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THE CONCEPT OF MARINE SEISMIC RESEARCH QUALITY COEFFICIENT OF TO IMPROVE ITS ACCURACY AND EFFICIENCY

ABSTRACT

The paper presents the stages of quantitative coefficient of marine seismic researches creation for the geophysical vessels towing the geophysical seismic equipment understood as system of seismic streamers where set of geophones are installed. The quality coefficient of geophysical research works is based on the mathematical model of the deviation of the position of the arrangement of streamers geophone points with relation to their idealized position. The proposed coefficient can be used during realization of seismic researches and for short-term prediction of their quality.

Keywords:
geophysical maritime seismic research, the quality of marine geophysical works, seismic vessel navigation.

INTRODUCTION

Geophysical market analysis shows that complex solutions for exploration of hydrocarbon deposits (and recently hydrates deposits as well) are commonly used at sea. Nowadays marine seismic using acoustic waves or electromagnetic waves is in use during geophysical explorations.

Marine seismic surveys are conducted by specialized vessels towing seismic equipment. Part of the equipment comprise airguns triggering acoustic waves.

Acoustic waves reflected by geological structures under seabed are sensed by hydrophones (acoustic signal receivers) located inside seismic streamers. The analog signal is than converted to a digital signal and recorded onboard seismic vessel. The ship is also equipped with an auxiliary geophysical data processing systems.

Towed seismic gear typically has a range of equipment to control its position comprising of: deflectors, spreaders (called doors), dilt-floats (head-buoys), tail buoys, and devices to control the depth of streamer (called birds) and position of the cable in the vertical plane (patented solutions like Digifin or Nautilus). Size of such towing spread is often exceeding 10 km x 1 km (fig. 1).

Real time positioning of the towed spread is usually obtained through a combination of satellite methods (tail buoys, vessel's reference point, airguns, dilt floats) and acoustic methods (Streamers). Additionally seismic vessels are equipped with sea current profilers (eg ADCP) to measure ocean currents in the area of the vessel and under her bottom. Planning of the survey is conducted by seismic crew supported by dedicated software (eg. SurvOpt) The program helps to schedule sequence of survey lines to be performed so, that time required for line-change is minimized.

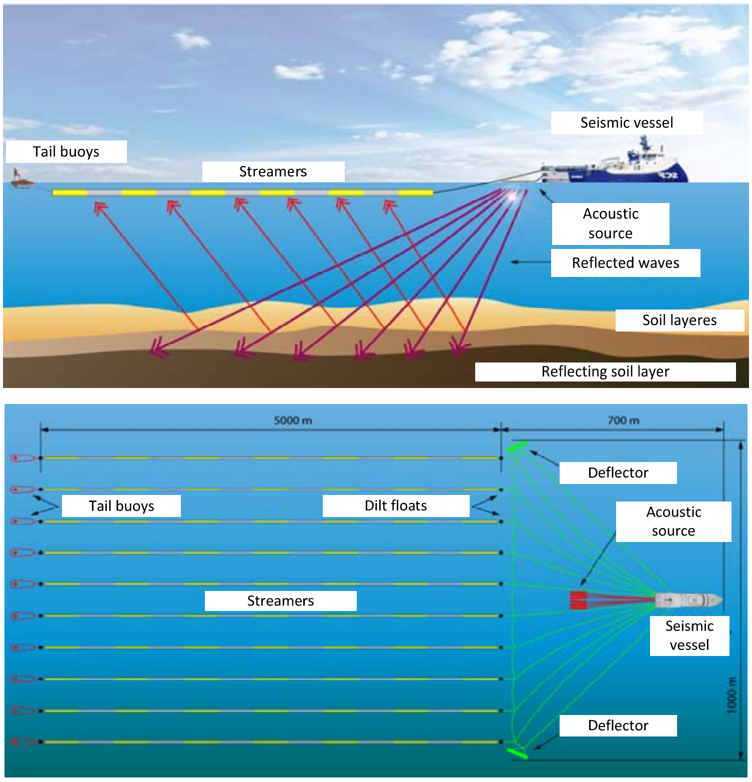

Fig. 1. Scheme showing example of towed seismic spread; view from the side and from above

A significant limitation of current methods is remote use of mathematical models of the vessel with the towed gear (e.g. equipment to generate an acoustic wave — airguns), streamers, hydrophones, deflectors and others) and barely existing combining them with geophysical models of propagation and reception of acoustic signals in different geological conditions in order to increase seismic surveys efficiency.

There is surprisingly little number of publications depicting the concept of mathematical models of seismic vessels. One of them is a paper of [Pipchenko A., 2013], however, it shows a very simplified model and there is no information about the possibility of its use. The study of hydrodynamics of airguns was the subject of Ersdals PhD thesis [Ersdal E., 2004]. The dissertation of Pedersen [Pedersen O., 1996] is the only comprehensive study existing in the literature but it considers the problem from the point of view of the forces exerted on the cables only.

During analysis conducted with assistance of professional seismic navigators and specialists engaged in geophysical companies in surveys planning it was noted, that there is a number of unresolved issues that cause a decrease in efficiency and safety of the surveys. Another observation made during the analysis is the lack of the literature dealing with the quality of work in terms of ships maneuvering especially while navigating in area with obstacles. Although there are heuristic rules used to assess the quality and efficiency of seismic surveys involving, for example, a hypothetical setting of the geometric center of the towing system (e.g. middle point of seismic streamers) and maintaining of such a center as close to the survey line as possible (a point is assumed to be between 1/3 and 1/2 the length of the set). These points convinced authors to begin working on the study. The main idea is to creation of a quality coefficient of seismic surveys and its application in practice.

MODEL OF QUALITY COEFFICIENT OF MARINE SEISMIC SURVEYS

Seismic equipment towed behind the ship is a flexible three-dimensional set (fig. 2) moving according to the movement of the vessel within imposed restrictions. Due to external factors (e.g. cross currents) deviation of the towed seismic streamers from course made good (called feather angle) appears. Another effect of external factors is a non-parallel streaming of seismic cables (called colloquially trousers effect). Mentioned effects are significant for the navigator and for the acquisition process. These effects occur while course alteration is in progress even in a still water, but also when sailing straight (essential for conducting surveys) but with presence of cross currents affecting the gear. It should be noted that the influence of the currents vary for the vessel and for the in-water equipment. This effect must be properly taken into account. Modeling of large diversity of speed and direction of the current on different depths is essential.

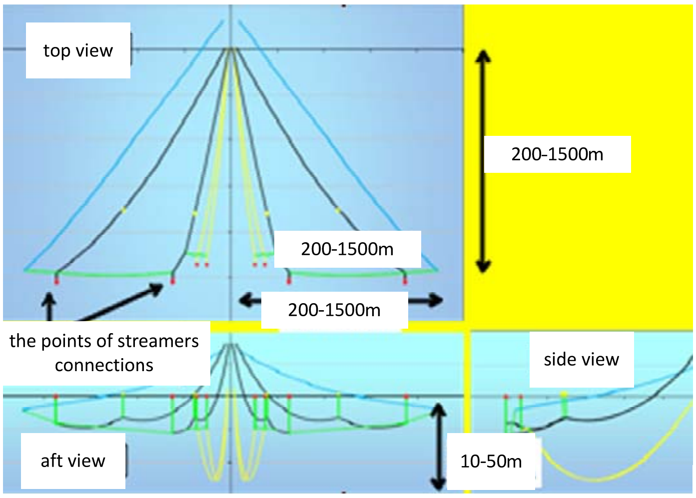

Fig. 2. Schematic example of auxiliary/transition cables (Lead-ins) distribution of 3D vessel (receiver cables are not included) [based on SeaBird company vessels configuration]

Among many problems affecting marine seismic surveys one significantly important is the steering of towed equipment. Methods of controlling of receiver cables are quite limited. It is a complex problem affected by turbulence caused by propulsion, cross currents, seas and other factors causing deviation of the towed streamers from course made good (called 'feather angle') as shown in figure 3 and/or non-parallel streaming of the cables (called colloquially 'trousers effect) figure 4.

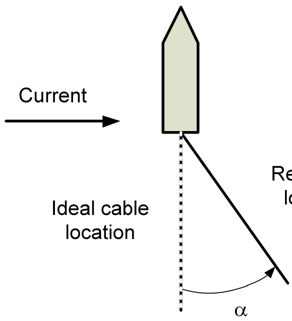

Fig. 3. Deviation of the towed streamers from course made good (called feather angle)

Due to limits such as maximum working load of the towed gear and the available engine power, maximum speed of seismic vessel with the gear in the water is usually 5–6 knots. This increases the range of mentioned effects.

There is an equipment on the market used for cables steering such as Nautilus^{TM} and DigiFin^{TM}, however it is not available for all companies in seismic industry. Main reasons for that are high costs, limited compatibility and patent rights. In addition, due to their small size their capacity to control cables is not sufficient, when deviation angle is greater than 5–10 degrees. Since they operate on rudders principles, a turbulent flow of water impairs reception of acoustic signals. When the effect of steering devices is greater than 2–3 degrees created noise reaches maximum acceptable level.

Positioning of the in-water equipment is achieved by a combination of satellite methods (tailbuoys, diltfloats, gun arrays) and acoustic methods (receiver cables). In addition, shape of the towed streamers is determined with use of magnetic compasses distributed along cables. The measurement results are presented through a graphical interface, allowing operator (seismic navigator) to have a constant overview of the spread. Compasses are usually placed every 300 m (fig. 4). In addition, an acoustic positioning system of receiver cable (acoustic ranging units) spaced typically at 100 m intervals near cable-heads, middle part and their tail sections, allows to obtain a final position relative to the tail/head buoy and to the vessel. These positions are obtained by measurement of ‘time of flight’ of the signal between adjacent acoustic transmitters/receivers in the network. In addition, the ship itself is usually equipped with transmitters placed underneath ship’s hull (called hull pingers), lowered typically before commencing of data acquisition.

One of the leading manufacturers of seismic positioning equipment (Sonardyne) manufactures acoustic units capable to transmit on 1 channel and receive on 4 channels. Additionally the equipment has capability to receive 4 of 60 unique digital signals. That allows simultaneous ranging. Obtained data including distances are sent to the ship with help of induction coils. Acoustic transmitters can be equipped with sensors to obtain the local velocity of propagation of sound for more accurate position. Attached drawing (fig. 4) shows both the ranges obtained by the acoustic receivers and the positions obtained by DGPS. It should be noted that usually range of a single couple of acoustic transmitters/receivers does not exceed 1 km. In the example shown on figure 4. cable length is 7950 m. Proportions have not been preserved deliberately.

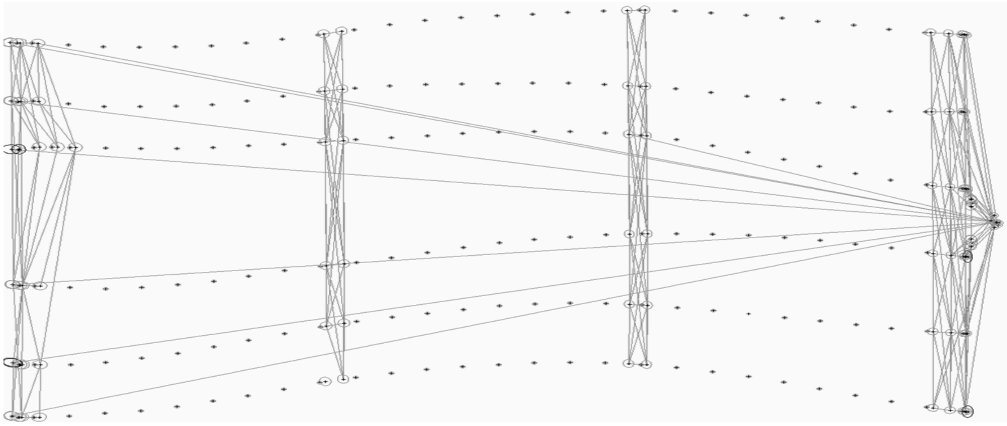

Fig. 4. The graphical interface with an overview of the shape of cables, condition of acoustic ranging units and compasses (visible effect of non-parallel stream of cables colloquially called 'trousers effect')

In order to create the model of quality coefficient of marine seismic researches two-dimensional Cartesian coordinate system was used (fig. 5). On the coordinate system assumption was made for the position of the reference point on the vessel used for relative positioning of the towed equipment S(x_s,y_s), and the individual points on the receiver cables as $G(x_{ij}, y_{ij})$, where *i* is the number of cable from the starboard side, and *j* — is number of hydrophone on the cable (fig. 4). Thus i-by-*j* matrix of position of hydrophones *G* was established.

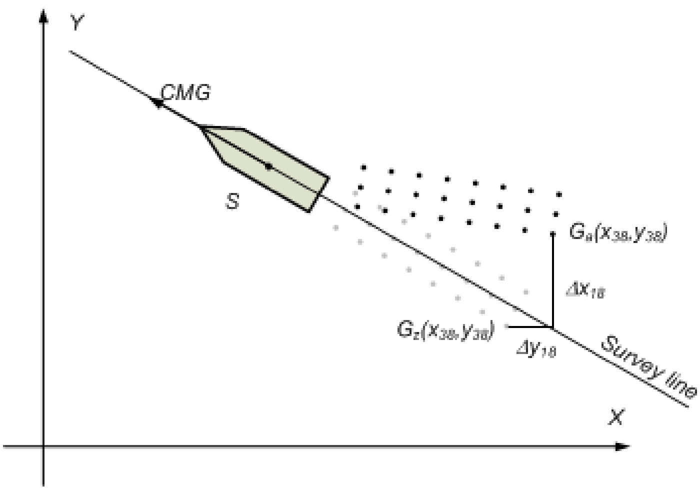

Fig. 5. Adopted Cartesian coordinate system

At the beginning the origin of Cartesian coordinate system was shifted where the reference point on the ship *S* (NRP — Nominal Reference Point) is located. To do this, from the value of the coordinates of individual hydrophones on the cables subtracted values of the coordinates of the current position of the reference point S. Than a rotation of the whole set was conducted. The angle of the rotation is formed by survey lines and true north (fig. 6). The coordinates of shifted and rotated set $G_a(x_{aij}, y_{aij})$ were defined as follows:

$$x_{aij} = (x_{ij} - x_s)\cos\alpha - (y_{ij} - y_a)\sin\alpha \qquad (1)$$
$$y_{aij} = (x_{ij} - x_s)\sin\alpha - (y_{ij} - y_s)\cos\alpha,$$

where:

G — position of the hydrophones before shifting and rotation;
G_a — position of the hydrophones after shifting and rotation;
S — position of Nominal Reference Point before shifting;
α — angle of the rotation (rotation center located in origin of coordinate system);
x_{ij}, y_{ij} — coordinates of the hydrophones before shifting and rotation;
x_s, y_s — coordinates of Nominal Reference Point;
x_{aij}, y_{aij} — coordinates of the hydrophones after shifting and rotation.

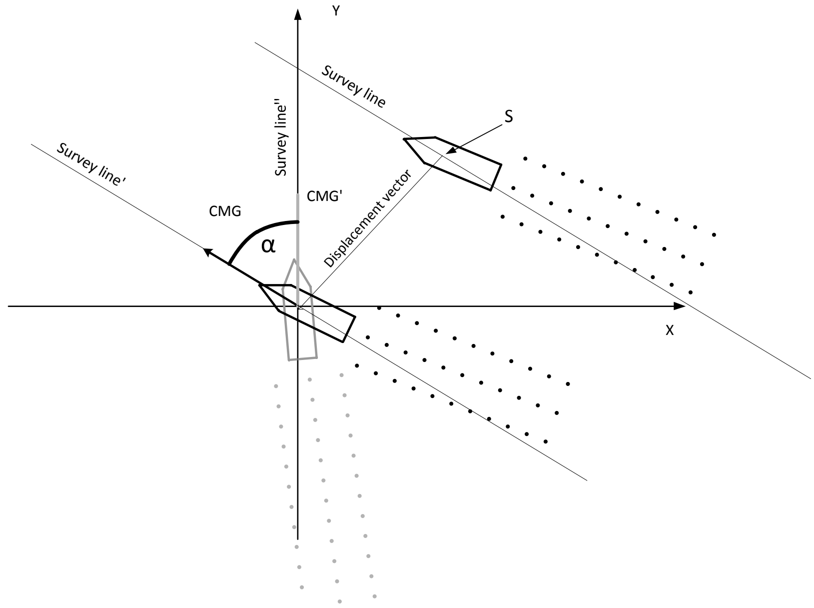

Fig. 6. Shifting and rotation of the set

Based on the specified spread configuration ideal position of the hydrophones was assumed as $G_z(x_{ij}, y_{ij})$ so that:

$$x_{zij} = C + ((j-1)b)) \quad (2)$$
$$y_{zij} = -p(i - 0.5(l+1)),$$

where:
C — distance along a survey line from the ship to the first hydrophone based on specified spread configuration;
b — the standard distance between every following hydrophone;
p — separation between cables based on specified spread configuration;
i — a number of a cable;
l — number of cables;
j — the number of the hydrophone

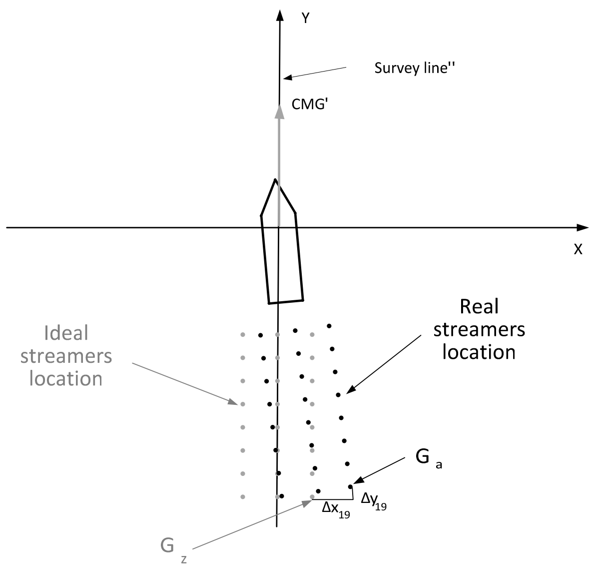

Fig. 7. Planned and real position of the cables after shifting

Quality assessment can be obtained at every shot generated by the source (gun arrays), when the ship is in production. As a shot we understand generation of an acoustic wave in order to obtain picture of geologic structures in survey area. Frequency of the record vary typically from a few to several seconds depending on the ship's speed over ground, distance between each shot and capability of compressors to build up pressure required by gun arrays.

Quality assessment is carried out by calculating the standard deviation of hydrophones along the survey line (Y-axis) and across the survey line (X-axis). For this purpose, ideal positions of each hydrophone was calculated (fig. 7) and compared with the current registered hydrophone position $G_a(x_{ij}, y_{ij})$ This way matrices of deviation of hydrophones were defined as $\Delta G(x_{ij}, y_{ij})$:

$$\Delta x_{ij} = x_{aij} - x_{zij}, \tag{3}$$

$$\Delta y_{ij} = y_{aij} - y_{zij}.$$

Later on the standard deviation of hydrophones was calculated respectively across the survey lines and along the survey lines using formulas:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n}(\Delta x_{ij})^2}{n}};$$

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n}(\Delta y_{ij})^2}{n}},$$

where:
n — number of hydrophones.

Furthermore the actual average separation between successive cables (fig. 8) was calculated as follows:

$$D_{śr(i,i-1)} = \frac{\sum_{i=1}^{n}\sqrt{(x_{aij}-x_{ai-1j})^2+(y_{aij}-y_{ai-1j})^2}}{n},$$

where:
$D_{śr(i,\, i-1)}$ — the average separation between a pair of successive cables;
n — number of pairs of hydrophones in two cables.

The calculated distances were used to determine the following: a separation coefficient and a non-parallel streaming coefficient.

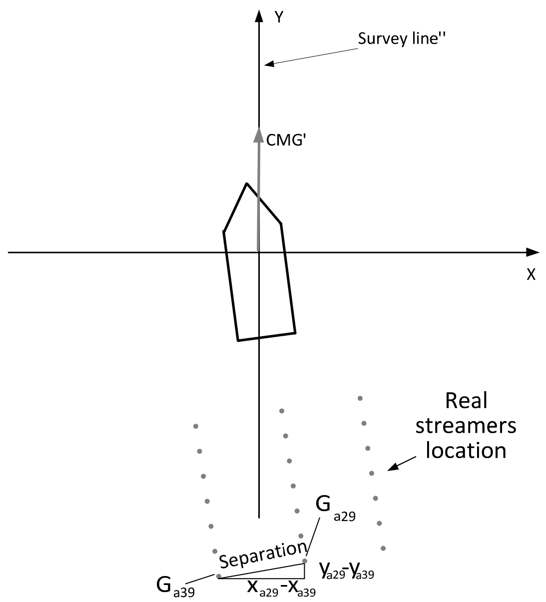

Fig. 8. Obtaining of local separation of two consecutive cables

Value of the separation coefficient was calculated as follows:

$$M_s = \frac{D_{śr(\max)}}{D_{śr(\min)}},$$

where:

$D_{śr(\max)}$ — the largest average separation of two consecutive cables;

$D_{śr(\min)}$ — the smallest average separation of two consecutive cables.

The value of the non-parallel streaming coefficient (called colloquially 'trousers effect') was calculated as follows:

$$M_n = \frac{D_{śr(\mathrm{mid})}}{D_{śr(\mathrm{poz})}},$$

where:

$D_{śr(\mathrm{mid})}$ — the average separation of the two middle cables;

$D_{śr(\mathrm{poz})}$ — the average separation of all remaining consecutive cable pairs.

Ideally, the value of each of said coefficients is 1.0, which should be assumed as a preferred and desirable. Should the shape of the cables deteriorate, values of coefficients will increase.

MODEL VALIDATION

In order to verify the accuracy of the model an application that allows real-time calculation was created. Values of the coefficients were presented to the operator. The study was conducted on the R/V Geo Pacific. At that time ship was equipped with six towed cables with a length of 7950 m and separation of 100 m. Due to the patent rights cables were not equipped with devices to steer them in the horizontal plane (DigiFIN). Another type of such device — Nautilus, could not be installed because of lack of compatibility with the streamers used by the ship.

The study was conducted in the area of São Tomé and Príncipe (Brazil). In this location speed and direction of the observed currents was varied enough to get the cables crossed with difference in depth of 1 m only. Encountered difficulties, were even bigger because maintenance of the cables is often made while in a turn, where speed of cables through water is different from each other (to carry out a maintenance cable needs to be surfaced). This is due to the fact that the control of depth of the cables is done by rudder type devices (called birds) steered from Instrument room — the heart of every seismic vessel. Without the steering devices and without a proper speed through the water cables are sinking because of their negative buoyancy. Negative buoyancy of streamers helps to prevent them from surfacing when strong swell from stern direction is encountered. Table 1 presents variable in time values of selected quality coefficients.

Table 1. Values of chosen coefficients determining location of streamers on R/V Geo Pacific in production; At the time of research variable speed and direction of currents was encountered

Shots remaining to end of line	Average angle of cable's deviation from CMG [°]	Standard deviation along X axis (across survey line)	Standard deviation along Y axis (along survey line)	Width of the towed equipment	Non-parallel streaming coefficient	Separation coefficient
1740	5,4	584,6	42,4	1501	1,02	1,22
1720	5,1	575,2	43,6	1484	1,06	1,27
1700	5,0	561,8	39,8	1479	1,11	1,32
1680	4,6	536,7	37,1	1444	1,16	1,41
1660	4,4	511,4	34,2	1419	1,21	1,48
1640	3,7	466,8	29,6	1362	1,25	1,53
1620	3,5	445,9	30,3	1321	1,30	1,58
1600	3,3	405,4	23,4	1284	1,34	1,63

The obtained results were compared with the recorded file showing position and shape of cables in the analyzed period (fig. 9). Based on the experience of the operator it was possible to determine the values of the coefficients where risk of entanglement of streamers or deterioration in the quality of work was realistic or imminent. The role of the operator is to steer the gear in order to maintain value of the coefficients as close to 1.0 as possible.

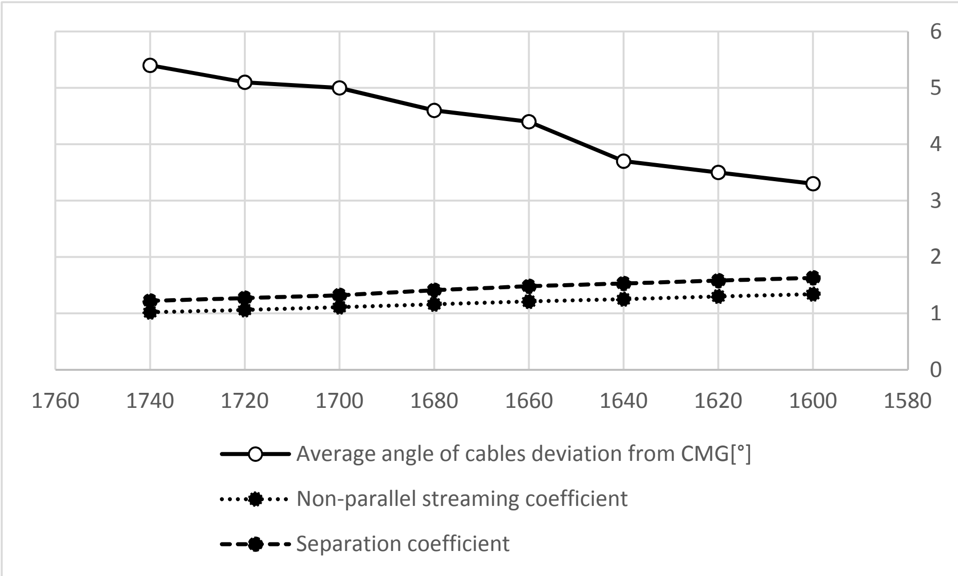

Fig. 9. The negative correlation coefficient of non-parallel streaming coefficient and average angle of cable's deviation from CMG (on the X axis: shots remaining to end of line)

CONCLUSIONS

The paper presents the model of quality coefficient of marine seismic surveys created to improve their efficiency. A number of quantitative indicators was introduced to improve the assessment of the position of the towed gear in relation to the desired value. Two of these coefficients indicate the streamer parallelism and their real separation related to the desired separation.

Model can assist in building statistics to help determine the most favorable configuration of cables in specific conditions/areas or for a specific vessel. In the present case an increasing influence of the spiral slipstream can be seen, while average angle of cable's deviation from CMG is decreasing (fig. 8). The magnitude of the effect is also influenced by factors such as depth and the length of cables. The last two values depend on, among others, the geophysical constraints in survey area which is not changed often. Therefore there is a need for continuation of research.

The model determines the coefficients that allows to observe the rate of change in cables behavior. So far, in prediction of cables shape and movement across survey line, front compasses were used as main indicator. This can lead to incorrect decisions, especially when operating in area affected by currents variable in time or depth.

A further verifications of coefficients is planned with combining them with the geophysical structure of surveyed area, so that seismic navigator would be able to consciously control the quality and efficiency of conducted research. The application is to be expanded with the tools to control the position of the sources (Gun arrays). It is planned to expand the constructed model so, that it will assist bridge navigators in decision making, especially when 'Close Passing' or executing emergency maneuvers.

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STRESZCZENIE

W artykule przedstawiono budowę ilościowego wskaźnika jakości morskich prac sejsmicznych dla jednostki holującej osprzęt geofizyczny w postaci układu kabli sejsmicznych z zainstalowanym zespołem geofonów. Wskaźnik jakości prac geofizycznych opiera się na matematycznym modelu odchylenia położenia układu punktów kabli geofonowych w stosunku do położenia wzorcowego. Wskaźnik ten może być wykorzystany przy realizacji prac sejsmicznych oraz krótkoterminowego prognozowania ich przebiegu w aspekcie jakości.