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UNSTEADY FLOW SIMULATION (HYDRAULIC MODEL TEST)

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1. Introduction.

Modernization of agriculture, industrialization and improvement of lifestyle have brought increased water requirements and greater fluctuation of them. Thus, water resources have come to be crucial and are of paramount importance to the maintenance and progress of civilization as it is known today. Under these considerations, unsteady supply of water is required in order to balance the fluctuating water requirements with the control of surplus water during the water management.

Facilities such as check gates, regulating reservoirs, small ponds, offtake regulators, etc. have been adopted as facilities to provide the distribution system with appropriate buffer function and to make efficient unsteady water supply. In order to distribute and manage water efficiently and to operate properly those facilities, it is necessary to simulate the hydraulic behavior of the distribution system at arbitrary points and times.

Due to most problems related to gradually varied unsteady flow require the a numerical solution of governing equations (continuity and motion equations) and associated boundary conditions, this paper shows the application of the theory of gradually varied unsteady flow and its simulation through the performance of a hydraulic model test in an experimental channel.

The simulation was performed using the software JICA96A.FOR (discharge and water depth as boundary conditions) and JICA96B.FOR (water depth upstream and downstream as boundary conditions).

2. Objectives.

The main objectives of the hydraulic model test were:

a) To understand the procedure of making unsteady flow simulation at a project site.

b) To verify the efficacy and applicability of unsteady flow simulation model in order to describe the hydraulic behavior of an open channel.

3. Unsteady flow analysis.

The governing equations of gradually varied unsteady flow are the continuity and motion equations. These equations consider that the curvature of the wave profile is mild; the change in the water depth is gradual; the vertical component of the acceleration of the water particles is negligible in comparison with the total acceleration; and the change in total head depends on the effects of friction and acceleration. In general, the fundamental equations can be expressed as follows:

a) Continuity equation.

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}+q'=0$$

b) Motion equation.

$$\frac{\partial y}{\partial x}+\frac{\alpha V}{g}\frac{\partial V}{\partial x}+\frac{1}{g}\frac{\partial V}{\partial t}+\frac{\partial z}{\partial x}+S_f=0$$

where Q is the discharge, A is the flow cross-sectional area normal to the direction of the flow, V is the mean velocity, q' is the laterally discharge per unit length, y is the water depth, x is the length of the channel, t is the time, g is the gravity acceleration, α is the energy coefficient or *Coriolis* coefficient, S_f is the energy line slope, and z is the vertical distance of the channel bottom above the datum.

The mathematical model for unsteady flow simulation considers difference expressions of fundamental equations and an operational grid system. The software JICA96A.FOR and JICA96B.FOR were developed under those considerations.

4. Procedure.

The hydraulic model test was divided in two stages: experimental stage and data analysis stage.

4.1. Experimental stage.

This stage was conducted at the Hydraulics Laboratory of the National Research Institute of Agricultural Engineering, Tsukuba, as it is explained below.

a) The lucite experimental channel was surveyed to get the bed elevation and bottom with. In addition, the grid system was defined considering an interval of 2 meters among meshes.

b) Automatic water level recorders (servo-meter) were installed along the experimental channel at meshes 2, 22, 48, and 70 in order to record water depths.

c) The hydraulic model test was carried out regarding four different trials. Each trial lasted 5 minutes (300 seconds).

Case 1: Discharge was increased from 11.9 l/s to 25.6 l/s.
Case 2: Discharge was decreased from 26.3 l/s to 12.5 l/s.
Case 3. Discharge was increased from 4.1 l/s to 21.2 l/s.
Case 4. Discharge was decreased from 21.2 l/s to 5.1 l/s.
The variations were made operating a valve upstream end of the channel.

d) For each case, the water depth was recorded at meshes 2, 22, 48, and 70, and the discharge was measured every 30 seconds downstream end using a triangular weir.

e) Water depth, measured at meshes 2 and 70, and discharge, measured using the triangular weir, were used as boundary conditions.

4.2. Data analysis stage.

4.2.1. Estimation of roughness coefficient (n) for the experimental channel.

a) Firstly, two values of n were assumed, in most cases 0.008 and 0.013. Using initial discharge and water depth as boundary conditions upstream end and downstream end, respectively, the software JICA96A.FOR was executed for each value of n (steady flow condition).

b) With calculated water depth (h_c) and initial measured water depth (h_o), the ratio h_c/h_o was calculated for the mesh 22. Then, the relationships h_c/h_o and each assumed value of n were plotted and the actual value of roughness coefficient

was estimated regarding h_c/h_o equal 1. The same procedure was repeated to determine h_c/h_o at mesh 48, however, from mesh 2 to mesh 22 the estimated value of *n* was considered. The actual value of *n* from mesh 50 to mesh 70 was determined considering the estimated values from mesh 2 to mesh 48 and following the procedure described above.

c) The steps a and b were performed for every case.

4.2.2. Simulation of unsteady flow to determine the relationships water depth-time, and discharge-time.

a) The hydraulic parameters, water depth and velocity, corresponding to steady flow condition were calculated using the average values of *n* and initial discharge and water depth for each trial. The JICA96A.FOR was used for this purpose.

b) The data file to execute the unsteady flow simulation, for each case, was prepared using the water depth and velocity, estimated in the former step, as initial conditions at each mesh. Water depth was used as boundary condition upstream (mesh 70) and downstream (mesh 2) ends.

c) The software JICA96B.FOR was executed for each case using the created data files. Then, the relationships water depth-time at meshes 22 and 48, and discharge-time at meshes 3, 21, 47, and 69 for every case were drawn.

5. Results and results' analysis.

5.1. Estimation of the roughness coefficient.

The table 5.1 and figure 5.1 show the estimated roughness coefficient for the experimental channel.

Table 5.1. Estimated roughness coefficient.

Mesh	Case 1	Case 2	Case3	Case 4	Average
2-22	0.0102	0.0101	0.0127	0.0106	0.0109
24-48	0.0084	0.0083	0.0083	0.0083	0.0083
50-70	0.0097	0.0092	0.0099	0.0095	0.0096

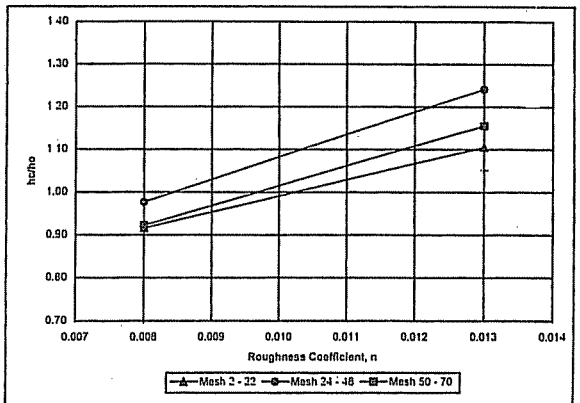

Figure 5.1. Estimated Roughness Coefficient. Case 1

According to Chow V. T., the roughness coefficient varies from 0.008 to 0.010 for lucite, material of what the experimental channel was made of. For all cases, the estimated values of roughness coefficient, from mesh 24 to mesh 70, are within that range. However from meshes 2 to 22, the estimated roughness coefficient is more than 0.010, especially the case 3, in which the lowest initial discharge was used.

Two reasons could explain this result, i) from meshes 2 to 22, the channel included a culvert and two curves where the construction joins were defective, so that, the roughness coefficient might be increased; ii) as consequence of the existence of two curves, the velocity distribution at these sections is modified, therefore, the Manning

equation could not be applied to describe the hydraulic behavior, consequently the estimations of roughness coefficient made using such formula might be not representative.

5.2. Simulation of unsteady flow to determine the relationships water depth-time and discharge-time.

Analysis of water depth at meshes 22 and 48, for all the cases, shows that the deviation between measured and estimated water depth is not considerable. The maximum deviation occurred in increasing discharge trials (case 1 and 3) at mesh 48, where the measured water depth shows a wavy behavior. This issue indicates the not uniform valve operation when the discharge was increased. At mesh 22, the wavy path disappeared probably as a consequence of the buffer function of the channel. In decreasing discharge trials (case 2 and 4), the measured water depth did not show wavy behavior at mesh 48 after the valve operation. See figures 5.5 to 5.9.

Analysis of relationships discharge-time is very useful to determine the arrival time and related velocity of water wave at different meshes (sections) of the channel, when increasing discharge conditions are being considered. In practical cases, these conditions happen when a storm occurs. The arrival time and velocity of water wave are very helpful hydraulic parameters to decide the proper operation of supplying, regulating, control, and protecting facilities of open channels because they tell us when and how to open or close such structures.

The arrival times in case 3 are larger than those of trial 1 due to the initial discharge in case 3 was smaller than in case 1, consequently the velocity of the water wave was lower and then larger arrival times resulted. In fact, the wave velocity for case 3 was 1.0 m/s, meanwhile in case 1 was 1.2 m/s.

Relationships discharge-time for decreasing discharge conditions are also useful to determine the proper operation of regulating, control, and protecting facilities, then ensuring the water supply. See figures 5.13 and 5.16.

Regarding all cases, the hydraulic behavior of gradually varied unsteady flow, and its simulation through a mathematical model, is affected by the boundary conditions upstream and downstream ends, i.e. initial and final water depth and discharge; the variation range of them; operation of facilities, and the time interval considered to make the variation of hydraulic parameters and to execute the simulation analysis.

6. Conclusions.

According to the hydraulic model test results, the following conclusions were formulated:

a) The deviation between the measured and calculated water depth and discharge for all the cases was no considerable, so that, the unsteady flow simulation was successful.

b) The unsteady flow simulation is an useful and powerful tool to describe the hydraulic behavior of an open channel and constitutes the best way to decide the most proper operation of supplying, regulating, control, and protecting facilities of water distribution systems.

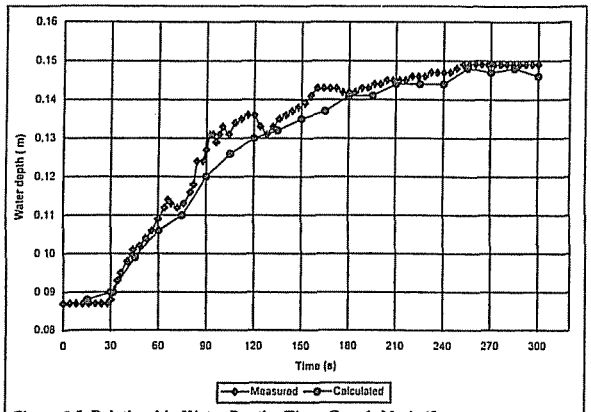

Figure 5.5. Relationship Water Depth - Time. Case 1. Mesh 48

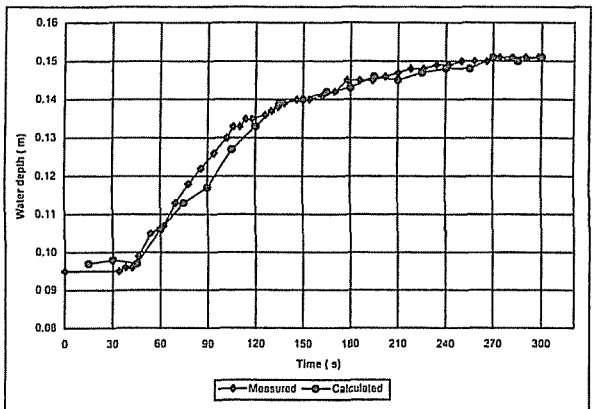

Figure 5.6. Relationship Water Depth - Time. Case 1. Mesh 22

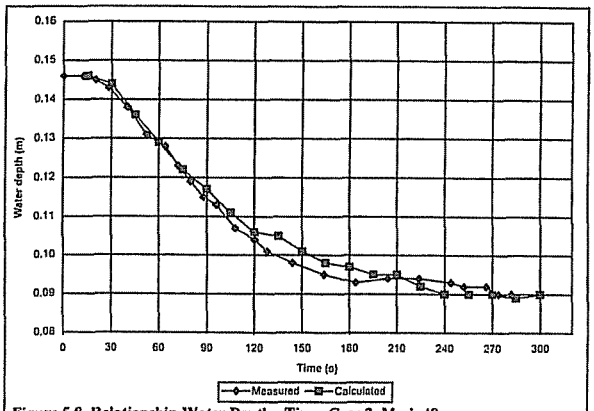

Figure 5.8. Relationship Water Depth - Time. Case 2. Mesh 48

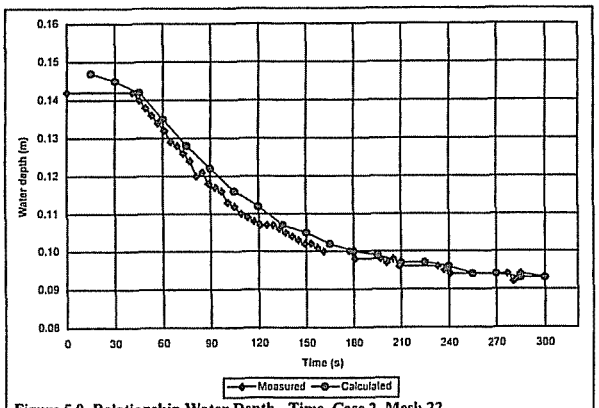

Figure 5.9. Relationship Water Depth - Time. Case 2. Mesh 22

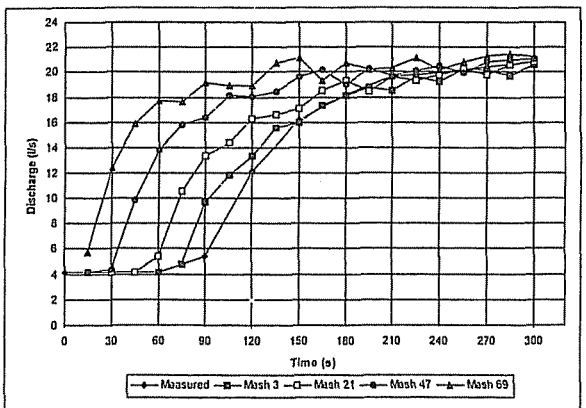

Figure 5.13. Relationship Discharge - Time. Case 3

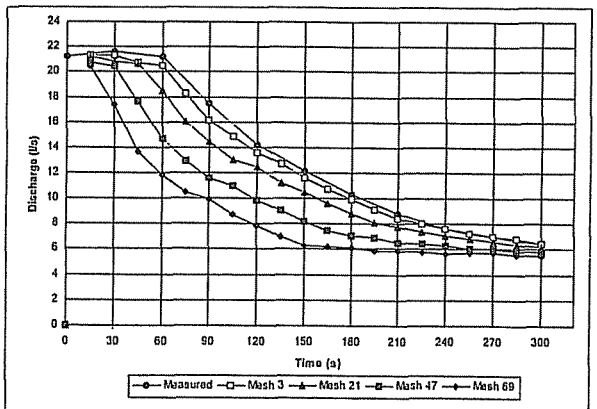

Figure 5.16. Relationship Discharge - Time. Case 4

c) In order to get accurate determinations of hydraulic parameters (water depth and discharge), using unsteady flow simulation, it is essential to estimate with accuracy the roughness coefficient of the channel and to pay special attention on definition of boundary conditions upstream and downstream, i.e. initial and final discharge and water depth, the variation range of them; operation of facilities, and the time interval considered to make the variation of hydraulic parameters and to execute the simulation analysis.

7. References.

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