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STATISTICAL ANALYSIS OF PARAMETERS OF SELECTED WORLDWIDE YACHT PORTS AND MARINAS IN TERMS OF DESIGN GUIDELINES

ABSTRACT

In relation to the current development of the sailing, modernization and development of yacht ports and marinas are necessary. The preparations process, stages of the design, analyses and finally construction of yacht ports is time-consuming and laborious. In the article a statistical analysis of selected design parameters was described. In order to carry out the analysis a database was created based on 210 ports from different regions of the world such as: Europe, North America, Australia and South Asia. Google Earth was used to obtain the actual values of the analyzed parameters. Most of achieved results was described in the form of tables or graphs.

Keywords: statistical analysis, design guidelines, port parameters, yacht port, marina, turning basin area.

1. INTRODUCTION

Observed over past years growth of an interest in the sailing tourism caused the need for the development or the modernization of yacht ports and marinas. The basic purpose of the design work is to determine the minimum port parameters to ensure the highest level of safety of the vessels. In order to determine the parameters of recreational ports is necessary to define maximum dimensions of the craft that can safely navigate within the designed basin. The dimensions concern the following: the total length and breadth of the yacht, the draft and the height above the water level. When developing the spatial plan of the port, a series of data must be appoint-

ed, these include the location of breakwaters, locks, ramps, piers, berths, mooring piles, etc. The article presents the statistical analysis of design guidelines focused on such parameters as: areas of the basin of the port, minimal lengths of the berthing line, the minimum widths of the port entrance, widths of the approach channel, widths of the fairways and minimal diameters of the turning basin. For the purpose of the analysis, a database of 210 yacht marinas from various regions all over the world was created.

2. PARAMETERS OF YACHT PORTS AND MARINAS

The management measures for marinas are applicable to the facilities and their associated shore-based services that support recreational boats and boats for hire [Franco, 2008]. At the beginning it is worth to mention the characteristics of yacht ports and marinas.

Marine and inland yacht ports consist of: water areas port engineering structures, port areas, buildings, technical port facilities in order to ensure the safety of moored yachts, maintenance works of yachts, recreational or tourist crafts and floating equipment. To fulfill its tasks, the yacht port must have appropriately shaped water basins sheltered from winds, waves, currents, ice as well as adequate land areas. All of the mentioned plus an adequate equipment provides professional service for yachts, their crew and for other yacht port users, as predicted in the spatial ordinances for yacht ports [Mazurkiewicz, 2010].

Marina is a yacht port including residential buildings as: pavilions or other club and port facilities providing hotel accommodation, shops, bars, cafes and restaurants and all functions required by temporary or permanent residents. Leisure centers can also be included [Mazurkiewicz, 2010].

2.1. Basic Water Area of the Yacht Ports

For design purposes the basic area of the yacht port equals $S_w = 130$ m^2. Basic area of yacht port means area needed to allow for both: safe time alongside and all maneuvers necessary to get the yacht underway. Referring to the number of home based yachts, this area can be (in meters) calculated as follows [Mazurkiewicz, 2010]:

$$S_w = 130\left(N'_p + N'_t + N'_r\right) = 130\left(\tfrac{2}{3}N_p + \tfrac{1}{2}N_t + \tfrac{1}{5}N_r\right) = 130\left(\tfrac{2}{3}N_p + \tfrac{1}{6}N_p + \tfrac{1}{50}N_p\right), \quad (1)$$

and finally:

$$S_w \cong 111 N_p \ \text{or} \ 78 \ C_j \ , \tag{2}$$

where:
N_p - number of home port yachts,
N_r - number of yacht under maintenance,
N_t - number of visiting yachts,
C_j – maximum number of berthing spots.

By specifying the overall size of the yacht port area, the maneuver area S_m is also taken into account. It can be assumed that the maneuvering area is approximately equal to the basic area S_w. Guidelines of Poland found not to differ significantly from other countries (Australia, United States and Mediterranean guidelines). Wind force of 3 degrees Beaufort scale has been assumed in all data sets. The results presented
in different ways (diameter or surface) and in different units, after being reduced to the common denominator, found to be almost identical. For design purposes, a minimum radius of the maneuver area of 1.5 to 2.0 Lc has been assumed.

2.2. Basic Land Area of the Yacht Port S_l

The design of marina requires careful attention to design parameters to maximize benefit, provide functional use and ensure safe berthing for yachts [Dalibor & Prsić, 2005]. In order to determine S_L, the following areas should be determined in advance.

- Assuming that number of car parking spots equals the number of home port yachts, the minimal car park area S_p is given by the following equation [Mazurkiewicz, 2010]:

$$S_p \cong 20 N_p \ \text{or} \ 14 C_j, \tag{3}$$

- By specifying the minimum parking area for cars with a boat trailer S_t and assuming that this surface must provide 50% of the cars with a boat trailer which are temporarily located in port (N_t), and that a surface $S'_t = 60 \ \text{m}^2$ per trailer unit is required, the following relation is given [Mazurkiewicz, 2010]:

$$S_t = S'_t \times \frac{1}{2} N_t = 60 \times \frac{1}{2} N_t = \frac{1}{6} \times 60 \times N_p = 10 N_p \ \text{or} \ 7 C_j, \tag{4}$$

- Roofed parking area S_h to home yachts during a winter season, is calculated for 1/3 of number of home port yachts (N_p) assuming average area for one yacht of $S'_h = 60$ m^2 [Mazurkiewicz, 2010]:

$$S_h = S'_h \times \frac{1}{3} N_p = \frac{1}{3} \times 60 \times N_p = 20 N_p \text{ or } 14 C_j \qquad (5)$$

- The unit area of $S'_d = 175$ m^2 is used to indicate parking area for yachts under maintenance S_d, [Mazurkiewicz, 2010]:

$$S_d = S'_d \times N_r = 175\, N_r \cong 18 N_p \text{ or } 12 C_j \qquad (6)$$

Taking into account listed above component areas the basic land area of the yacht port S_L can be indicated as [Mazurkiewicz, 2010]:

$$S_L = 1.1 \times \left(S_p + S_t + S_h + S_d \right) = 75 N_p \qquad (7)$$

or

$$S_L = 1.1 \times \left(14 C_j + 7 C_j + 14 C_j + 12 C_j \right) = 52 C_j \qquad (8)$$

2.3. The Total Area of the Yacht Port S$_J$

After comparing the basic water area S_w with basic land area S_L one can note that the basic land area equals approximately 0.68 of the basic water area [Mazurkiewicz, 2010]:

$$S_J = S_W + S_L = 111 N_p + 75 N_p = 186 N_p$$
$$\text{or}$$
$$S_J = 77 C_J + 52 C_j = 129 C_j \qquad (9)$$

It is worth to highlight that in some countries the basic land area of yacht port equals 80% of the basic water area of yacht port, but can reach even 50%. Similar relation is used in Italy: $S_W = 55\%$, $S_L = 45\%$. For these assumptions the following was obtained [Mazurkiewicz, 2010]:

$$S_J = 1.8 \times 78C_j = 140C_j \text{ or } S_J = 2.0 \times 78C_j = 156C_j \qquad (10)$$

2.4. The minimum width of the yacht port entrance

The minimum width of the yacht port entrance should be between 20 m and 30 m. The width depends on the maximum beam of yacht B_{max}. The minimum value is set in the range of 4.5 to 6.0 B_{max}. [Mazurkiewicz, 2010]. For large yacht ports, the accepted width of the port entrance should be 100 m for the first thousands of yachts, increasing 25-30 m for every next thousands of berthing yachts. Additionally the minimum width of the entrance is to be (L_{Cmax} +2.0 m), where L_{Cmax} is total lenght of the maximum yacht provided for the port in meters.

By specifying **the minimum width of the approach channel** to the yacht port, it is assumed that:

➢ It should equal to at least twice the width of its entrance,
➢ The width (as stated bellow) should not be less than 30- 35 m of designed depth of channel H_k:

$$B_d = nS_m + 2.4B_{max} + 1.6(n - 1)B_{max} \qquad (11)$$

where:
B_d- width of approach channel of designed depth H_k [m],
n- number of yachts sailing in column,
S_m- sketch of the mast of the yacht [m],
B_{max}- maximum beam of yachts allowed to navigate within approach channel [m].

2.5. The minimum width of inner channels and fairways

In order to determine the minimum width of inner channels and fairways, as stated by B. Mazurkiewicz (2010), the following conditions must be taken into account (see Fig.1):

a) Interior channel
- Minimum width : 20.0 m or 1.5 L_{Cmax} - (choosing higher value)
- Preferable width: 25.0 m or 1.75L_{Cmax} - (choosing higher value)

b) Interior fairway

- Minimum width: 1.5 L_{Cmax}
- Preferable width: 1.75 L_{Cmax}

where:

L_{Cmax} – maximum length of yacht allowed to enter the yacht port [m].

2.5. The minimum average diameter of the turning basin of yacht port *D*

When designing the turning basin, the average value is 50 m, or 70 m for open 'all seasons' marinas with a large number of berthing spots. On some occasions the minimum diameter of the turning basin from $D = 1.5 L_{C\,max}$ up to $D = 2.0 L_{Cmax}$ can be accepted [Mazurkiewicz, 2010], where L_{Cmax} is maximum length of yacht allowed to enter the yacht port [m].

2.6. The total length of the berthing line *Lj*

The total length of the berthing line (all wharves, piers, jetties located in the port are taken into account) depends resulting from the number of berthing spots, can be calculated by following relation [Mazurkiewicz, 2010]:

$$L_j \cong 2.5 C_j \tag{12}$$

here C_j is maximum number of berthing spots.

The following average lengths l_j of the berthing line for a single berthing spot is assumed as follows:

- $l_j = 4.0$ m, for one yacht moored perpendicularly to the jetty,
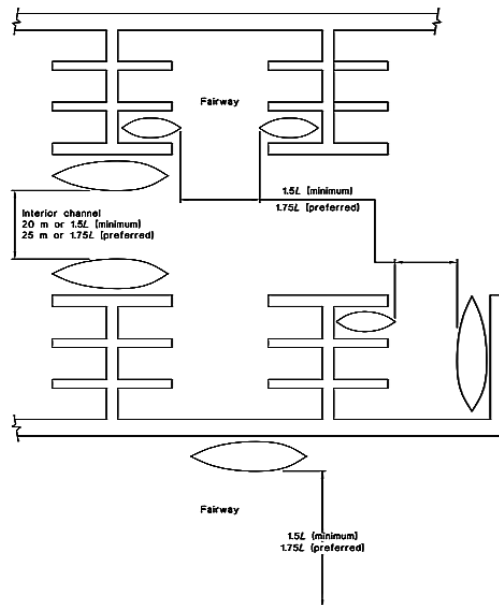- $l_j = 10.0$ m, for one yacht moored along the jetty.

Figure 1. Minimum widths of fairways in yacht port. Source*: The Australian Standards Guidelines for design of marinas.*

2. COMPARISON OF PORT GEOMETRIC CHARACTERISTICS

Available recommendations, includes very detailed requirements for the design and execution of specific structures [Mazurkiewicz, Wiśniewski, 2008]. In order to carry out an analysis, a database based on 210 ports from different regions of world was created. The comparison analysis was performed, assuming the following three different types of ports, *i.e.*: open ports (from the ocean side), partially sheltered ports (from the sea side), completely sheltered (inland).

The following geometric parameters of the existing yacht ports, obtained through Google Earth, are as follows:
- length and breadth of the basin,
- area of the land part of the sailing port,
- the length of the berthing line,
- width of the port entry,
- width of internal fairways and approach channels,
- diameter of the turning basin,
- number of berths spots for yachts.

In order to get insight into relation between the water basin area and the land area of yacht ports and marinas, the length and breadth of the two component surfaces were measured in all 210 cases considered for the analysis. The measured basin area was reduced to the lowest common denominator and stated as the average value for the given division of ports. The perfect recommended design proportion between the water basin area and the land area of yacht port is 45% up to 55%.

The research indicated (Fig. 2) that this proportion stays in accordance with the are ports completely sheltered. It should be emphasized that it isn't possible to rule marinas out of the group of the entirely shielded ports, which differ significantly from this value (analogous to the results of open and partially sheltered waters).
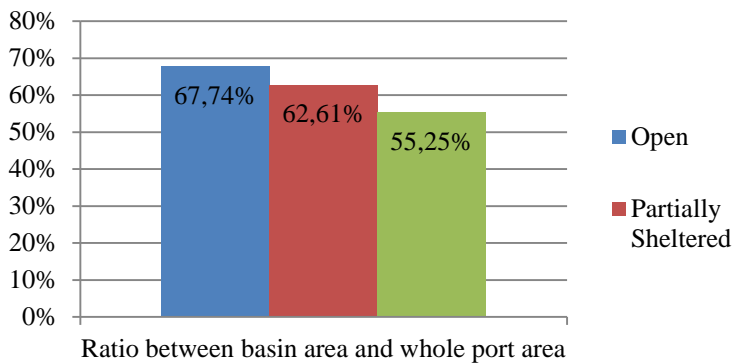

Figure 2. The ratio between the water basin area to the total area of yacht port.
Source: Authors.

Consideration of the maximum quantity of yachts allowed to enter the port is the next point of the comparative analysis. In order to carry out this part of analysis, all the berthing spots in the marina in the marinas were counted, and the results were used to compute the water basin area of yacht port, S_w, according to the design guideline given in Eq.(2).

Table. 1. Comparison between the average design and real values of yacht ports.

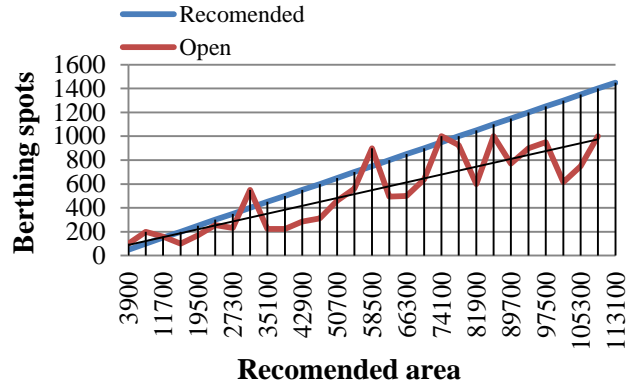| TYPE OF YACHT BASIN	AVERAGE RECOMMENDED DESIGN VALUE [thousand m^2]	AVERAGE REAL VALUE [thousand m^2]
OPEN	85,4	79,5
PARTIALLY SHIELDED	74,5	134,9
COMPLETELY SHELTERED	70,8	111,46

Source: Authors.

Figure 3.1. The ratio between basin area and number of berthing spots for open ports. Source: Authors.

From graphs presented in figs. 3.1 to 3.3 decreasing tendencies are noticeable. The port is more sheltered, the surface area is smaller and the port is designed for fewer vessels. The table below shows the results of comparison the ratio of actual water area of a port to one craft.
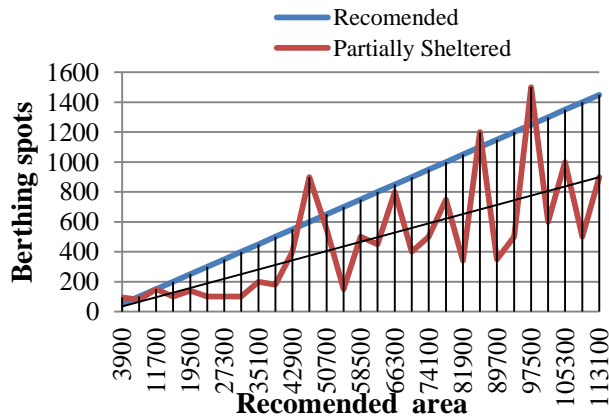

Figure 3.2. The ratio between basin area and number of berthing spots for partially sheltered ports. Source: Authors.
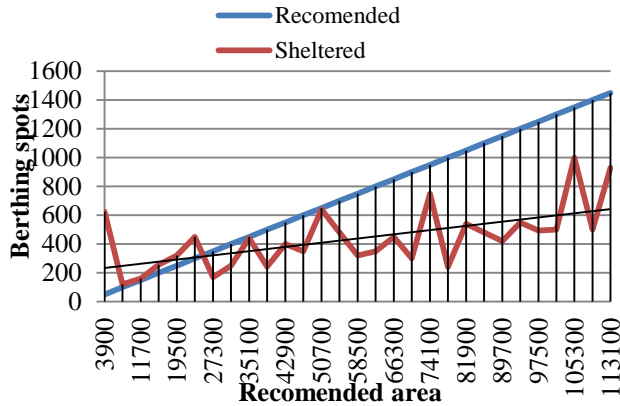
Figure 3.3. The ratio between basin area and number of berthing spots for sheltered ports.
Source: Authors.

Table. 2. Comparison between the water basin area and the single yacht.

TYPE OF YACHT BASIN	AVERAGE RECOMMENDED VALUE [m]	REAL VALUE [m]
OPEN	60-100	101,9
PARTIALLY SHIELDED	60-100	78,1
COMPLETELY SHELTERED	60-100	72,6

Source: Authors.

When designing yacht ports, the parameters of the maximum yacht capable of navigating safely within the port limits are also determined. By analyzing the ratio of the maximum values of the width of the entrance to the width of the yacht (Fig. 4), deviations in all types of surveyed waters were noted. Recommended design data of minimum 30 m found not to be fulfilled in most cases.
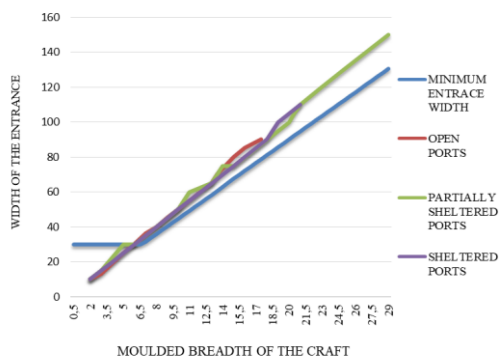

Figure 4. Comparison between the width of the entrance to the maximum beam of the yacht.
Source: Authors.

The comparison of the turning basin to the length of the maximum vessel able to safely navigate within port limits was the next analyzed parameter. Yacht ports with an outer turning basin were not taken into account for the analysis. By analyzing the actual values from the investigated ports indicates that, in all three considered types of ports, the diameter of the turning basin was larger than the recommended value of $1.5L_{max}$. Only occasionally it was smaller, but still above $1.2L_{max}$.
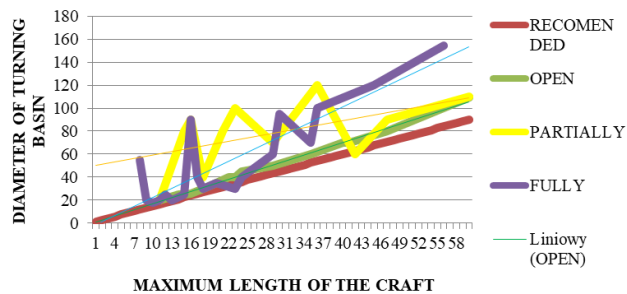

Fig.5. Comparison between the diameter of turning basin to maximum length of the craft. Source: Authors.

Considering the relation between the length of the berthing line and the number of berthing spots, one can conclude that the more sheltered the port is, the less space for one yacht is. In most ports, the length of the berthing line is shorter than the minimum value $2.5Cj$. Thanks the analysis bellow it can be noted that some port facilities are not properly designed for a good yacht service.

CONCLUSIONS

Using the Google Earth program, a special database was created for the purpose of the analyses described in the paper. The database consists of several geometric characteristics where the real values thereof were collected from 210 yacht ports from different regions all over the world. All yacht ports were divided into main groups, i.e.: open ports (from the ocean side), partially sheltered ports (from the sea side) and completely sheltered (inland). Summarizing the results obtained, you can come to the following conclusions. More the basin is sheltered, the port area is smaller, so port is designed for less number of visiting yachts. Only in ports designed for small crafts, the minimum widths of approach channel do not exceed the recommended 30 meters. Similar findings have been made in the analysis of the width of internal fairways. Most of turn basins found to be not less than recommended design size of min $1,5L_{max}$. Only in occasional cases, the width of the turn

basin found to have smaller value, but never less than $1.2L_{max}$ allowing for freely rotation even the largest designated yachts. By analyzing the ratio between the length of the berthing line and the berthing spots it has been noted the port is more sheltered the less maneuvering area for single craft. In most ports, the length of the berthing line found to be less than the minimum value 2.5Cj. Some of berthed yachts sticks out berthing spot, therefore directly reduce the width of the approach channels. To summarize results of the listed above analyses, in order to ensure safe navigation, it is necessary to continually upgrade the design data and existing yacht ports and marinas.

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STRESZCZENIE

W związku z bieżącym rozwojem żeglarstwa, konieczna jest modernizacja oraz rozwój portów jachtowych i marin jachtowych. Proces przygotowania, etapy projektowania, analizy i wreszcie budowa portów jachtowych jest czasochłonna oraz pracochłonna. W artykule opisano statystyczną analizę wybranych parametrów projektowych. W celu przeprowadzenia analizy stworzono bazę danych opartą na 210 portach z różnych regionów świata, np: Europa, Ameryka Północna, Australia i Azja Południowa. Do uzyskania rzeczywistych wartości analizowanych parametrów wykorzystano Google Earth. Większość uzyskanych wyników została opisana w formie tabel lub wykresów.