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ANALITICAL AND SIMULATION METHODS FOR DETERMINE VESSEL'S SAFETY MENOEUVRING AREA – USEFULNESS ASSESSMENT

ABSTRACT

The paper presents the accuracy of five analytical and one simulation methods used for dimensioning the safety waterways for maneuvering vessels. The accuracy of above methods has been estimated on the basis of results obtained from the real experiments. The analysis of accuracy enables to assess the usefulness of above mentioned methods and their applicability to waterways designing.

Keywords Manoeuvring Area, Vessel's Safety.

INTRODUCTION

Assessment of safety of ship navigating along the waterway is carried out on the basis of adopted safety criteria. One of the main criterions is dimension of safety maneuvering area. The dimension may be determined by several methods, which may be divided into three main groups [3], [5], [7], [12]: analytical, simulation and based on real experiments.

The crucial vices of analytical methods are relatively low accuracy and their limitations. The good points are simplicity and relatively short time required to gain the outcome [3], [5].

The simulations based methods are more time and money consuming compared with analytical methods. To obtain reliable outcome the hydrodynamic model of given vessel need to be constructed as well as the models of analyzed area and prevailing conditions.

The real methods are active and passive. The active methods concern the maneuvering trials to obtain the maneuvering characteristics of given vessel.

The aim of passive methods is to verify and determine the safety level of simulations based methods and analytical methods. A distinctive feature of real methods is taking the measurement of object's which dynamics is variable. Due to high costs the real experiments are not widespread practiced.

This paper addresses the real experiments methods, comparison of real experiments' outcome with data obtained from simulation and analytical methods and assessment of analytical and simulation methods usefulness.

REAL EXPERIMENTS METHODS

Methods described in the paper are based on real experiments which take advantage of laser technique of distance measurement and electronic technique of horizontal angles measurement. The measuring device used for the purposes of the experiments is pulsed laser rangefinder with encoder attached (MDL LaserAce 300) mounted on the tripod [7]. The adopted techniques of taking measurements enabled precise positioning of given object (vessel) or certain point onto the surface of the object. Two methods were worked out: static and dynamic.

Static method

The static method enables to determine the width of vessel's safety maneuvering area along straight leg of waterway, which length does not exceed two times ship's length. The measuring device is takes measurements along given line, which is usually perpendicular to the waterway's main axis. The measuring kit consists of laser rangefinder and data recorder. The method may be applicable to determine safety maneuvering area for vessels navigating through the leg of waterway enclosed by bridge's abutments.

Ship's path width determination

The width of ship's path in a single passage may be defined as an area between point of ship's hull which is closest to measuring post and its reflection on the opposite side of vessel, taking into consideration that the ship's hull is not parallel to measuring line, due to wind and current. The width of safety maneuvering area is determined using statistical methods, based on the numbers of passages. To determine the ship's path width it is required to divide continuous ship's hull waterline contour into given number of points. The number of points is set experimentally, after given number of passage is recorded.

The following formula is used:

$$m = 2 \cdot \frac{\sum_{i=1}^{i=n} k}{n} \tag{1}$$

where: m – number of points describing the hull's waterline outline,
k – number of measurements recorded during single passage of analyzed ship,
n – number of passages recorded.

Ship's hull waterline contour is referred to local coordinate frame, with beginning in the centre of waterline contour, and is expressed as the matrix:

$$S = \begin{bmatrix} dx_1 & dy_1 \\ dx_2 & dy_2 \\ . & . \\ dx_m & dy_m \end{bmatrix} \tag{2}$$

where: d_{xm} – distance of n^{th} point of waterline contour form the center along x axis,
d_{ym} – distance of n^{th} point of waterline contour form the center along y axis,
m – number of points describing hull's waterline outline.

While conducting the experiment, distance along constant direction from the measuring station to point on the hull of moving ship was recorder. The number of points recorded was similar for every single passage. The data obtained during measurements was expressed as the matrix:

$$D = \begin{bmatrix} d_1 & \alpha_1 \\ d_2 & \alpha_2 \\ . & . \\ d_k & \alpha_k \end{bmatrix} \tag{3}$$

where: d_k – distance to ship's hull from measuring station, recorded in k^{th} measure,
α – constant direction of measuring line,
k – number of measurements during single passage of ship.

The algorithm to determine the layout of ship's hull during ship's single transit is shown in figure 1. Both distance and direction are referred to local frame which begins in position of measuring station.

Both matrices are expressed also graphically as curves, it is useful during first stage of algorithm, where two curves are compared and proper points along experimental curves are assigned to theoretical ones.

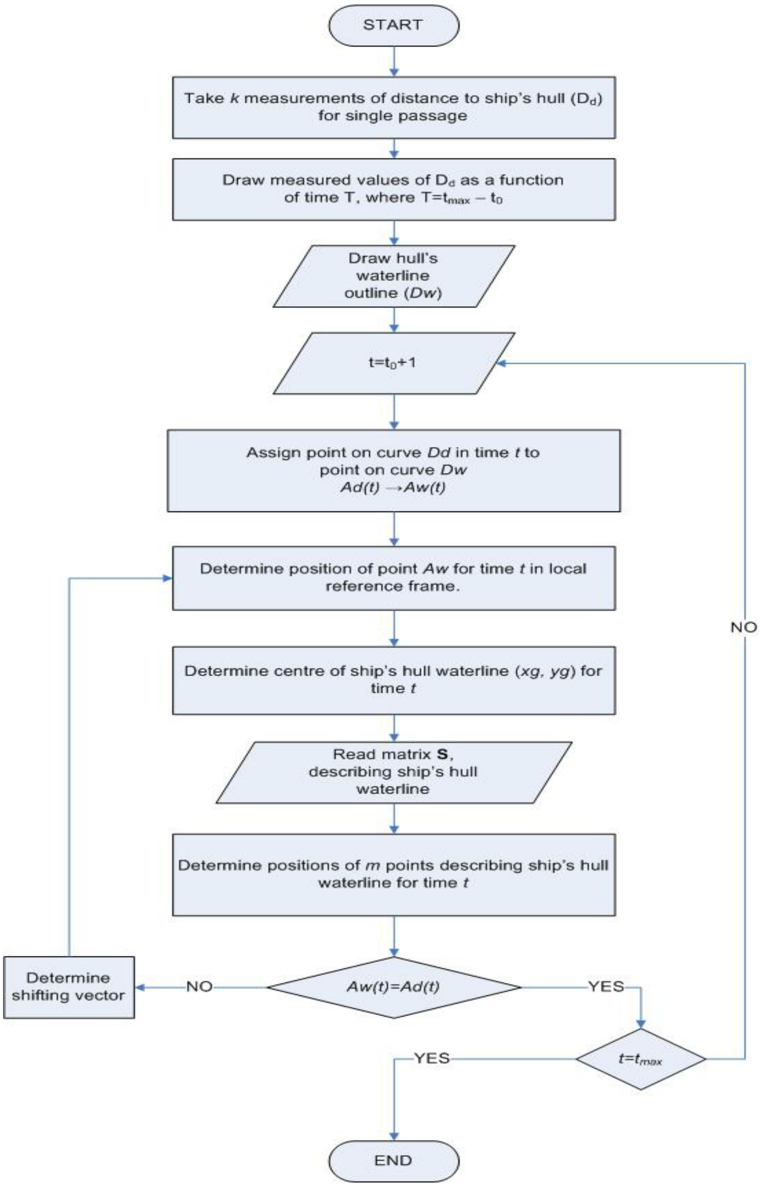


Fig.1. Algorithm of ship's waterline layout determination adopted in static method

Dynamic method

The dynamic method is lack of limitations compared with the static method. The measuring device consists of laser rangefinder, encoder and data recorder, mounted on tripod which is placed on the given position ashore and calibrated along known direction. To determine vessel's swept path, tracking technique had been applied, where non simultaneous measurements were done towards two target points placed on vessel's hull [7]. The principle of the technique is presented in figure 2, where the consecutive measurements are numbered accordingly. Due to adopted tracking technique and non simultaneous measurements some errors occur. Using the mathematical and statistical methods the models of these errors may be constructed and influence of uncertainties may be compensated [9]. Also data from other sources like GPS RTK, if available, are useful for tuning the uncertainties' model [8].

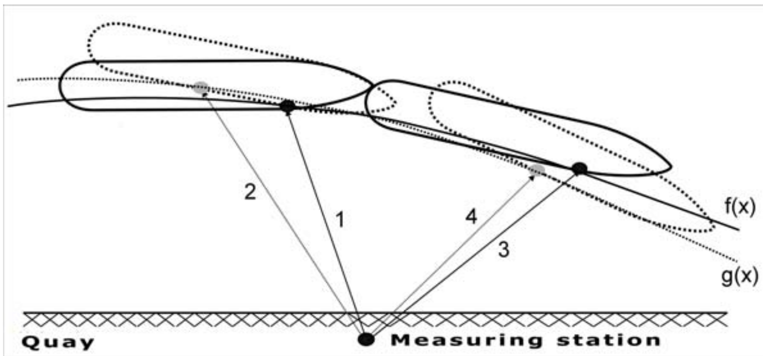


Fig.2. Tracking of two target points – measuring technique adopted in dynamic method

Ship's path width determination

To determine vessel's path width in a single passage, in a given sector of waterway, discreet measurements of target points shall be transformed into continuous functions. Due to estimation of four target points' trajectories by polynomials, the single passage of ship is described by four equations. Two of them describe trajectories of target points close to measuring station, the other two concerns opposite side of the ship. For each passage, in each sector of waterway the maximum distance from reference line to curves drawn by each polynomial lo left and right is found. The distance between those outermost points is considered path width in given sector of waterway for single passage. The algorithm to determine the layout of ship's hull during ship's single transit is shown in figure 3.

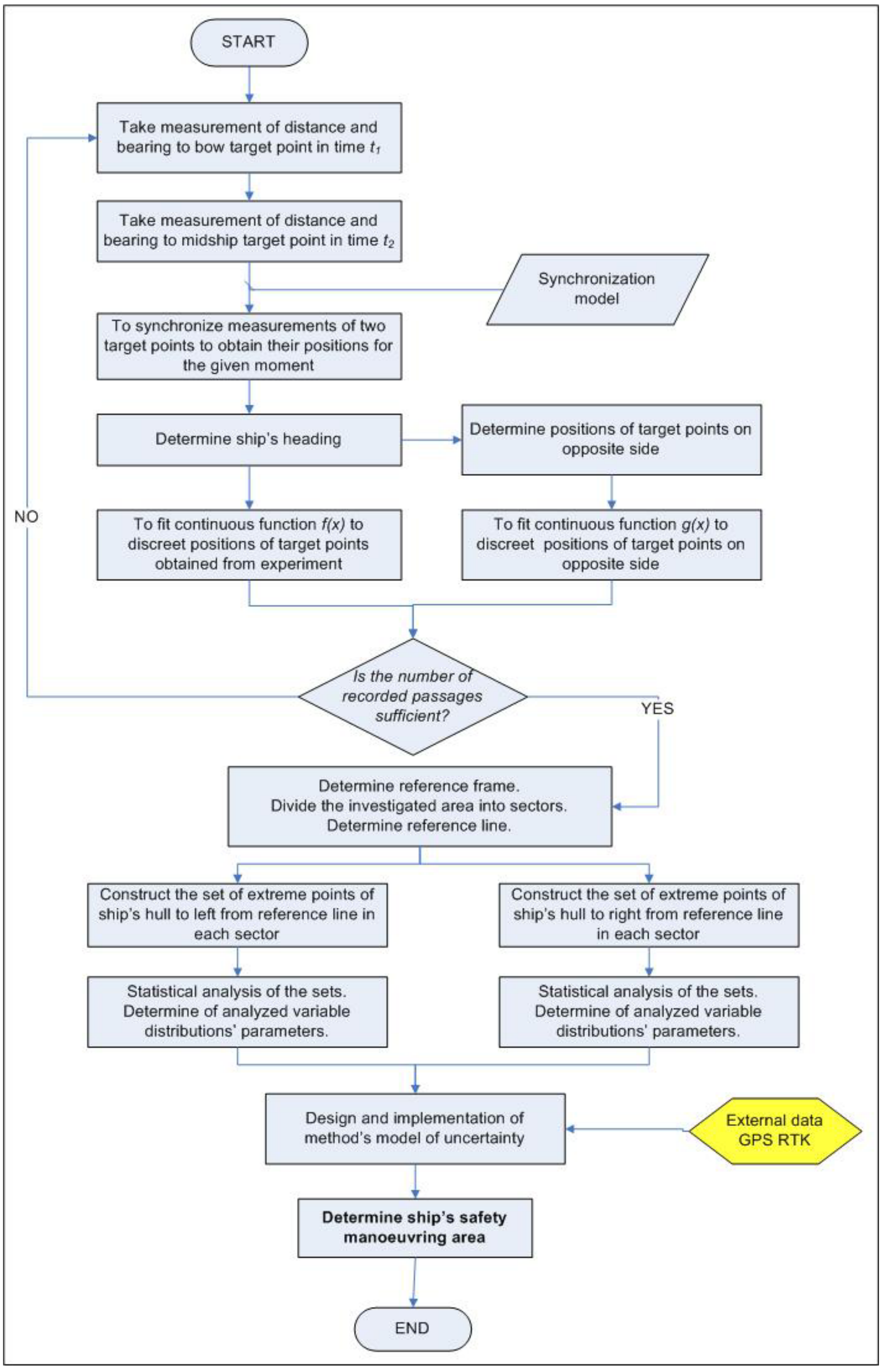


Fig.3. Algorithm of ship's safety maneuvering area determination adopted in dynamic method

Safety maneuvering area determination

The researches, which took advantage of two above presented methods led towards determination the width of safety maneuvering areas and probability of collision with harbor facilities for three types of vessels, during harbor departure maneuvers. Two methods used the same algorithm of collision probability determination, which is based on probabilistic model [3], [12]. The random variable *X* is defined as maximum distance of vessel hull outline to left and right from the adopted reference line in each sector during single passage. From single passage two random variables in each sector are obtained, one variable for left and one for right side from the reference line. On the basis of set of passages the distribution of analyzed variables may be defined (Fig. 4). Based on the former researches it may be assumed that distribution of analyzed random variable *X* is described by normal distribution [3], [5]. Therefore: *X: N(m, σ)*, which distribution's parameters are: *mean (m)* and *standard deviation (σ).* The vessel's path width, in given sector, for given conditions and for specified maneuver may be computed by the following formula [3]:

$$d_i = (\bar{x}_{li} + c \cdot \sigma_{li}) + (\bar{x}_{pi} + c \cdot \sigma_{pi}) \tag{5}$$

where: d_i - path width in given sector i,

$\bar{x}_{li}, \bar{x}_{pi}$ - mean of the maximum distances of vessel hull outline's points from reference line in given sector,

σ_{li}, σ_{pi} - standard deviation,

c - coefficient dependent on adopted confidence level (for confidence level 0,95, c=1,96).

Figure 4 presents general rule to determine the following parameters:

- analyzed variables' distribution,
- horizontal dimension of safety maneuvering area on adopted confidence level,
- probability of accidents caused by exceeding the adopted safety isobaths.

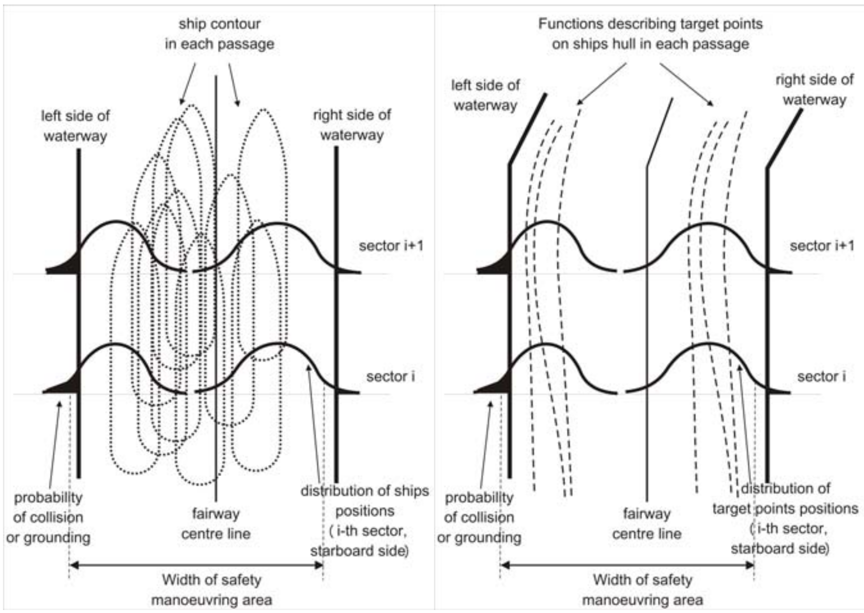
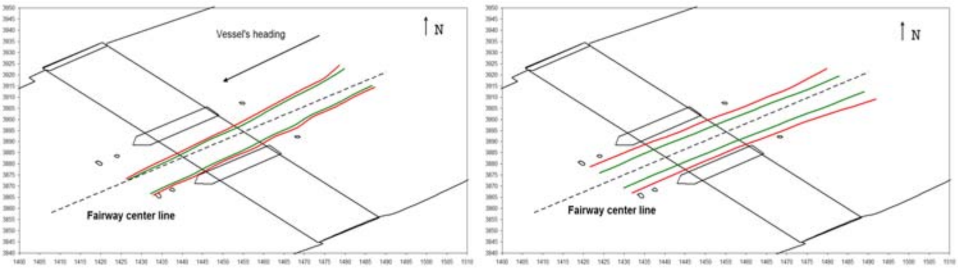


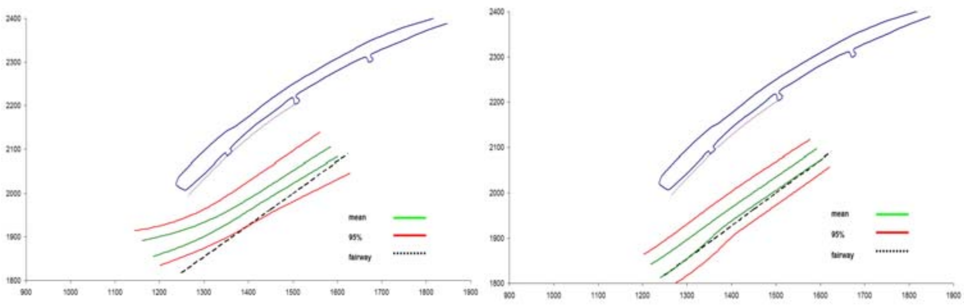
Fig.4. Distributions of vessel hull outline's maximum distances from the reference line, and probability of collision calculation for two methods: static to left and dynamic to right

Figures 5 and 6 present maneuvering areas obtained on the basis of above formulae using data coming from real experiment and simulations. Two areas were considered and two real experiment based methods were used: static (Fig. 5a, 6a) and dynamic (Fig. 5b, 6b).



a b

Fig.5. Safety maneuvering area obtained by means of static method (a) and simulation method (b) - inland passenger ship passing under bridge



a b

Fig.6. Safety maneuvering area obtained by means of dynamic method (a) and simulation method (b) – sea ferry m/f Jan Sniadecki leaving harbour of Swinoujście

THE COMPARISION OF METHODS' RESULTS

The verification was carried out for two types of vessels maneuvering on three types of waterways in the following order:

– inland passenger ferry navigating along straight leg of waterways enclosed by bridge's abutments,
– sea ferry navigating along straight leg waterway,
– sea ferry negotiating bend of waterway.

The following methods were reviewed:

– simulation method based on the hydrodynamic model of vessel's movements constructed in Institute of Marine Traffic Engineering, MU Szczecin,
– analytical method constructed in MU Szczecin on the basis of Three Components Method by Iijima Y. and Honda K. [4],
– PIANC recommendations [10],
– CCG recommendations [1],
– USACE recommendations [11].

The particulars of analyzed vessels and conditions under which experiments were conducted are tabulated below:

Table.1 Vessels' particulars and experiments' conditions

	Inland passenger ferry	**Sea ferry**
LOA [m]	52.78	155.1
Breadth [m]	8.1	21.6
Draft [m]	1.3	5.1
Max. observed speed over ground [kt]	4	12
Wind direction – relative	transverse	transverse
Max. wind velocity [m/s]	2	7
Current direction - relative	against	against
Current velocity [m/s]	0,25	0,25
Number of passages recorded	24	23
Type of waterway	Straight leg enclosed by bridge's abutments	Straight leg of waterway
		Bend of waterway

Results of simulation method verification

The verification process was based upon theory of statistical hypotheses comparison. The random variable adopted for the verification purposes was width of safety maneuvering area computed on given confidence level (0,95). The following tests were used [2]:

– test of normality (Shapiro – Wilk, Kolmogorov – Smirnov),
– test for evaluation of variations' equality (test F, Levene test),
– test for evaluation the differences in means between two groups (t-test),
– t-test's nonparametric alternative (Mann-Whitney test).

The following hypotheses were constructed:

$$\mathbf{H_0}: \mu_{Ss} = \mu_{Sa} \quad (6)$$

$$\mathbf{H_1}: \mu_{Ss} \neq \mu_{Sa} \quad (7)$$

where: μ_{Ss} - the mean value of random variable *„width”* in given sector from simulations,
μ_{Sa} - the mean value of random variable *„width”* in given sector from real experiment.

The variable *width* was defined as an extreme distance of vessel's hull from reference line to left/right for given sector of waterway. The results of comparisons are shown in Fig.7, where the width of safety maneuvering areas of *m/f Jan Śniadecki* and inland ferry computed by simulation and real methods are presented.

The following sentences were proved by statistical tests:

– the width of safety maneuvering area for *m/f Jan Śniadecki* navigating along straight leg of waterway, computed by means of simulation methods differs from real method (Fig.7),
– the width of safety maneuvering area for *m/f Jan Śniadecki* negotiating the bend of waterway, computed by means of simulation method does not differ from the real method (Fig.7),
– the layouts of safety maneuvering areas for *m/f Jan Śniadecki* in waterway determined by simulation and real methods differ significantly (Fig.6),
– the width of safety maneuvering area for inland ferries navigating along straight leg of waterway, computed by means of simulation method differs from real method (Fig.7).

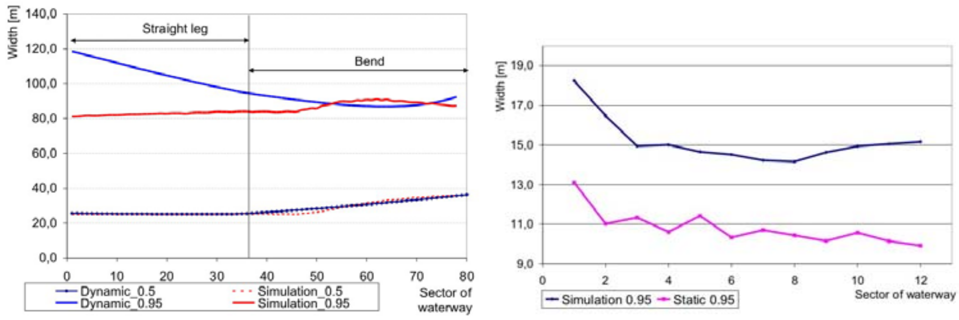


Fig.7. Width of safety maneuvering areas for m/f Jan Śniadecki (to left) and inland ferries (to right)

Results of analytical methods verification

The process of analytical methods verification was based upon results comparison with results coming from real methods. Each analytical method outcome is expressed as a single number in contrast to simulation and real methods, which results are expressed as a string of numbers depending on the number of sectors along waterway. The results of analytical methods are:

– the width of safety maneuvering area computed on given confidence level (0,95) in case of 3 components and INM methods,
– the minimum safety width of channel in case of methods based on PIANC, CCG and USACE recommendations which are lack of probabilistic nature.

The results of real based experiments methods are the widths of safety maneuvering areas computed on given confidence level (0,95).

The diagram presented in Fig.8 shows the differences between results obtained by means of analytical methods and real experiments methods for three types of waterways and maneuvers in the following order:

– inland passenger ferry navigating along straight leg of waterways enclosed by bridge's abutments (named as *bridge*),
– sea ferry navigating along straight leg waterway (named as *straight*);
– sea ferry negotiating bend of waterway (named as *bend*).

The differences, named also the method's error, were computed on the basis of general formula:

$$\Delta = \frac{(w_M - w_R)}{w_R} \cdot 100\% \tag{8}$$

where: Δ - method's error;

w_M - width of waterway computed by analytical method;

w_R - width of waterway computed by real experiment method.

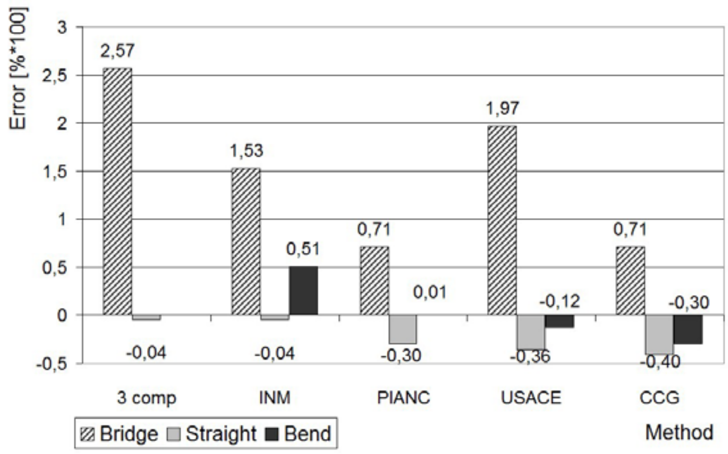


Fig.9. Errors of five analytical methods

CONCLUSIONS

Founded on research summarized above, the following observations were made, concerning results of simulation and analytical methods for determine vessel's safety areas:

1. Simulation method

- in case of inland ferry, navigating along straight inland waterway enclosed by piers of a bridge, width of safety maneuvering area is greater by 0,5 ship's breadth than width obtained by static method,
- in case of sea ferry, navigating along straight leg of harbor entrance waterway, the width of safety maneuvering area is greater than width obtained by dynamic method,
- in case of sea ferry negotiating bend of harbor entrance waterway, the width of safety maneuvering area is the same (statistically) as the width obtained by dynamic method,
- the layouts of safety maneuvering areas in waterways determined by simulation and real methods differ.

2. Analytical method

- in case of inland ferry, navigating along straight inland waterway enclosed by piers of a bridge, widths of safety maneuvering area obtained by analytical methods are generally greater than width obtained by static method, with following differences:
  - CCG (71%),
  - PIANC (71%),
  - INM (153%),
  - USACE (197%),
  - 3 components (257%).
- in case of sea ferry, navigating along straight leg of harbor entrance waterway, the widths of safety maneuvering area obtained by analytical methods are generally smaller than width obtained by dynamic method, with following differences:
  - 3 components (-4%),
  - INM (-4%),
  - USACE (-36%),

- PIANC (-30%),
- CCG (-40%),

– in case of sea ferry, negotiating bend of harbor entrance waterway, the differences between widths of safety maneuvering area obtained by analytical methods and dynamic method are as follows:

- PIANC (1%),
- INM (51%),
- USACE (-12%),
- CCG (-30%),

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