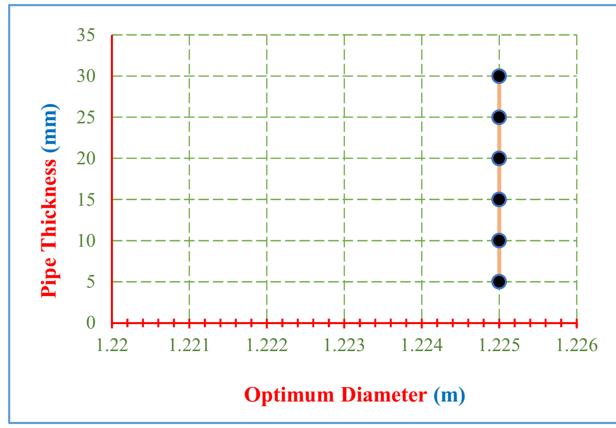

Figure 15: Pipe thickness vs optimum diameter.

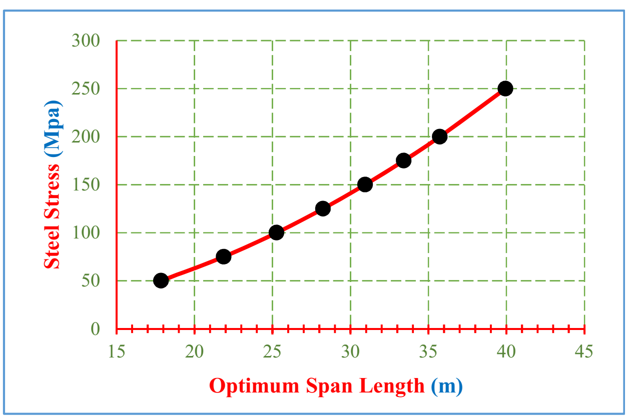

Figure 14: Steel stress vs safe span length.

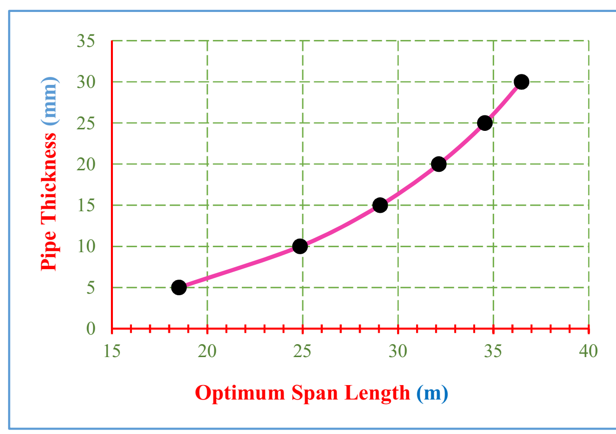

Figure 16: Pipe thickness vs safe span length.

Table 9: Pipe thickness vs optimum diameter and safe span length

t (m)	5	10	15	20	25	30
D (m)	1.225	1.225	1.225	1.225	1.225	1.225
Lo (m)	18.52	24.87	29.07	32.15	34.56	36.49

(4) As shown in Figures 5 and 6, pipe length has almost no effect on the value of optimum diameter and safe span length. It shows a few pipe diameter changes and almost no safe span change. There is no direct relationship among the pipe length, the optimum diameter, and the safe span length.

(5) When we increase the manning roughness coefficient by 800%, only a 30.86% increase in the optimum diameter appears. On the other hand, the safe span will show nearly no change in its value for the manning coefficient of more than 0.03. This agrees with what is mentioned by the authors of ref. [13], as the effect of the manning coefficient is not high until it reaches n = 0.015, at which the aqueduct's hydraulic state is undesired.

Conflict of interest: The authors declare that they have no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are comprised in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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