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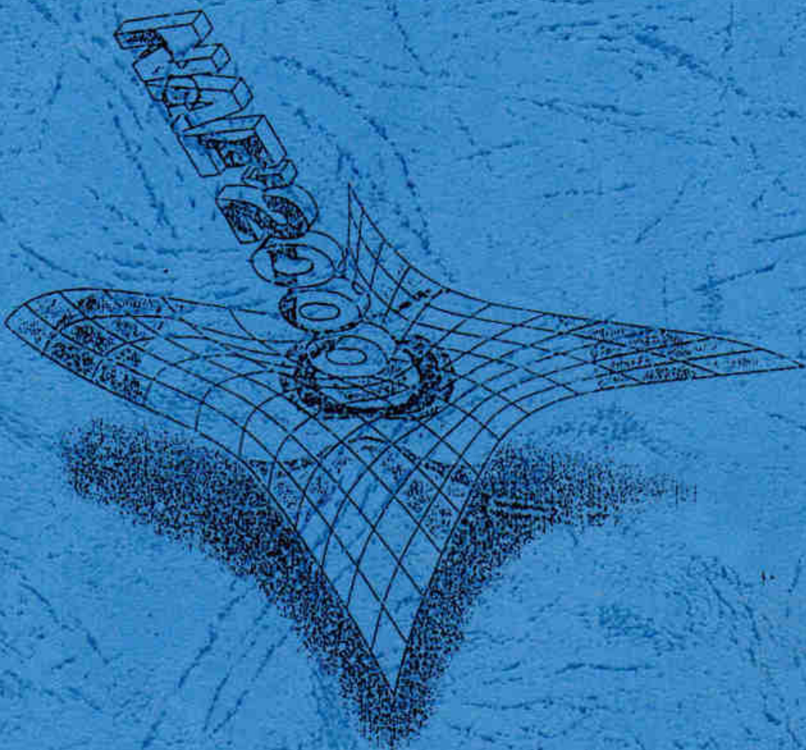

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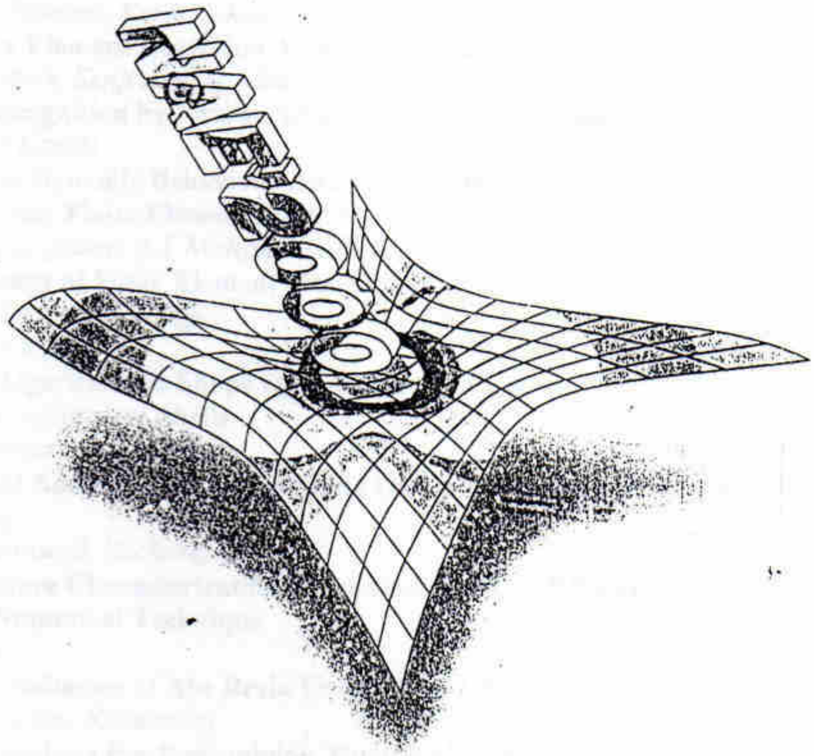

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USING 1-D MODEL TO SOLVE THE UNSTEADY FLOW IN THE ESTUARY AS A NAVIGATION CHANNEL

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Abstract

In the estuary as a navigation channel, the predominant problems are current and sedimentation. The sedimentation that occurs in the navigation channel will have influence to the availability of the keel clearance of the ship. In order to fullfill the demand of this water-depth, consequently the dredging work has to be done periodically.

Estuary gets influence from the upstream boundary condition (discharge hydrograph) and downstream boundary condition (tidal hydrograph). The unsteady flow of the estuary is determined by both of these boundary condition and physical condition of the channel such as cross section area, friction, slope.

Simulation of the 1-D model is conducted in order to solve the unsteady flow. The dredging work causes the changing of the water-depth and cross section area. The result of the simulation gives the insight the changing of the water-depth that can be used for the operational of the ship over the navigation channel.

1. Introduction

The estuary can be used as a navigation channel. In this circumstance, port or harbour lay on the side of the river. During the ship sailing from the port or harbour to the open sea, and vise versa, it was need the minimum water-depth in order to get the safety sailing. Keel clearance or the minimum water-depth that should be available in the navigation channel is depend on several factor, such as draft of the ship, wave induced squat, type of the bed load sediment.

Estuary is the area that gets influence from the upstream boundary condition (discharge hydrograph) and downstream boundary condition (tidal hydrograph). The predominant matters of the estuary are current and sedimentation. Sedimentation process will caused the reducing of the availability of keel clearance. Therefore, the dredging work has to be done periodically. Dredging work is costly; therefore the prediction of the increasing keel clearance by means of deepening bottom of the channel should be computed carefully.

In order to solve the unsteady flow in the estuary area by means of the analytical (exact) solution of the governing equations by direct integration is almost impossible for most practical problems. The application of the numerical method and aiding by computer tools become more powerful to solve the unsteady flow. At time being, a lot of software of 1-D unsteady flow models are available. In order to use this mathematical model properly, the insight of the theory and knowledge of the physical (nature) phenomena are needed.

2. Finite Difference

The equations to describe one-dimensional, unsteady, open-channel flow can be derived from balances of mass and momentum. These hydrodynamic equations can be written in many different forms but the most common form for river and channel flows is that of de St. Tenant described in Equation 1 for mass and Equation 2 for momentum.

$$\frac{\partial h}{\partial t}+\frac{1}{b}\frac{\partial Q}{\partial x}=0 \quad (1)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}(\beta\frac{Q^2}{A})+gA\frac{\partial}{\partial x}(h+H)+gAS_f=0 \quad (2)$$

Where:

Q = discharge (m^3/s)
h = water-depth (m)
b = storage width (m)
A = cross sectional area (m^2)

$S_f = |Q|\, Q/K^2$

$K = cA\sqrt{R}$

K = conveyance (m^3/s)
C = chezy resistance coefficient ($m^{0.5}/s$)
R = hydraulic radius (m)
β = boussineq coefficient
H = bottom elevation (m)
g = gravity (m/s^2)

Each of the equation is a continuous description of a hydraulic phenomenon. The equations represent continuous functions that describe the relationships between various fluid descriptors at every point in space (x) and time (t). Exact solutions of the equations would themselves be continuous functions describing the unknown variables in terms of the independent variables x and t. Such a solution function can be represented as a surface above the x-t plane.

The analytical (exact) solutions of the governing equations by direct integration is almost impossible for most practical problems. A very powerful method for solving problems of free surface flows is the Method of Characteristics. However, due to its complexity for general problems it is used mainly to assist in the specification of the boundary data required in a numerical computation.

A wide range of numerical methods has been developed to solve the governing equations using computers. By far the most commonly used numerical methods used in hydraulic engineering practice are finite difference methods.

The finite difference method of solution involves a transformation of the continuous descriptions of the phenomena into discrete equations where the values of the unknown variables are calculable only at predetermined points in space and time.

By introducing a superscript n for time level and subscript j for space level then a point on the x-t plane located a distance $n\Delta t$ from the time origin and $j\Delta x$ from the space origin can be denoted as h_j^n. This point and points surrounding it can be denoted as shown in Figure 1.

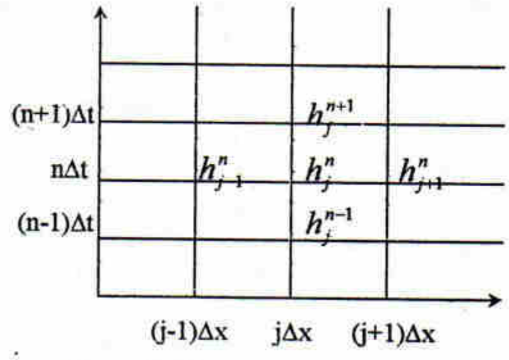

Figure 1. Discrete values of h(x,t)

In order to solve the governing equations numerically they must be discretised on x-t plane. For example, the differential term $\partial h/\partial x$ represents the tangent of the depth function in the x-direction. This can be discretised in one of the following ways:

a. $\left(\frac{\partial h}{\partial x}\right)_j = \frac{h_{j+1}-h_j}{\Delta x}$

forward difference approximation

b. $\left(\frac{\partial h}{\partial x}\right)_j = \frac{h_j-h_{j-1}}{\Delta x}$

backward difference approximation

c. $\left(\frac{\partial h}{\partial x}\right)_j = \frac{h_{j+1}-h_{j-1}}{\Delta x}$

centred difference approximation

In the above explanation it was seen the explicit schemes. The time step used by these schemes is restricted by the Courant condition. Furthermore, the time step restriction will be given a more precise formulation as a preliminary to investigating the implicit schemes, where it can be made considerably less onerous.

The terminology of an implicit scheme will now be applied here to any scheme that has a definite order or direction of computation in the space of the independent variables. In such a scheme, two or more unknowns at the upper time level are related to one another in each elemental operator, so those unknowns are linked between operators and, through these, to the upper-time boundary conditions. The unknowns are thus defined implicitly and not explicitly relative to other values known at lower time levels. Correspondingly, so long as the operators are connected to make a computation possible at all, an explicit scheme is one that is indifferent to the order or direction of computation in the space of the independent variables (see Minns et. al, 1997).

The order of computation of an implicit scheme is called the algorithmic structure of the scheme. Thus the scheme has two algorithmic structure, the one, a left to right sweep, and the other, a right to left sweep.

An implicit scheme made by A.Preissmann in Sogreah (see Wignyosukarto, B., 1986) can be described in the following finite difference equation:

$$\frac{\partial f}{\partial t} \approx \frac{1}{2}\left(\frac{f_{j+1}^{n+1} - f_{j+1}^{n}}{\Delta t} + \frac{f_{j}^{n+1} - f_{j}^{n}}{\Delta t}\right)$$

$$\frac{\partial f}{\partial x} \approx \theta \frac{f_{j+1}^{n+1} - f_{j}^{n+1}}{\Delta x} + (1-\theta)\frac{f_{j+1}^{n} - f_{j}^{n}}{\Delta x}$$

$$f(x,t) \approx \frac{\theta}{2}(f_{j+1}^{n+1} + f_{j}^{n+1}) + \frac{1-\theta}{2}(f_{j+1}^{n} + f_{j}^{n})$$

$$\tfrac{1}{2} \le \theta \le 1$$

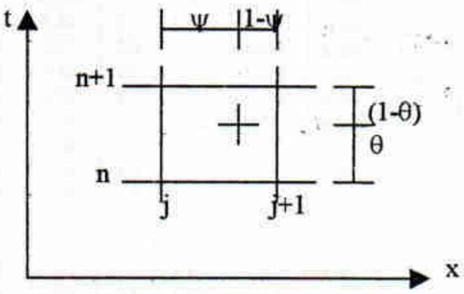

Figure 2. Scheme of the Preissmann type.

3. Channel Depth

The development of supertankers about a decade ago has led to increases in ship sizes for other cargoes as well. This increase in ship dimensions – including draft- has led to a need for deeper and wider harbour approach channels. The additional depth also means that the channel will be longer, too, in view of the usual sea bed slope near coasts. The volume of material that must be dredged in order to provide one unit of extra channel depth increases rapidly as the channel depth increases. All of these factors combined with the increasing scarcity of capital for such large-scale investments make it necessary to optimise the depth of ship channel chosen.

The most well known sources of depth data are hydrographic charts published for mariners. Because these charts are for mariners, the charted depths are the shallowest depths in the vicinity; the actual seabed lies below the surface defined by the charted depths. Thus, dredging quantities especially initial dredging quantities – estimated using such chart tend to be too high (Bijker, 1997).

4. Research methodology

Flow model system consist of the pre-processor to select and entry data, the computing program to solve the flow equation, and the post-processor to show the result and can be read easily.

In the mathematical model, a hundred percent reproduction of the nature is impossible. Therefore a simplification of the system is needed. Calibration has to be done in order to achieve a good approximation between the mathematical model and physical system.

In order to know the influence of the deepening the bottom of channel, as input data are upstream boundary condition (discharge Q), downstream boundary condition (level of tide h), cross section area, slope of the channel, bottom friction (chezy or manning coefficient). This in put data is used for any kind of the slope of the bottom. Dredging work causes the changing of the slope of the bottom of the channel. The result is the water-depth. The expectation of the result is the value of deepening bottom's channel is not equal with the increasing of water-depth.

5. Result and discussion

Model simulation is carried on the channel that 19 sections divide the channel, and every section has 500 m length. The Q = 50 m^3/s, coefficient of manning = 0.027, and rectangular channel with wide of the bottom b = 50 m. A is bottom height (as reference level is horizontal line), and B is water-depth. For h = 4.50 m the result can be illustrated as follows:

Table 1. Model simulation of h = 4.50 meter

A1 m	B1 m	A2 m	B2 m	A3 m	B3 m	A4 m	B5 m
0.00	4.50	0.0	4.5	0.00	4.50	0.00	4.50
0.13	5.14	0.1	5.28	0.08	5.28	0.03	5.32
0.25	5.49	0.2	5.67	0.15	5.67	0.05	5.74
0.38	5.71	0.3	5.93	0.22	5.94	0.08	6.03
0.50	5.90	0.4	6.12	0.30	6.13	0.10	6.26
0.63	6.03	0.5	6.27	0.38	6.29	0.13	6.44
0.75	6.15	0.6	6.40	0.45	6.43	0.15	6.61
0.88	6.24	0.7	6.50	0.52	6.54	0.18	6.74

1.00	6.32	0.8	6.58	0.60	6.64	0.20	6.87
1.13	6.39	0.9	6.66	0.68	6.72	0.23	6.98
1.25	6.46	1.0	6.73	0.75	6.80	0.25	7.08
1.38	6.51	1.1	6.79	0.82	6.87	0.28	7.17
1.50	6.56	1.2	6.84	0.90	6.93	0.30	7.25
1.63	6.60	1.3	6.88	0.98	6.98	0.33	7.33
1.75	6.63	1.4	6.93	1.05	7.03	0.35	7.41
1.88	6.65	1.5	6.96	1.13	7.08	0.38	7.48
2.00	6.71	1.6	7.00	1.20	7.12	0.40	7.54
2.13	6.74	1.7	7.03	1.27	7.16	0.43	7.60
2.25	6.80	1.8	7.07	1.35	7.20	0.45	7.66
2.38	6.83	1.9	7.10	1.42	7.23	0.48	7.71

The section number 8 for example, the deepening of 0.8 meter (or height of the bottom of 1.00 m to 0.2 m), causes increasing water-depth in order of magnitude 0.55 meter (or 6.32 m to 6.85 m). For the 16th section, the deepening of 1.6 meter led to increasing water-depth of 0.83 meter.

For h = 5.00 m, the result can be illustrated in Table 2 as follows:

Table 2. Model simulation of h = 5.00 meter

A1 m	B1 m	A2 m	B2 m	A3 m	B3 m	A4 m	B5 m
0.00	5.00	0.0	5.00	0.00	5.00	0.00	5.00
0.13	5.70	0.1	5.50	0.08	5.50	0.03	5.54
0.25	5.91	0.2	5.82	0.15	5.82	0.05	5.89
0.38	6.07	0.3	6.04	0.22	6.05	0.08	6.14
0.50	6.19	0.4	6.21	0.30	6.22	0.10	6.35
0.63	6.28	0.5	6.36	0.38	6.36	0.13	6.51
0.75	6.36	0.6	6.47	0.45	6.49	0.15	6.67
0.88	6.42	0.7	6.57	0.52	6.59	0.18	6.79
1.00	6.47	0.8	6.66	0.60	6.68	0.20	6.91
1.13	6.52	0.9	6.73	0.68	6.75	0.23	7.02
1.25	6.56	1.0	6.80	0.75	6.83	0.25	7.12
1.38	6.59	1.1	6.85	0.82	6.90	0.28	7.20
1.50	6.62	1.2	6.91	0.90	6.95	0.30	7.28
1.63	6.66	1.3	6.95	0.98	6.99	0.33	7.36
1.75	6.70	1.4	7.00	1.05	7.04	0.35	7.43
1.88	6.77	1.5	7.04	1.13	7.09	0.38	7.49
2.00	6.77	1.6	7.07	1.20	7.13	0.40	7.56
2.13	6.62	1.7	7.11	1.27	7.17	0.43	7.62
2.25	6.71	1.8	7.15	1.35	7.20	0.45	7.67
2.38	6.36	1.9	7.18	1.42	7.23	0.48	7.72

The section number 8 for example, the deepening of 0.8 meter, causes increasing water-depth in order of magnitude 0.44 meter. For the 16th section, the deepening of 1.6 meter led to increasing water-depth of 0.79 meter.

And for the h = 5.50 m, the result can be illustrated in table 3 as follows:

Table 3. Model simulation of h = 5.50 meter

A1 m	B1 m	A2 m	B2 m	A3 m	B3 m	A4 m	B5 m
0.00	5.50	0.0	5.50	0.00	5.50	0.00	5.50
0.13	5.99	0.1	5.77	0.08	5.81	0.03	5.85
0.25	6.15	0.2	5.98	0.15	6.05	0.05	6.12
0.38	6.28	0.3	6.14	0.22	6.23	0.08	6.32
0.50	6.38	0.4	6.27	0.30	6.37	0.10	6.50
0.63	6.45	0.5	6.38	0.38	6.49	0.13	6.65
0.75	6.52	0.6	6.47	0.45	6.60	0.15	6.79
0.88	6.58	0.7	6.55	0.52	6.70	0.18	6.90
1.00	6.63	0.8	6.62	0.60	6.79	0.20	7.01
1.13	6.67	0.9	6.69	0.68	6.85	0.23	7.11
1.25	6.71	1.0	6.74	0.75	6.92	0.25	7.20
1.38	6.75	1.1	6.79	0.82	6.98	0.28	7.27
1.50	6.77	1.2	6.84	0.90	7.03	0.30	7.35
1.63	6.82	1.3	6.87	0.98	7.08	0.33	7.42
1.75	6.82	1.4	6.91	1.05	7.12	0.35	7.49
1.88	6.86	1.5	6.95	1.13	7.16	0.38	7.55
2.00	6.92	1.6	6.98	1.20	7.20	0.40	7.61
2.13	7.17	1.7	7.02	1.27	7.24	0.43	7.67
2.25	7.20	1.8	7.05	1.35	7.28	0.45	7.72
2.38	7.32	1.9	7.10	1.42	7.30	0.48	7.77

The section number 8 for example, the deepening of 0.8 meter, causes increasing water-depth in order of magnitude 0.38 meter.

Sections that nearby the boundary condition do not show stable yet. The increasing of water-depth is less than deepening of bottom channel. Therefore, the dredging work should be done carefully in order to reach the requirement of keel clearance. The comparison between deepening and increasing of water-depth can be seen in figures as follows:

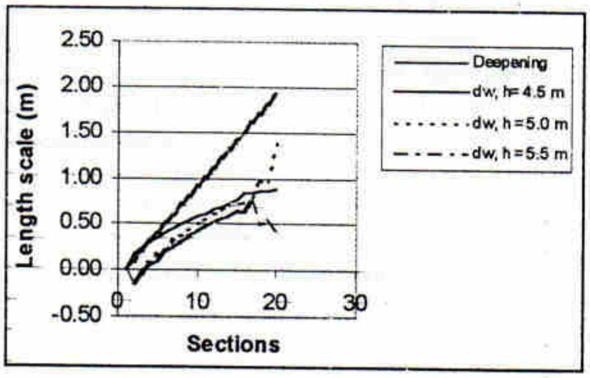

Figure 3. Comparison between deepening of bottom channel and increasing of water-depth

6. Conclusions

a. 1-D model can be used to solve the unsteady flow in the estuary as a navigation channel.
b. There are different between the magnitude of deepening of the bottom channel by dredging work and increasing of water-depth.

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