FORECASTING POSSIBLE ECOLOGICAL STRESSES IN RIVER ESTUARIES AS A RESULT OF ACCIDENTS AT MAIN OIL PIPELINES

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Issues of forecasting possible ecological stresses in river estuaries as a result of accidents at the main oil pipelines particularly, identification of the trajectory of oil jet flowed into the estuary are reviewed. Linear idealization of the velocity distribution in the river is used at the first stage of identifying the trajectory of the oil jet flowed into the estuary which is a one-branch river mouth expanding towards the sea. In this case, the jet trajectory has a very complicated shape, initially it runs down and then, when it reaches the point, where the flow changes its direction, the radius of the jet curve changes. The jet makes loop and just after this comes up to the flow surface. Mathematic program, Maple 95 does not provide an evident mathematic solution since the presence of the jet loop creates certain uncertainties. In order to avoid such difficulties, a modified sub-program of Maple 95 will be written according to which the calculation of the jet coordinates is run by areas. In particular, the program terminates the calculation and initiates recalculations as soon as the jet trajectory changes its direction. The difference between the results obtained and the in-situ data does not exceed 15-20%. Thus, it is evident that the method suggested for preliminary engineering evaluation is quite acceptable.

Key words: ***Oil-trunk pipelines, estuary, system approach, flow turbulence.***

As it is known, oil is viscous oily liquid of dark brown color and poor fluorescence. Oil and oil products are the most widespread polluting substances of the world ocean. In the 80ies of the last century, 10,23% of the world's oil production flowed into the ocean. The largest oil spill is associated with its transportation from the production region.

Estuary (uestuarium in Latin – submerged mouth) is a one-branch month expanding towards the sea. Estuary is formed when the drifts brought by the river are taken by the sea flow or tide and part of the sea which is adjacent to the mouth is too deep. In such case the drift would not deposit even if it is transported at a long distance into the sea. The velocity of the tidal flow at the mounts of big rivers is added to the velocity of the river flow. Therefore, strong flow from the river to the sea is formed during the tide. The drift is transported beyond the river month and during tide it is subject to strong washing. The largest estuary (Gironde) in Europe is 75 km long. Gironde (France) is a common mouth of rivers Garonne and Dordonne which is connected to the Gulf of Biscay. Its smallest depth at the fairway is 8m. Such rivers as Yenisei and Amur (Russia), Thames and Hamber (Great Britain), Sena (France), Yangtze (China) have typical mouths in form of estuaries. The controversy to the estuary is delta – the mouth which is split into several flows. Rivers like Nilos, Amazon, Volga have classical deltas. For estuary formation it is necessary that the velocity of the low tide exceeds the velocity of the high tide and in addition, there should be the drift deficit in the mouth. The best example would be the comparison of two big rivers of China – Yangtze and Hwang Ho. Their annual liquid flows are respectively 126 and 690 km^3 and solid – 1887 and 501 million tons. Therefore, there is disproportion between the liquid and solid downflows and hence, the estuary is formed, and there is the excessive drift at the Hwang Ho mouth which is formed by delta.

In the intercommunication of fresh and sea waters within the estuary, in order to evaluate the role of the tide, let's briefly review various types and factors of estuarial circulation which are the most important in their formation. From hydrodynamics point of view, the estuary classification specifying the estuarial circulation and providing identification of the most part of effective forces and processes contains a lot of parameters the majority of

which is unknown. From application point of view, empirical classification based on just one, R/V nondimensional parameter, where R and V are respectively the volumes of fresh water and sea water entering the estuary during the tide of the estuaries, is simpler [1,2].

According to the R/V relation value, all the estuaries can be split into four types (table 1). If the tide volume V is less than the fresh water volume, i.e. R/V>1, then the fresh water will float on the surface of the denser salt water without any significant mix up and the estuary is formed with the salty wedge. It consists of two water layers: fresh on the surface and salty in the lower layer. Water salinity is almost equal along the entire estuary length. Change between the layers is bounded by the frontal zone between the layers where the main part is plaid by the turbulence intensity. If the tide volume equals to or is more than the river downflow, then the relation R/V = 0,1-1,0 and the estuary will turn into the strongly stratified or partially mixed estuary. Fresh water motion in the upper layer of the strong tidal flow creates the displacement on the separating surface which excites instability in form of periodically originated and destroyable internal waves. Crests of the destroyable waves go beyond the separating surface and transport salt water to the higher level in form of take away. When R/V=0,005-0,1, then the estuary turns into the poorly stratified estuary which is often called partially mixed estuary. The tidal flow is so strong at this moment, that the motion of the entire water mass becomes turbulent. Consequently, the change of the mass and salt between the upper and lower layers occur at the both sides. When the tidal volume increases and the relation R/V<0,005, then the turbulent mix up is so intense that the difference in the salinity of the upper and lower layers vanishes and the estuary turns into the vertically mixed estuary [2].

Table 1

Type	R / V	Circulation	Stratification
1	≥ 1	Poor	Salty wedge
2	0,1 – 1,0	Partially mixed estuary with taking salt from the bottom layer of the water to the upper one	Strong
3	0,005 – 0,1	Partially mixed estuary	Poor
4	≤ 0,005	Vertically mixed estuary	No

In the tidal mouth of the rivers the major mechanism of regulating the distribution of the drift concentrations is the estuarial circulation [3]. It is formed in case of quite large vertical and horizontal water density gradients. In the upper flow part, in case of positive water surface inclination, the flow is directed to the sea. In the lower flow part, the flow is conditioned by latitudinal density gradients and the flow is directed to the river. Necessary condition for the formation of the estuarial circulation in the stratified flow is the inclination of the boarder separating various density waters towards the sea. According to the tide phase, the river and sea water intercommunication zone shifts towards the bed. The result of flow averaging and salinity distribution (during the tide cycle) is the remaining estuarial circulation. At such mouths, at the bottom, in the river bed, there is always provisional "zero" point, where there is no flow. The flow above this point is directed to the sea and below it – there is a reverse river-directed flow. Averaged condition of the "zero" point, as a rule, complies with the density gradient distribution limit towards the river. It separates the bottom flow of the drift directed from this point to the upper level and the lower level to the reverse direction.

Resulting motion at the bottom towards the river, high velocities of the tidal flow and strong turbulence result in the formation of a maximum turbidity zone in the "zero" point region within which high concentration of the bottom drift, the so called "silt plug" or "turbidity plug" would often create.

The most interesting is the case when liquid left from the coordinate source is denser than right from it. This is the case in the estuaries [4-6] and it is characteristic to the salination (salt penetration). In such estuaries the sea shore of which is located within the section with the coordinate x=0, the velocity U_r corresponds to the stationary river flow containing fresh water. If the consumption of the fresh water in the estuary is constant and constant is the tide wave amplitude from the sea side, then for the observer which moves by the periodic tide velocity, there exists the stationary salinization distribution. Thus, for the idealized estuary, stationary salinization distribution is effected by the following factors:

- **turbulence intensity inside the salinization area [7];**
- **fresh water consumption;**
- **difference between fresh water and sea water densities at the estuary entrance.**

Stationary salinization distribution for the idealized estuary is provided in a following dependence [7-10]:

$$\frac{C}{C_0} = e^{-\frac{U_r x}{D_t}}, \qquad (1)$$

Where D_t is turbulent diffusion factor depending on the frequency and amplitude of the tide wave (particularly, it increases when these values increase) [11-13].

The results of experimental researches run in real estuaries of the White Sea coast rivers Kereti and Kemi provided in [14,15] are very interesting. Such processes as salinity formation, water desalination formation; change of weighted drift content at a vertical level, etc. are studied here. It is also justified here, that the actual estuaries are the zones of marginal filter effect and as a result of mixing up the river and sea waters here, almost all the drifts weighted in water are removed.

Considering the intercommunication between the human being and the environment, the interest in the estuaries, when the conditions change, was basically expressed from three positions: 1. change of the bed section and bottom deepening for the purposes to increase the efficiency. 2. Use of the estuaries for removing production and domestic residuals. 3. Control of fresh downflows and change in the tidal estuaries. Recently, there arose the fourth general estuary pollution problem which may be caused by accidental oil spill into the estuaries.

However, each above mentioned issue can be considered as an independent reason for the change of the regime, the effects associated with them are not isolated from one another and should be reviewed with systems approach [16-18].

Let's use rectilinear idealization at the first stage of the identification of the trajectory of oil jets into the estuaries, than the distribution of local velocity at vertical level will be given with the following expression:

$$V_x = u_1 + \frac{z}{H}(u_1 + u_2), \qquad (2)$$

Where u_1 and u_2 are respectively local surface and bottom velocities (figure 1).

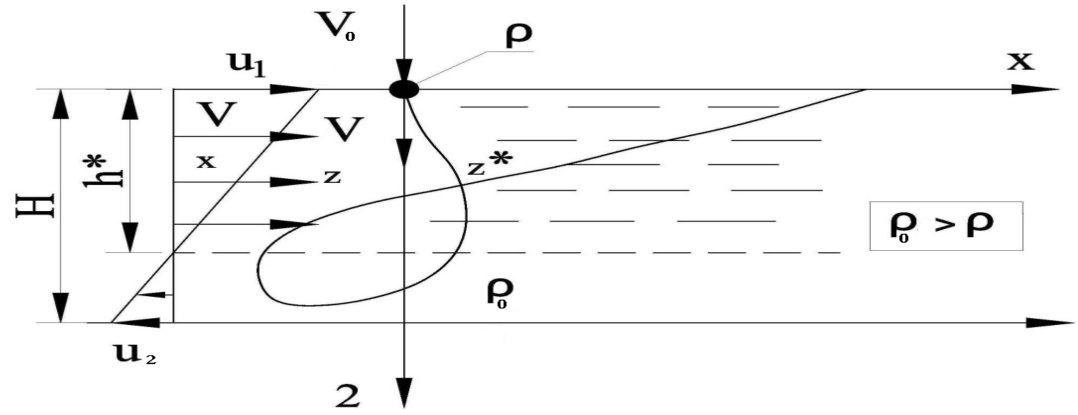

Figure 1. Diagram of the identification of the trajectory of oil jet into the estuary if the jet velocity is distributed in a rectilinear way

It is obvious, that the depth z^*, on which the jet changes the direction, can be found from the condition $V_z = 0$ and will have:

$$z^* = -\frac{u_1 H}{u_1 + u_2}. \tag{3}$$

Average velocity value in the estuary is obtained from the following condition:

$$\frac{z^* u_1}{2} - \frac{(H - z^*)u_2}{2} = VH, \tag{4}$$

Where V is the average jet velocity, therefore from the equation (3) will obtain:

$$V = \frac{u_1^2}{2(u_1 + u_2)} + \frac{u_1 - u_2}{2}. \tag{5}$$

It is obvious that in this case the jet trajectory does not have complicated shape. The jet first goes down and then, when it achieves the point, where the jet changes the direction, the jet curve radius changes, it makes loop, and just right after this comes up to the surface.

The jet trajectory in the estuary case is identified by the same order as we had in case of the one direction flow. Some complications that were not encountered in a former case arise, in particular: 1. Mathematical programme (software) Maple 95 does not provide an evident mathematic solution. 2. Presence of loop creates some uncertainties (in particular, it is evident that the solution is monotonous due to the phenomenon dynamics, but it is not single-valued). Mathematic programme Maple 95 does not perceive the jet loop and considers its solutions as complex numbers.

In order to avoid this, sub-programme under which the jet coordinate calculation is conducted by areas was written. In particular, the programme terminates calculation and starts to recalculate as soon as the jet trajectory changes its direction.

As an example 5 numeric tests were reviewed for the following parameters: 1. $u_1 = 4$ m/sec; $u_2 = 4$ m/sec. 2. $u_1 = 5$ m/sec; $u_2 = 3$ m/sec. 3. $u_1 = 3$ m/sec; $u_2 = 5$ m/sec. 4. $u_1 = 2$ m/sec; $u_2 = 6$ m/sec. 5. $u_1 = 6$ m/sec; $u_2 = 2$ m/sec. Other parameters are as follows: $V_0 = 5$ m/sec; $H = 10$ m.

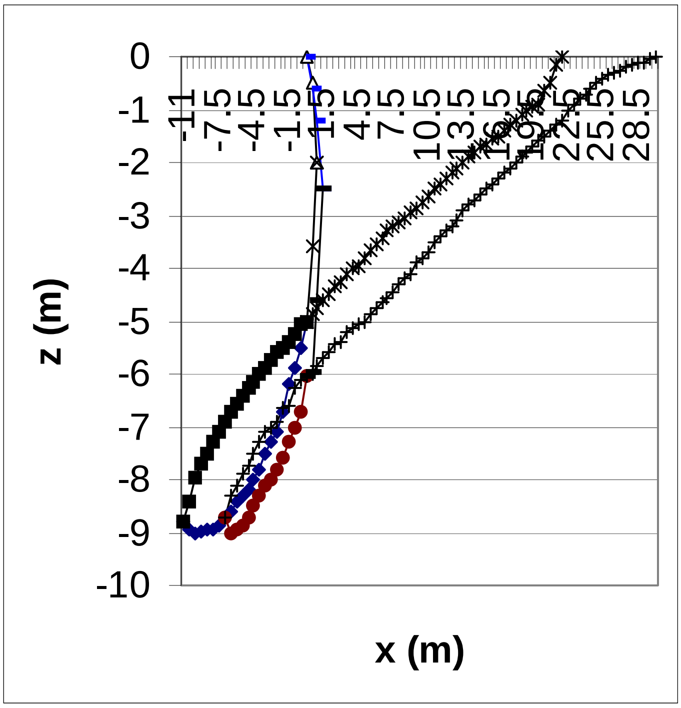

Figure 2. Trajectories flown into the estuary drafted with Maple 95, if 1 - u_1 = 4 m/sec; u_2 = 4 m/sec; 2 - u_1 = 6 m/sec; u_2 = 2 m/sec

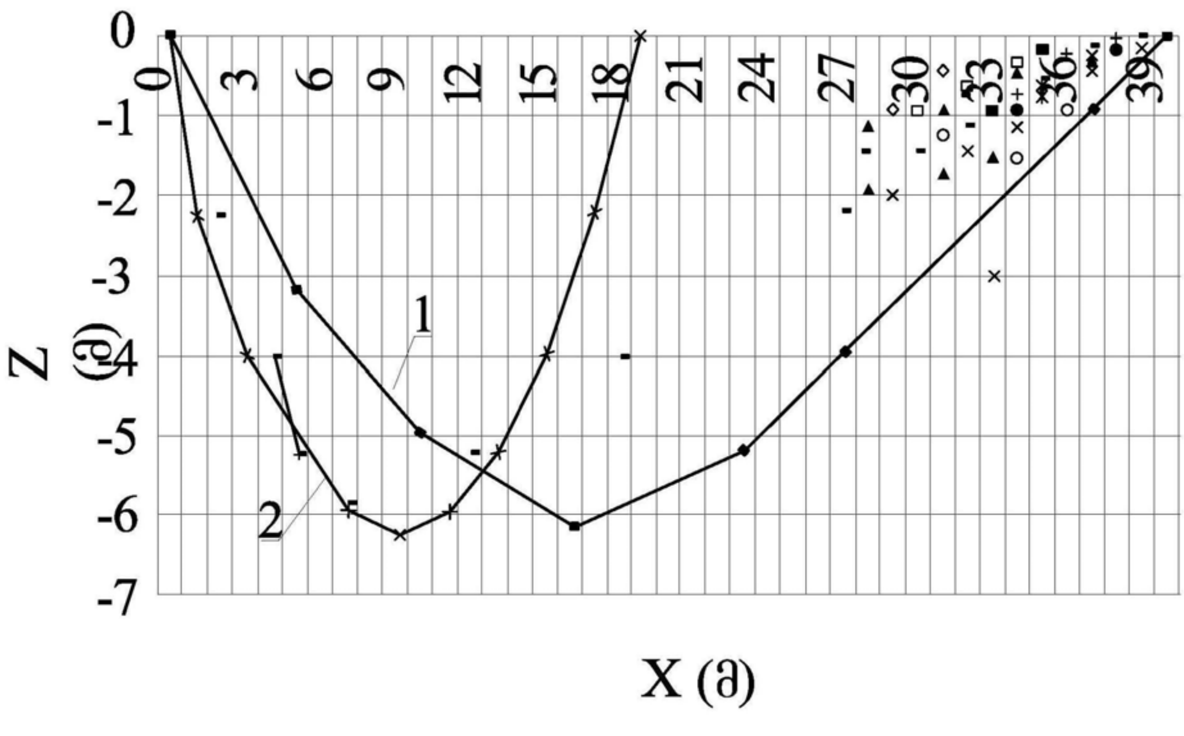

Figure 3. Jet trajectories flown into the estuary: 1 – real trajectory drafted with Maple 95; 2 – trajectory drafted for triangle velocity distribution and in-situ data

The cases realized with the modified mathematic programme Maple 95 that correspond to the first and fifth cases of the example discussed above, are given in figure 2 (for comparison purposes both trajectories are provided in one figure).

Figure 3 shows the jet trajectory drafted with the mathematic programme Maple 95 and in-situ data are provided in [13]. The difference between the results obtained by us and the in-situ data does not exceed 15-20%. So, it is evident, that the method suggested by us is quite acceptable for preliminary engineering evaluation.

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