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SIMULATION METHOD OF PIPELINE SECTIONS RANKING BY ENVIRONMENMTAL HAZARD DUE TO OIL DAMAGE SPILL

Geoinformation modelling serves as a methodological basis for development of means for prognosis of environmental and social consequences of accidents at trunk pipelines. One of numerous aspects of this problem is fragmentation of a pipeline into linear objects by environmental characteristics including technical state and probable environmental and social consequences of an accident. Rational planning of the pipeline linear section overhauls, declaration of industrial and environmental safety, development of valid standards for the pump station emergency service and other aspects depend on the correct solution of these problems.

When making management decisions under the conditions of uncertainty or limited initial information a comparative assessment (ranks) of probable accident consequences at these pipeline sections should become an effective means for determining the required reliability level of a trunk pipeline section.

INTRODUCTION

A long operation period and growing requirements to the environmental safety of pipeline transport objects put the problems of operation reliability, prevention and reduction of failures as well as development of efficient methods for emergency elimination on the list of most important tasks of pipeline operation. This list of problems is united by the notion of "monitoring".

Monitoring of trunk pipelines' reliability includes series of key problems. The solution of these problems is at different stages of development.

Today technical state control is being developed rather successfully. Test methods for technical diagnosis of a pipeline wall state such as special in-pipe tools ("Calliper", "Ultrascan", "Linelog", "Axix-MT" and others) are widely applied in pipeline transport. There are also external methods for direct nondestructive testing. They include magnetic and magnetic-flux crack examination, radio wave and radiation flaw inspection, ultrasonic examination and also acoustic emission as well as electric and heat flaw testing of pipe insulation.

Problems and technical equipment for effective diagnosis of oil leakage are successfully developed by experts of JSC "Sibnefteprovod" [1], company "Energoavtomatika", ABB firm (Germany), Combit AB and Controlotron (Sweeden) [2]. Canadian firms "Enbridge Pipelines Inc." and "Iconic Inc." develop API standards for extended application of automated systems for oil leakage control over the world [3].

A most advanced domestic research of this problem is assessment of accident consequences. Results of numerous studies were presented in the "Methods for assessment of environmental damage caused by pipeline ruptures" [4] developed by specialists of the Institute for Problems of Energy Resources Transport.

Achievements in solving the problem of prognosis for environmental and social consequences of failures and related problems of pipeline maintenance are much more modest. Methodology of prognosis is at the initial stage of its development. One of numerous aspects of this problem is fragmentation of the pipeline into linear objects by environmental characteristics including both technical state and probable environmental and social consequences of an accident. Rational planning of pipeline linear section overhauls, declaration of industrial and environmental safety, development of valid standards for the emergency service and other aspects depend on correct solution of these problems.

Prognosis tasks may be solved only with application of up-to-date tooling and methodology of geoinformation modelling.

HARD AND SOFTWARE OF THE METHOD

A geoinformation system (GIS) is a computer system designed for collection, communication, storage, processing and retrieval by the final user of territorially (or spatially) referenced data. The system contains spatially oriented data in the form of digital electronic maps of different scale and thematic content and also tools for data processing and representation. GIS technology is based on the idea of co-processing of cartographic material in the form of electronic maps and attributive information that characterises the mapped objects. In our case we consider the objects of trunk pipelines for their quantitative and qualitative control and analysis of their state.

Layer – thematic aspect is the basis for semantic structuring in GIS. Similar objects of an electronic map are stored in a definite file structure called "a cover" or a layer of the electronic map. Examples of different layers of the electronic map may be: a road net, a river net, populated areas, a linear section of a pipeline, etc.

Data stored in GIS databases may be used for viewing and presentation as well as for organisation of complex thematic queries, computations and modelling of different situations.

PRINCIPLES OF DAMAGE MODELLING

The first stage of modelling the consequences of oil spill from a damaged pipeline and creation on this basis of prognosis for a accident developing is the construction of a 3-Dimensional model of a hydrologically correct relief grid, or a digital elevation model (DEM). The relief grid is a basis for solving hydrological tasks of analysis of liquid substances' behaviour in the process of their movement over the terrain under the effect of the gravity. It is assumed that not only liquids in a general sense are considered as liquid substances but also gases that are heavier than the air.

Source information is presented by an electronic map of rectangular cell structure with NxM cells. The absolute value of the relief height is entered into every cell centre **h(i,j)**. Dimensions of all grid cells are equal and they are defined by the accuracy of the required results and the initial data. For generation of the relief grid it is expedient to use objects of an electronic map as additional data: relief contours, height point levels and water edges marks, drainage network. On a linear section of a pipeline in the points of the pipeline crossing with cell borders of the geographic map the profiles are selected through which lines are drawn in the direction of the maximum relief slope – the shortest declivity (maximum gradients of elevations). Lines in geoinformation systems always have a parameter of "direction". These directions are naturally closed into a drainage network determining relief gradients (because rivers always flow in the direction of the relief slope). The received coordinate lines also determine most probable routes of liquid flow through the cells of the initial electronic map. Another family of coordinate characteristics is presented by relief contours (isolines).

For calculation of lacking values of a hydrologically correct relief grid interpolation functions are applied. These functions use the values of relief contours, height marks and directions of river course, etc. The result of determining the path of liquid flow is shown in Figure 1.

Thus the created 3-dimensional model of hydrologically correct relief grid consisting of two coordinate families – maximum gradient lines and relief contours serves as a basis for prognosis of a accident developing on pipelines.

The relief grid for determination of oil outflow
on the Tuimazy-Ufa-2 pipeline section

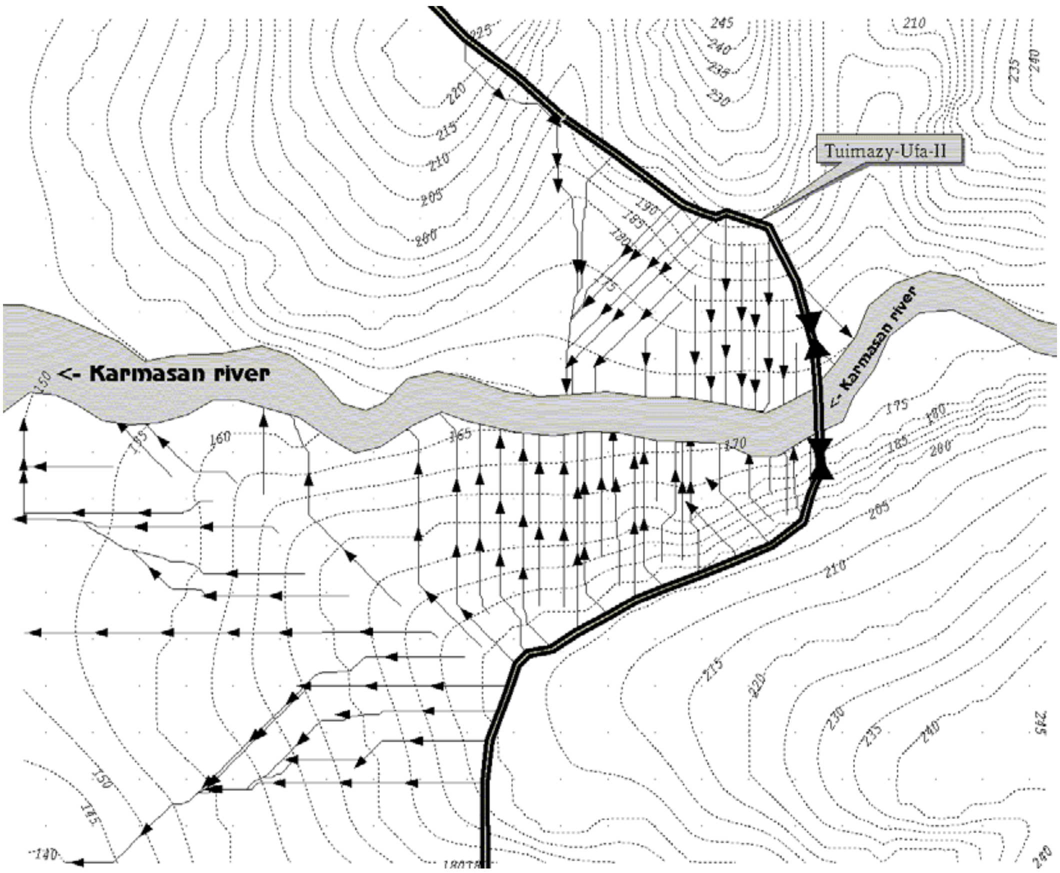

Fig. 1

It should be noted that now the described operations may be realised only on the basis of RISC working stations, for example Sun Sparc Station type and a GIS software

ARC/INFO version 7.0 and later. This is primarily due to a large volume of processed intermediate information and to the use of a rather detailed digital map of the locality.

The second stage of prognosis development is determination of probable pollution plume and accumulation ability of the ecosystem elements by the relief grid. Directions and routes of failure oil escape are determined by the family of the shortest slope lines. However the width of the pollution plume depends on the intensity of oil outflow, on the time period of escaping and on the oil flow properties. It also depends on the relief slope, sorption properties of soil and vegetation (snow) cover.

Apparently non-stationary motion of oil over the relief is described by the balance equation with corresponding initial and boundary conditions:

$$P_{oil}\frac{dV}{dx}dx+\frac{dh}{dt}n_e\cdot p_{gr}+q=0, \tag{1}$$

since $p_{oil,}\, p_{gr}$ - oil and soil density, kg/m^3;

h – depth of oil penetration into soil defined by the equation of diffusion [5];

$n_{e\,-}$ oil capacity of soil according to “The Methods for calculation of pollutant discharge …”, Samara, 1996. It is recommended to be 0.04 m^3/m^3;

q – relative hydrocarbon emission into the atmosphere according to “The Methods for determination of pollutant emissions into the atmosphere by enterprises of the Russian Federation”, Astrakhan, 1998. It will be assumed 3.158 g/(m^2 ·h) for the case of evaporation from an open surface;

V – velocity of oil flow along the path of the shortest slope defined by the Chezy equation [5]:

$$V=C\cdot\sqrt{R_h\cdot i_0}, \tag{2}$$

since C – Chezy coefficient that depends on the properties of soil and vegetation (snow) cover [5];

R_h – hydraulic radius of oil flow that defines the width of the pollutant plume, m;

i_0 – relief slope.

This equations system has been solved by the method of final elements with decomposition of the computation field according to initial geographical information on the electronic map of rectangular cell structure. Pits, earthen containers, dams and other objects increase the storage capacity of the cell due to accumulation of oil in lower places of the micro-relief. Closed relief contours with maximum gradient lines directed inside these zones accurately enough describe the relief peculiarities and allow geometrically estimate the capacity of such depressions in the ground.

However the initial information on ground peculiarities and vegetation (snow) cover as well as the micro-relief and the situation are subject to season and time changes.

Due to the fact that the real state of the area in the vicinity of the pipeline is changing more often than the topographic maps used for GIM construction are renewed (once in 10-20 years) there arises the necessity for the Earth surface remote sensing from the space.

Remote sensing of the Earth carried out by satellite observation systems opens wide prospects for solving the tasks of geoinformation modelling. By now considerable experience has been accumulated in application of remote sensing data to define more precisely geographic position of nature and technology objects, their inner state including environmental aspects and correction of topographic maps.

According to the degree of spatial generalisation the remote sensing information may be discriminated as follows:

- global space data with spatial resolution of ~1 km and corresponding to the maps at the scale of ~1:2500000 (NOAA, Meteor, Ocean satellites);
- regional space data with spatial resolution of ~100 m and corresponding to the maps at the scale of ~1:250000 (“Resource 01” satellite, scanner MSU-SK);
- local space data with spatial resolution of ~n×10m and corresponding to the maps at the scale of 1:n×25000, where $1 \leq n \leq 10$ (satellites “Resource F”, “Resource 01”, scanner MSU-E, Landsat, Spot, IRS, JERS, ERS, Radarsat, airborne survey).

Implementation of geoinformation modelling presenting by itself synthesis of space and cartographic information was tested on a operating pipeline trace. Data of remote sensing with spatial resolution of 160 km permitting to evaluate the situation in the pipeline Tuimazy-Ufa area were used as space information. It is clearly seen in the model that some geographical objects (populated areas, water storage reservoirs, forest borders) have considerably changed their position what is important for assessment of probable adverse impact on the population and the environment due to a pipeline failure.

The third stage of the pollutant hazard analysis includes division of the pipeline route into linear objects and comparative evaluation of oil escape volume from every object.

In case of oil getting into any aquatic body the environmental damage and the area of pollution are considerably increased. That is why it is important to divide the pipeline route into sections (linear objects) from which the escaped oil is flowing into one and the same aquatic object.

The main problem of constructing an algorithm for ranging the pipeline trace sections that would be suitable for further application to PC consists in quantitative evaluation of the environmental pollution risk. On certain assumption it may be reduced to a relative assessment of a failure probability at some trace section and pollution of important environmental, municipal or industrial and administrative objects.

The task of ranging the pipeline sections by environmental hazard is based on comparison of failure consequences at different pipeline trace sections under “equal” conditions of the failure development. Let us assume as “equal” the conditions of a damade occurrence (a scenario with mean time of the failure identification and closing pipe valves along the route for 2.5 hours) and also “equivalent” sizes of damade holes. Applying methods of reducing different configuration of holes and considering the products of their areas and the corresponding discharge coefficient ($\mu \cdot f_0$) it is possible to unify the assessment of numerous different factors affecting the outflow volume such as conditions of vena contracta effect and the shape of the hole, physical properties of oil and the environment, pressure head and velocity flow etc. “Equivalent” diameter of the damade hole is defined by the equation:

$$\mu \cdot f_0 = \pi \cdot d^2 / 4 \text{ or } d = 2 \cdot \sqrt{(\mu \cdot f_0 / \pi)}, \tag{3}$$

since μ - discharge coefficient through the damage hole [4];

f_0 - the area of the failure hole, m^2.

It is advisable to limit the size of diameters by 2 cm because in case of a large size of holes the oil escape will exceed 10…15% of the pipeline capacity what implies another scenario of the failure developing.

The assessment of the escaped oil volume is made by "the worst" case – the point of the pipe body with minimum height for every pipeline section:

1. Oil spill under the operating pressure in the pipeline section is defined by the time from the moment of the pipeline rupture to the moment of the damade identification and shut off pumping station ($\tau = 2.5$ hours).

$$V_1 = \mu \cdot f_0 \cdot \tau \sqrt{(2gH_H)}, \tag{4}$$

since H_H – the pressure of the flow determined as the distance between the point of outflow and the pipeline hydraulic slope lines in the pipeline operation mode.

2. Oil spill with alternate pressure is determined by the time of pipeline valves shutting ($\tau = 2.5$ hours):

$$V_2 = \mu \cdot f_0 \cdot \tau(\sqrt{(2gH_k}))/2, \tag{5}$$

since H_K - hydraulic pressure head defined as the difference between the elevation of the highest pipeline point on the pipeline section between two shut valves and the place of oil outflow.

3. Oil outflow from the plugged pipeline (V_3) is determined by the volume of the pipe emptying taking into consideration the oil held in "dead" zones of the pipeline sections and the pressure of oil vapour pressure holding the hydraulic oil column over the hole:

$$H_{ст} = (P_{атм} – P_s)/\rho g. \tag{6}$$

The total volume of oil outflow may be estimated as a sum of outflow volumes at every stage. A typical relationship of oil outflow into the environment depending on the equivalent size of the hole in characteristic pipeline profiles is given in Figure 2.

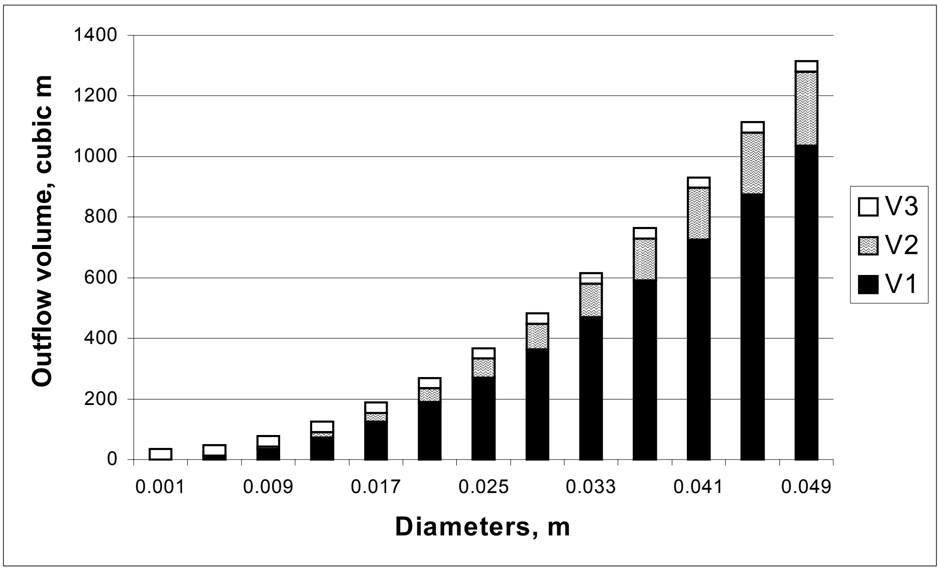

Fig. 2. Oil spill volume on the section No. 21 of the pipeline Tuimasy-Ufa-II between Pump Stations Yazikovo-Nurlino

For small - size holes with ∅ ≈ 1 mm practically the whole volume of oil escape is defined by the capacity of the emptied pipe, the time of outflow is rather long if such method of repair as slot of a repair pipe section is not applied. The situation with spill volume less than 10 tons is not identified as a damage. However detection of such defects takes much time and requires special methods, so the time of outflow under the working pressure may be much longer than 2.5 hours.

For “large” holes with ∅>2mm oil escape to the surface will be evident and fast. The volume of the pipe emptying is small and may be neglected. The bulk of the product will flow out during the first stage and will be defined by the pressure of the profile having a flaw in the operation mode of the pipeline.

Distribution of the accident outflow along the pipeline section Tuimazy-Ufa-II between PS Yazikovo and Nurlino through damageholes of equivalent ∅0.01m are shown in Figure 3.

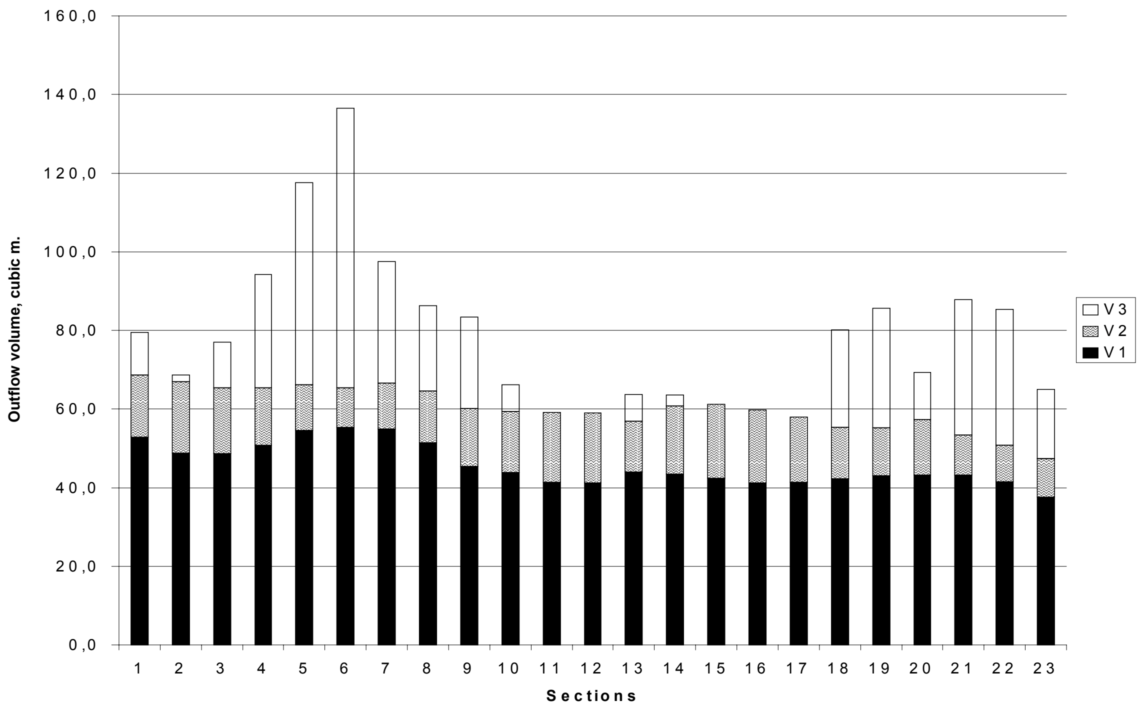

Fig. 3. Distribution of the damage spill through holes of ∅1cm along the pipeline section Tuimazy-Ufa-II between PS Yazikovo and Nurlino

Similar calculations were made for statistically valid series of accident hole diameters.

The volume of the failure oil escape into the river was estimated by modelling the accinent according to the aforementioned scenario. Assuming that the environmental damage is proportional to the volumes of escaped oil polluting aquatic bodies let us introduce a parameter μ_{li} for consideration as a relative value of probable damage pollution:

$$\mu_{l_i} = V_{\sum i} / V_{\sum max}, \qquad (7)$$

since i – index of a pipeline section;

$V_{\sum max}$ - maximum value of probable accident outflow into the river within the section Yazikovo-Nurlino.

The results of ranging the failure by environmental impact are presented in the Table.

Table of priorities on the pipeline section Tuimazy-Ufa-2 between Yazikovo and Nurlino

Section No.	Name of aquatic body	Section rank
6	Batmak-Karmasan	1,000
5	Nameless- Batmak-Karmasan	0,862
7	Karmasan	0,714
4	Nameless- Batmak-Karmasan	0,691
21	Sartovka- Karmasan	0,644
8	Karmasan	0,632
19	Nameless– Potoky-Karmasan	0,627
22	Shemiak-Karmasan	0,625
9	Nameless- Karmasan	0,611
18	Nameless– Tabuldak-Karmasan	0,588
1	Nameless-Sanny-Karmasan	0,583
3	Nameless-Nameless -Chermasan	0,564
20	Nameless-Potoky-Karmasan	0,508
2	Nameless-No name-Chermasan	0,503
10	Nameless- Karmasan	0,485
23	Nameless-Sikiyazka-Karmasan	0,476
13	Tabuldak-Karmasan	0,467
14	Uza-Dioma	0,466
15	Uza-Dioma	0,448
16	Nameless– Tabuldak-Karmasan	0,438
11	Tabuldak-Karmasan	0,433
12	Uza-Dioma	0,432
17	Uza-Dioma	0,425

Note: “Nameless ” means a brook without any name on the map of the area.

In spite of the fact that the contribution of each factor into the total oil spill to a great extent depends on the size of the hole the result of ranging pipeline sections is mainly (by 87%) predefined by the position of the certain pipeline profile in the terrain relief.

CONCLUSION

1. Prognosis of failure consequences on a pipeline is a key problem of pipeline reliability monitoring. Solution of the problem is possible only with

application of advanced systems for processing, storage and representation of cartographic information (GIS).
2. The main principle for fragmentation of the linear pipeline section for further analysis is the environmental principle, by watersheds of aquatic bodies that are crossed by the pipeline trace.
3. The environmental prognosis reliability equally depends both on the methodological basis of geoinformation modelling and detailed peculiarities of a proposed scenario for the damage developing. In case of uncertainty of the main failure parameters it is expedient to use comparative assessments (ranks) while analysing adequacy of reliability level for the certain pipeline section.

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