Hydraulic Calculations Relating to the Flooding and Draining of the Roman Colosseum for Naumachiae

Research Report

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This report includes full details of the calculations used in determining flows into and out of the Colosseum. It should be read in conjunction with the published paper.

Contents

1. Flow in the Aqueduct

Figure 1: Scaling of Aqua Claudia (tape is extended to 1m)

1.1 Channel Size (see figure 1)

Note: following calculation is based on original sized digital figure (file 1 attached).
Above figure illustrates the principle only.
From the figure, 1 pixel of original figure = 0.0179m.
Height of channel = 82 pixels or 1.46m
Width = 47 pixels or 0.84m.

1.2 Channel Slope Readings

Elevation 8km outside city= 77m to channel (height from ground estimated by counting stones of known dimension), ground height by GPS
Elevation of Colosseum Arena Floor 17m (GPS)
Approximate height of Caelian above arena floor = 25m
Thus probable head of aqueduct outside Colosseum = 17+25 = 42m
Difference from 8km outside city = 77 – 42 = 35m
Average Slope of Aqueduct = 35/8000 = 0.004375, 1:229 or 0.4375%

1.3 Manning's Formula Flow Calculation

Assume depth of flow = 1.25m
A = 0.82*1.25=1.05
P= 0.84+(2*1.25)=3.34

R = A/P = 0.314
S= 0.004375
n= 0.015

Thus v= 2.03 and Q = vA = 2.13 cumecs or 184069m^3 per day

Frontinus has 184000m^3/day or 2.12 cumecs.

2. Flow in the Pipes from the Caelian Hill to the Colosseum
Assumed diameter = 0.3m
Assumed Head Difference =25m
Assumed Length = 300m
Slope = 25/300 = 0.08333
Assumed Hazen Williams C = 90
$v= 0.354*D^{0.63}*C*S^{0.54} = 0.354*0.3^{0.63}*90*0.08333^{0.54}$ = 3.9m/s
$Area=\pi D^2/4=0.0707m^2$
Q=vA=0.275 cumecs
Flow in 4 pipes = 1.03 cumecs.

3. Flow through the Arena – WaterCAD Analysis
This analysis is described in the paper. The parameters are repeated here for convenience.

The software used was Haestad Methods WaterCAD version 1.5.

Input data is given in Table 1. A sample WaterCAD input file is appended as file 2. The file appended includes pipe diameters at 150mm; these need to be edited individually to reproduce the other results. Full results are included in the paper.

Table 1: Details of network data used for simulation of flow through arena

Network Component	**Details**
Note: all pipes with Hazen-Williams C of 90 and minor loss coefficient of 0.37	
Reservoir at Caelian Hill	Constant surface elevation 50m
Pipe connecting Caelian and Colosseum	Length 300m, diameter 300mm.
Outer ring	Made up of 6no pipes each of 22m length. Constant elevation 25m. Diameters varied from 150-250mm
Radial connexions	7no pipes each of 66.50m length with free outfall at downstream end.
Hypogeum	Tank of base elevation 19m.

4. Drainage of the Colosseum – MATLAB Analysis
This calculation was based on a free outflow from a reservoir, ie:

$$\frac{b}{n} y_2^{5/3} s^{1/2} = b y_2 \sqrt{2g(y_1 - y_2)} = Q$$

Where y_1 is the upstream (reservoir) depth and y_2 the depth in the channel.

In this case this was solved by a simple explicit finite difference scheme. Initially y_1 is the initial depth in the hypogeum (1.5m – depths taken above the outlet invert). The equation gives y_2 and hence the outflow discharge Q, allowing the new y_1 to be determined at the next timestep.

The MATLAB program is appended as file 3. It operates from the MATLAB command window with the following command line

coldrain(slope, n, dt, resultsfilename)

slope is the outflow channel slope as a decimal, n the Manning's n, dt the timestep and resultsfilename a text string giving the file name to be written.

Sample results are attached as file 4. The results are formatted in three columns as follows:

Slope	time	depth
Manning's n	"	"
Time Step	"	"
Not used	"	"
….	…	…
Not used	"	"

The tests were run using MATLAB 6.5.

5. Attached Files

The following files accompany this report:

File Number	Filename	Description
File 1	colrr_fig1.jpg	Full size version of Fig 1 for scaling
File 2	colrr_wa.wcd	WaterCAD input file
File 3	colrr_matlabdrain,m	MATLAB script for drainage calculation
File 4	colrr_drainresultsexample.txt	Example results from MATLAB script