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Mooring Area and Mooring Buoys Plan

Z. Lušić & D. Pušić
University of Split, Split, Croatia

ABSTRACT: Developing tourism and growing number of tourist and other smaller vessels and personal boats require a larger number of berths, outside dedicated ports, and harbours. Vessels can always anchor, but for ecological, and commercial reasons mooring areas with installed mooring buoys are better and more efficient solutions. However, choosing mooring areas, their size, number of buoys, etc. compared to choosing anchorage areas, is a much more complicated procedure, even more so for not having a unified form nor practice. This paper analyses some of the main issues in the selection of mooring sites and fields, focusing on the factors that should be considered in the planning process. As a result of the carried-out analysis some basic recommendations will be given concerning the choice of mooring field shape, swing radius calculation, distance from the shore, nearby vessels, and other obstacles.

1 INTRODUCTION

Mooring area generally refers to the place where a ship, boat, or aircraft may be moored, but in the context of this paper the expression mooring area (or nautical anchorage area) will be limited to a defined area within which smaller vessels and boats will be moored to mooring buoys. Mooring buoy is a buoy that floats and is secured with a heavy weight (or special anchor) to the sea bottom. Mooring area for smaller vessels and boats, especially tourist ones, are normally located outside ports and harbours, in areas with heavier traffic i.e., in areas where there is an increased demand for mooring places, and the capacities of ports and harbours are not sufficient for the reception, or there are not any available at all. Unlike ordinary anchorages, they require some investment, although on a much smaller scale than harbours, wharves, marinas, and other similarly places designed to receive and accommodate ships. In comparison to anchorages, they are also much safer for users and environmentally more acceptable. They are especially popular in tourist attractive areas outside the cities, if the area is to be given in concession. The problems that arise are the result of the very nature of their usage. Namely concession holders and other service providers want to achieve as bigger economic capacity utilization as possible, and it is, from the beginning, in complete opposition to the safety and environmental protection factors. Therefore, a compromise should be reached regarding the size and the shape of the mooring area, the distance from the shore and other installations, the number of buoys within the area and the distance between them, the minimal depth, the types of buoy anchoring, etc. Another problem is the inconsistent practice and the lack of legal regulations. Two main challenges emerge: where and how to choose an area to define it as a mooring/buoys area, and then the selection of the field, its shape, and the number of buoys within. The chosen area must be economically justified, often even motivated by local politics, and at the same time it should take into consideration that reasonable level of safety is achieved. Reasonable safety here means an acceptable level of risk, taking into account the nature and severity of the potential damage and the likelihood that the damage will occur during the vessel's arrival/departure or stay at berth.

Once the area is selected, the field selection and buoys anchoring follow. The latter being the main subject of this paper, within which an overview of the existing recommendations and practices will be given, as well as corresponding guidelines of how to standardise and optimise the selection of mooring area size and shape, including the layout of buoys within the field. A special attention will be given to the determination of swing radius, i.e. the area around the buoy (anchor) that should be free of all other vessels (or obstacles). Previous research on this topic is quite limited; manuals, guides, recommendations, and real-world examples predominate. Regarding the selection of mooring areas, and anchorages in general, it is worth highlighting the work [Pušić, Lušić, 2022], guides dealing with the design of harbours, approach channels and basins in general [Pianq, 2014], [ROM, 2007], [Technical standards, 2002.] and the guidelines for moorings GL Noble Denton [Technical Standards, 2016]. Methods for mooring small vessels and recommendations for field installation can be found in [Mooring buoy Planning Guide, 2005], [Quartermaster, 2013], and a number of guides from individual port authorities [Anchorage area, 2019], [Moorings, 2015], [Falmouth Haven, 2022] or generally in guides from the Internet [McVinney, 2022], [Mooring basics, 2022], [Mooring basics, 2021]. Moorings in Split-Dalmatia County (SDC) are used for analysis of the form of mooring fields and examples from practice [Račić et all, 2019], [Action Plan, 2013].

2 ANCHORAGE LOCATION SELECTION

According to their purpose and shape, anchorage locations can be divided into two main types: those for accommodation of bigger vessels and those for smaller ones, bearing in mind that nautical anchorage areas are a special category for mooring of smaller boats onto anchored buoys within a specially defined area (mooring area). Anchorages for bigger vessels are usually located at the entrances, or near harbours and other populated places, but also where there is a need to wait for any reason. They are generally made in simpler geometric shapes and follow, more or less, same installation logic. On the other hand, anchorages for smaller vessels, or simply nautical anchorages, including the area of mooring buoys, are characterized by numerous differences, such as the choice of location, shape and size, capacity, anchoring techniques, purpose, etc. Regardless of the above, any anchorage planning should start from general rules and standards, and good practice, for both, large or small vessels anchorages. Some of the general recommendations in defining anchorage areas are as follows:

– they must be of a sufficient size to allow movement from any obstacle,
– they have to provide as safe as possible shelter from the influence of external factors, primarily from waves, wind, and currents,
– the bathymetry should be relatively flat and clear of any obstructions,
– the type of seabed should be considered,
– they should not interfere with the traffic of other vessels,
– they should be sufficiently distanced from other installations and objects,
– the distance between moored vessels should be such that their swing radii do not overlap, etc.

According to PIANC [PIANC, 2014] the design of an anchorage, in general, mainly depends on the following factors:

– size, dimensions, and characteristics of the vessel(s),
– type of operations expected to be undertaken,
– duration for which the vessel(s) will stay at anchor,
– site's general configuration and availability of space for manoeuvring,
– arrangement as a general anchorage area or have defined anchorage positions,
– number of defined anchoring points to be provided at the site,
– marine environment in the area and operational limiting conditions,
– site's physical characteristics and, in particular, depth and shape of the seabed and the ability of the seabed material for anchor holding,
– availability of pollution combating resources, etc.

According to Anchorage Area Design and Management Guideline (2019) the key elements in anchorage (mooring area) design are:

– anchorage location (water depth, holding ground, weather, port layout and infrastructure, other waterway users, vicinity of populous areas, communications to shore side facilities, etc),
– anchorage size and layout,
– anchorage use,
– environmental considerations (environmental assessment, disturbance to seabed from anchor drop and chain drag, management of emissions, pollutants or wastes, aesthetic value, marine pest Introduction, conservation-dependent species, local heritage values).

Considering all the above-mentioned criteria, design process should be clear and easily carried out. However a larger number of problems arise in practice, especially with nautical anchorage areas. These areas are usually given in concession, and the concession holders, together with local authorities, make economic cost-effectiveness and profit their priorities, which regularly results in bypassing safety and environmental factors in whatever way it can be done.

3 SIZE AND SHAPE OF ANCHORAGE AREA

Anchorages, areas where ships drop their anchors and anchor to the bottom to resist movement, are usually located off harbours, channels, popular destinations where ships wait to enter, or where there are no developed moorings, or anywhere there is a need for shelter. Anchorage areas can be "general anchorage areas" or "series of designated anchorages for different size ships". A general anchorage area is used where there are not so many vessels and where there is enough space for anchorage. On the other hand, a series of designated anchorages is used in areas where larger number of vessels is expected, where the space is limited and where there is a need to reduce the negative impact of anchorage on the seabed.

A series of designated anchorages will always be clearly marked, each individual anchorage site, as well as the outer border of the whole area. General anchorages can, but do not have to, have marked outer borders. If the borders exist, simpler shapes prevail (circles, square rectangles, parallelograms, rhombus, etc), for example see approach to the Europort [16]. General anchorages without clearly marked outer borders will be where incoming vessels are rare, as a reserve for other anchorages, as places for shelter, and where there is a general possibility to anchor.

The PIANC [Pianc, 2014] provides good guidance on how to determine the size of individual anchorage. Determination is based on the calculations of an anchorage circle of a determined radius (swing radius) based on a vessel anchoring roughly at the centre, an allowance for length of anchor chain deployed based on predominate water depth, tides, weather conditions, length of the vessel and a safety margin.

When anchorage (mooring) areas are given into concession, they are always defined by their external boundaries, and since they are always located in a relatively limited area with higher traffic intensity, the size and shape selection of the nautical anchorage, i.e., mooring area, will be more complex compared to conventional anchorages. If field areas are analysed in relation to the available space, the vicinity of the coast, the shape, etc., a great diversity, but also a significant deviation from already given recommendations, can be noticed (Figure 1) [Račić et all, 2019].

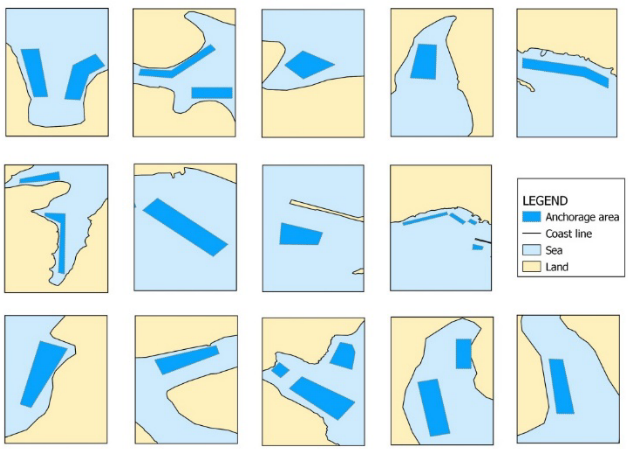

Figure 1. Diversity of anchorage area shapes (E Coast of Adriatic)

In defining the external boundary of the anchorage, as well as the external boundary of the mooring area, the key criterion should be the size of the expected vessels and their swing radii, i.e., defining every individual anchorage as it has already been described for the "series of designated anchorages". But common practice is that external boundaries of the mooring areas are defined without a detailed accommodation plan [Račić et all, 2019]. Outer border and maximum space of a mooring area are derived from general recommendations, and concession holders are enabled to choose the vessels accommodation plan at their own discretion, including the total number of buoys within the area and the distance between them. All this results in a greater diversity of area shapes, and tendency of concession holders to install as many buoys as possible to gain profit at the expense of safety. Namely, it has become a practice to accommodate bigger boats than the ones the anchorage had been designed for (by concession holders` requests), in a way to circumvent recommendations on minimum buoy distances. There are a number of examples where buoy distances are only a few metres larger than the moored boats, e.g., the East coast of the Adriatic (Figure 2) [Danielis Yachting, 2022], the English coast [Falmouth Haven, 2022], etc. In the study "Nautical Tourism Development Plan for Split-Dalmatia County" [Action Plan, 2013], a proposal for nautical anchorages for dozens of bays of SDC was given, and it is quite clear, from the plan, that criteria of safe mutual distance between moored boats cannot be met according to the number of planned vessels on the given area. Swing radii are not predetermined, as mentioned in Section 4 of the paper, and it can be concluded, from the area and accommodation capacities ratio, that the swing radius is approximately 1 meter larger than the length of the largest expected vessel, provided that the swing radii do not overlap. Some other conceptual solutions are on this track, too [Račić et all, 2019]. It is obvious that common practice includes placing buoys at a distance which is slightly larger than the vessel length, but also planning mooring areas in a way that the swing radii partly overlap.

Figure 2. Examples of anchoring (SDC). [Danielis Yachting, 2022], [Google Earth]

The intention of concession holders to accommodate as many vessels as possible is completely understandable, but the authorities which approve conceptual designs, and the ones that supervise their implementation should ensure the application of regulations and professional standards. If the area is too small for single buoy mooring, multiple anchor moorings technique can be applied (Figures 3 and 4). This technique allows the accommodation of a larger number of vessels per area unit, but it is also much more demanding in terms of installation, manoeuvring, external factors influence etc.

4 DISTANCE BETWEEN BUOYS

When determining the distance between buoys, it is crucial to determine the type of mooring and then calculate the corresponding swing radius with the appropriate reserve. Mooring at buoys can be swing mooring or multi-anchor mooring. Swing mooring (single-point mooring) is the most common type of mooring. In this type of mooring, a vessel is attached to a single anchored buoy and swings in a circle around that anchor. The swing radius depends on the length of the boat, the anchor/mooring line, and the depth of the water. Swing moorings should be designed so that the swing circles (area of influence) of each vessel do not overlap. However, in some areas where smaller vessels of similar designs dominate, it occurs that the swing circles overlap to increase the number of vessels in the available mooring area [Moorings, 2015]. There are several options for multiple moorings, the most popular being "Fore and Aft". In this mooring, anchors are set fore and aft to fix the position of the vessel. Trot mooring (Figure 4) is almost identical to fore and aft mooring; it is set away from shore and is intended for smaller boats [Mooring basics, 2021]. Considering that mooring at one buoy is the simplest and most commonly used way of mooring, but also the basis of all other ways of mooring, a somewhat more detailed analysis of determining the swing radius of the vessel, i.e., the area which is supposed to be free of all other objects, will be given bellow.

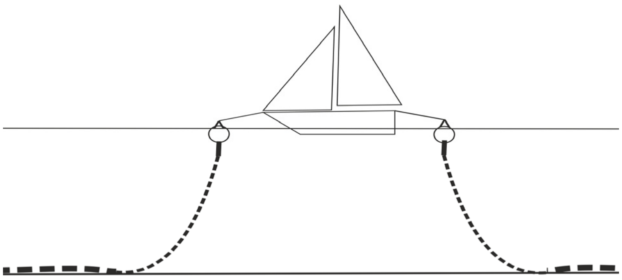

Figure 3. Fore and Aft mooring

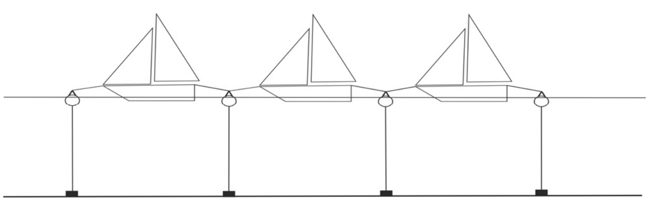

Figure 4. Troot mooring

The swing radius of a vessel depends on several factors and the most important ones are as follows:

- sea depth,
- sea level changes,
- vessel length (L)
- vessel mooring line length (S_{ml})
- anchor line length (A_L)

Sea level has its medium, reference value (hydrographic zero or chart date), but also its extremes, i.e., extreme high tide (EHT) and extreme low tide (ELT). Consequently, when taking into account the sea depth, the depth at extreme high tide (DEHT) and at extreme low tide (DELT) should be known. Length of vessel mooring line primarily depends on freeboard at the bow i.e., the vertical distance between the bow roller and the surface of the water and the chosen optimal angle from the mooring buoy attachment to the stem head. Vessel mooring line can be approximately defined as 2.5m height of freeboard [Mooring basics, 2022] or simply rounded up at 3m [Quartermaster, 2013]. Anchor line length is in function of depth and anchoring type. In order to define anchor line length, it is necessary to know the Scope, i.e., ratio of anchor line length and water depth. For standard anchoring the scope can reach 5 and more, but in case of buoy anchoring it is usually between 3 and 1. For example, in case of concrete anchors, scope is between 2.5 and 1, and for Helical and similar embedded anchors (screw piles) between 1.5 and 1 [Quartermaster, 2013]. These last ones provide the most secure fastening system in muddy bottom sediments and minimize the risk of vessels dragging or breaking away under adverse weather conditions and will be taken as referent value in text further on. For simpler calculations it can be taken that the anchor line length for embedded anchors is at least 3 m more than the sea depth during extreme high tide [Mooring buoy Planning Guide, 2005].

Figure 5 a) shows a standard mooring setup (for a single swinging mooring) that consists of 2 lengths of chain, heavy ground chain on the bottom, connected to a lighter chain on top. Bottom chain length should be 1.5 times the maximum height of water (i.e., spring high tide) [Mooring basics, 2022]. Figure 5 b) shows modern embedded helical anchor solution.

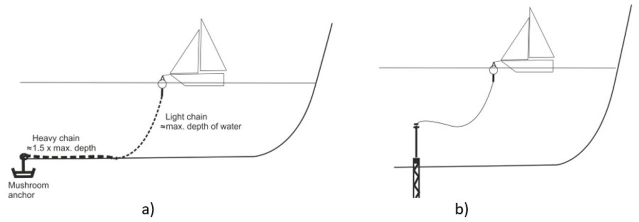

Figure 5. Standard mooring and embedded helical anchor with a mid-line float

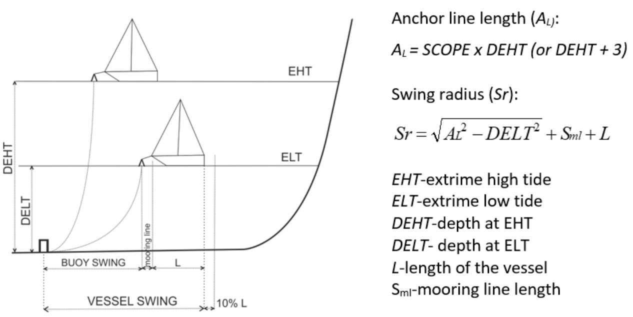

Figure 6. Swing radius

An example of how to calculate swing radius for vessels of different lengths, for the eastern Adriatic coast area, will be given hereafter. Sea level on the eastern part of the Adriatic oscillates within 80 cm [Tide tables, 2015). However, hydro-meteorological conditions should be taken into account, primarily air pressure and wind, which can additionally increase sea level, up to 0.8 m in the central Adriatic [Peljar/Pilot, 1999]. Although extremely rarely, levels over 2 m have been recorded [HHI news, 1999]. Accordingly, in the following calculations, a 1.5 m higher value from the level given in the nautical chart will be taken for extreme high tide levels, and 0.5 m less for extreme low tide. Also, the length of the anchor line will be increased for about three metres more than the extreme high tide, and three more metres for the mooring line, too. It is assumed that modern embedded anchors are used.

Thus, for the above conditions, and for smaller depths, it can be said that the swing radius is approximately twice the length of the ship (Table 1). Accordingly, the distance between the two adjacent buoys, i.e., anchor pins, should be four times the length of the vessel, if the vessels are identical. Since most boats intended for nautical anchorages are between 10 and 20 m, this means that the distance between buoys should be minimum from 40 m to 80 m. In practice, as already described, buoys, i.e., anchor pins are roughly at these distances, however the boats that use them are larger than expected and thus, swing radii of adjacent boats regularly overlap. One of the recommendations in the manuals says that it is necessary to ensure "sufficient swing room between boats, a minimum distance of 130 feet, between anchor pins for boats up to 65-feet in length. In some areas spacing has been increased to 200 feet between anchor pins" [Mooring buoy guide, 2005]. Another good example is Proposed buoy field for Dickton, for scope 1-1,5, which proposes swing radii of 78 ft to 91 ft for boats with length of 30 ft [Quartermaster, 2013]. So, for boats with length up to 20 m, the distances are about 40 to 60 m, which is not enough if swing radii overlapping for the largest vessels is to be avoided.

If it is assumed that all the vessels in the associated mooring area are of the same type and similar size, in case of a single swinging mooring, they should all behave in the same way, i.e., the effect of the external factors should more or less point them in the same or approximately the same direction. Moreover, with changes in the direction of the result vector of external factors, all vessels should also rotate symmetrically. So, in theory, they all rotate in the same direction. In this case, it could be considered acceptable for the swing radii of adjacent vessels to partly overlap [Moorings, 2015], it is sufficient to ensure that the adjacent buoy does not enter the swing circle. To make this happen, a whole range of conditions should be met, among which:

- all vessels are approximately the same type and size,
- vessels are generally of smaller sizes,
- the mooring site is well sheltered from the influence of the open sea,
- currents are minimal,
- sea level oscillations are minimal,
- shorter stay at mooring, e.g., day visits, overnight stays, and seasonal use.
- ensured security monitoring of the mooring and boats on the mooring site,
- and generally, use it exceptionally, when there are no other options.

For fore and aft mooring the distance between buoys can be approximately 3 lengths of the boat, as seen per the central line of the boat, while the transverse direction (clear width for one boat) can be two to three breadths (Figure 7), but not less than the breadth of the largest vessel increased by 1 to 2 m [Technical standards, 2002].

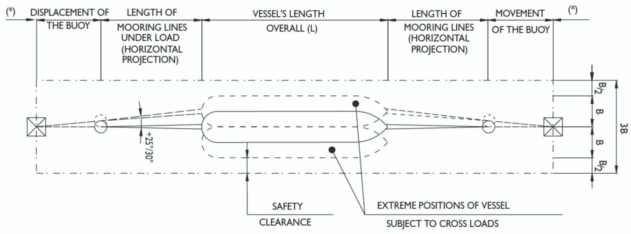

Figure 7. Area for fore and aft mooring [ROM, 2007]

From observing boats at anchorages, as well as from simulations, boats at single point mooring tend to align similarly within a micro location they are in. Under the influence of current, wind, and waves, they roughly align in the same direction, with extremely rare instances of exceeding +/-90° from the resulting direction of the current and/or wind. Crossing this boundary only occurs in situations of sudden changes in wind and/or current, accompanied by different types of connections and/or non-typical shape and size of the ship.

In nautical simulations (Transas NTPro 5000), a series of simulations were conducted to determine the behaviour of various vessels (length of about 10 to 20 m) in different currents and winds. The simulations were carried out by setting the appropriate initial value of current and wind, and then moderately changing the value of the wind direction or current (Figure 8). In all simulations, the vessels were directed in the same way, or all vessels were within courses within 180°. Only in extreme, almost unrealistic, situations of wind and/or current changes, it was possible for some vessels to temporarily direct in the opposite direction of the others.

Table 1. Swing radius for different water depths and vessels lengths

Chart depth (m)	Scope	ELT (m)	EHT (m)	Anchor line length (m)	Swing of anchor line (m)	Mooring line (m)	Swing radius (m) for different vessels length (m)				
							10	12,5	15	17,5	20
2.5	1.75	2	4	7	6.7	3	19.7	22.2	24.7	27.2	29.7
5	1.46	4.5	6.5	9.5	8.4	3	21.4	23.9	26.4	28.9	31.4
7.5	1.33	7	9	12	9.7	3	22.7	25.2	27.7	30.2	32.7
10	1.26	9.5	11.5	14.5	11.0	3	24.0	26.5	29.0	31.5	34.0
12.5	1.21	12	14	17	12.0	3	25.0	27.5	30.0	32.5	35.0
15	1.18	14.5	16.5	19.5	13.0	3	26.0	28.5	31.0	33.5	36.0
17,5	1.16	17	19	22	14.0	3	27.0	29.5	32.0	34.5	37.0
20	1.14	19.5	21.5	24.5	14.8	3	27.8	30.3	32.8	35.3	37.8
22,5	1.13	22	24	27	15.7	3	28.7	31.2	33.7	36.2	38.7
25	1.11	24.5	26.5	29.5	16.4	3	29.4	31.9	34.4	36.9	39.4
27,5	1.10	27	29	32	17.2	3	30.2	32.7	35.2	37.7	40.2
30	1.10	29.5	31.5	34.5	17.9	3	30.9	33.4	35.9	38.4	40.9

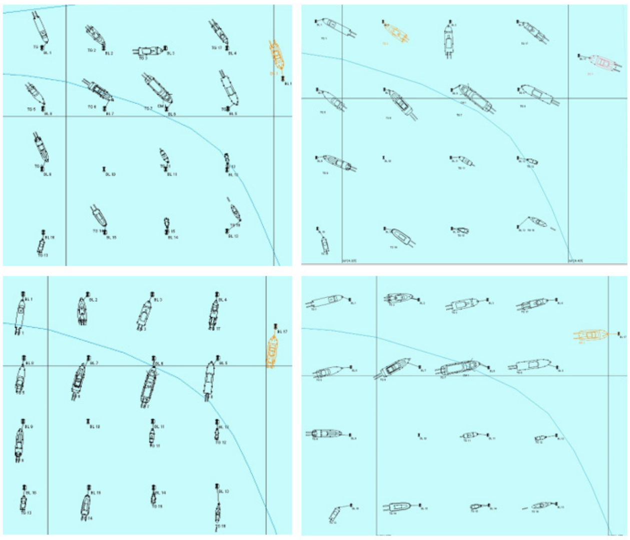

Figure 8. Circling of ships moored to a buoy (wind 15 kn NE, current 2 kn: 000, 090, 180, 270)

5 PROBABILITY OF CONTACT IN SWING MOORING

If a mooring area is designed so that the swing circles of the largest vessels do not overlap, even during the lowest water, then the probability of contact goes to zero, or exists only in situations of higher forces that cannot be influenced and cannot be predicted. The probability of contact of two vessels when going into partial overlap of swing circles will be analysed in the follow up.

When the swing circles overlap, the surface of the overlap does not increase linearly with the approaching of the buoys (centres of the circles of the swing radii). If for two swing circles of 20 m radius there is an overlap on the connection of the centres at 6 m (which is 30% of the total possible overlap of 20 m, i.e., to the buoy) the overlap of the surfaces is about 6.8%. For two swing circles where one is twice as large as the other for the same overlap (6 m or 30%) the overlap of the surfaces is about 7.9% (100% overlap of surfaces would be when the smaller circle of the swing radius touches the centre of the larger circle of the swing radius). So, if we take that the smaller overlaps of swing circles are up to about 10%, this corresponds to approaching the buoys by about 30-40%. Even if we go to the maximum overlap (radius of the swing circle equals the distance between the buoys) it is still less than 50% of possible overlaps of surfaces. The probability that two vessels will be in the area of overlap can be estimated in the following way. Assuming the probability that the vessel A is in the area of overlap P(A), or for vessel B the probability P(B). The probability P(A), or P(B), in principle can be represented by the ratio of the overlap area and the total area of the swing circle. The probability of finding one and the other ship in the overlap area (Po) is:

$$Po = P(A) \cdot P(B)$$

For example, the probability of finding two vessels in an overlapping area of 30%, for two swing circles of the same radius (C1=C2) is about $4.6 \cdot 10^{-3}$, and for $C1 = 2 \cdot C2$ it is about $6.2 \cdot 10^{-3}$.

Figure 9 shows how Po changes for different percentages of change of the overlap distance (100% when the swing circle of one boat touches the adjacent buoy). It is noticeable how the probabilities change minimally for overlapping distance up to 20~30%.

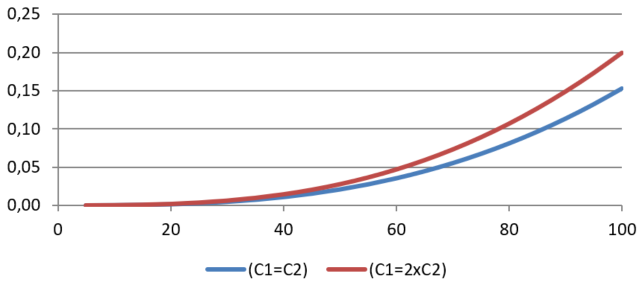

Figure 9. Change in the probability of finding in the overlap area

Calculated probabilities apply to the random movement of vessels around the mooring/anchoring point. However, in practice, vessels follow the same pattern of movement for the same external forces, and deviations from this are very rare. Accordingly, the real probabilities will be significantly less. If one wants to calculate the actual probability of contact, then in addition to the overlapping areas of the swing radii, the following should be taken into account:

- the probability of contact exists only for an atypical vessels, which does not circle as the majority,
- the largest vessels will not always be present, so the probability of contact also depends on the percentage of the moorings occupied by the largest vessels,
- swing radii are defined for extreme water levels, and these extremes have their own frequencies that can also be taken into account,
- mooring system failure,
- ship accidents, etc.

Also, the occurrence of a contact does not mean that an accident with harmful consequences will occur. Since we are talking about boats and small vessels with minimal movement speeds, normal fenders are sufficient for shock absorption. This is also confirmed by statistics which show that in the east Adriatic coast area there are almost no collisions with consequential damages caused by insufficient buoy distances. Having said all this, it is quite understandable that in practice there are examples where buoys are placed at smaller distances from each other than expected, taking into account the calculations of the swing radius of the largest vessel and for the most unfavourable situations for which this is formally declared.

6 THE SIZE OF A MOORING FIELD AND SOME SPECIFIC RECOMMENDATIONS

In selecting mooring areas as concession fields, the primary goal of the concessionaire is certainly to place as many buoys as possible in as little area as possible.

Each vessel at the mooring occupies a corresponding area, which in practice is usually described by a circle (for mooring at a single buoy) or a rectangle (fore and aft mooring). In fact, the total area of the mooring field is the pure sum of the areas allocated to each individual vessel. In the case of single swing moorings, compared to fore and aft mooring, things are more complicated, mainly because the area allocated to each vessel is defined by a circle and these circles end up being placed in the geometric shapes of squares, rectangles, trapezoids, and the like. Thus, the goal is to place as many circles as possible within the defined (regular) geometric figures, i.e., to arrange the circles side by side so that they describe as small an area as possible, assuming that the swing circles do not overlap and that "n" different types of ships of class "i" can be accommodated in an anchorage occupying a certain area "A". In other words, the goal is to have as little unused area as possible within the mooring area.

$$A-\sum_{i=1}^{n}N_iS^{(i)}\rightarrow min$$

A -total surface of a mooring area
S(i) - surface of individual anchorage for class "i" ships
N_i - number of class "i" ships (fields)

In the simplest case, the swing circles are arranged in a series of squares (or trapezoids) to define the outer boundary of the berthing area (Figure 10).

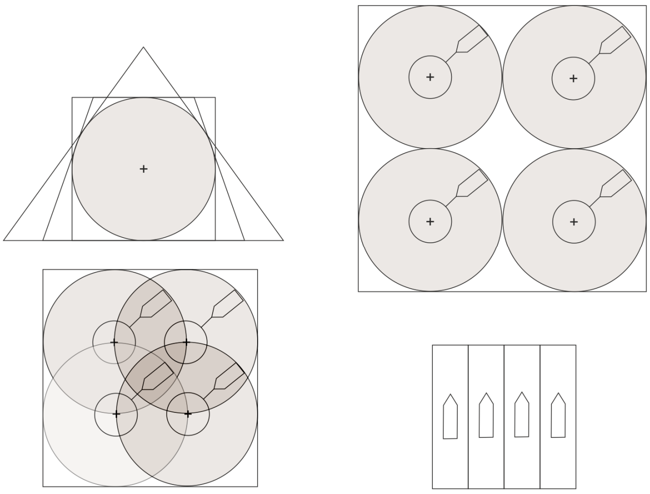

Figure 10. Swing circles in mooring fields and fore and aft moorings

On the example of two vessels, this means a "loss of space" of 21.46% (ratio of the area of the swing circle and the square or trapezoid in which it is arranged). Using the example of a field with 4 buoys and a distance between the buoys of 40 m (for vessels of about 10 m length), a total area of at least 6400 m2 must be provided to avoid overlapping of the swing circles. In case of maximum overlapping, the required area can be reduced down to 4000 m2 (the distance between the buoys corresponds to the swing radius of the largest vessel). For fore and aft mooring, even less than 1000 m2 can be sufficient (each vessel is assigned an area of width three times the width of the vessel, and the distance between the buoys, along the bow and stern lines, is three times the length of the vessel).

It is clear that the fore and aft moorings can accommodate the largest number of vessels per unit area, however, as mentioned earlier, these moorings require greater investment and more complicated maintenance. In addition, mooring and unmooring manoeuvres are more complicated, and the influence of wind, waves, and currents at berth is more significant. Accordingly, swing moorings predominate in practice, and with them the problem of overlapping swing circles.

As for the percentage of occupation of the cove, especially smaller ones, examples from practice show that it mostly goes up to 20%, rarely over 50% of the total available area of the cove [Pušić, Lušić, 2022]. Accordingly, but also taking into account environmental and safety factors, it can be confirmed that the total area of anchor fields should not exceed 50% of the cove. Certainly, it should always be taken into account that anchor (mooring) fields should interfere as little as possible with other traffic, and not to constrain access to the coast from the sea and vice versa, regardless of users. The conduct of ships at sea is governed by the International Regulations for the Prevention of Collision at Sea, which apply to all vessels.

The anchorage selection process is always a compromise between safety and ecology on one hand and economic factors on the other. Some of the main criteria can be grouped as follows:

- Safety of Navigation criteria (vicinity of traffic, distance from the shore and other dangers; underwater cables and pipelines; bottom type and type of shoreline; available space; protection from the wind, currents, waves; vessel type and size, etc.);
- Economic criteria (size of field, number of buoys, vicinity of popular destinations, ports, roads; etc.)
- Environmental criteria (type of anchor, distance from the open sea, shape of a cove, ship waste collection service, local heritage values, etc).

The general criteria and general recommendations are well known and have already been analysed in section 2 of the paper. However, some specific recommendations, which can be drawn from the general ones, good practice, and especially from the examples of mooring fields in Split Dalmatia County [Račić et all, 2019], [Action Plan, 2013], previous research [Pušić, Lušić, 2022] and manuals [Pianq, 2014], [ROM, 2007], [Quartermaster, 2013] can be summarized as follows:

3. Shape and size of the field
   - The shape of mooring field should follow the coastline as much as possible and strive for simpler geometric shapes like circle, square, rectangle, trapeze;
   - Mooring field boundaries should reflect known vessel lengths and estimated swing radius;
   - For small and closed coves, the mooring area should not take up more than 50% of the cove;
   - Minimal width of the field should not be less than double swing radius of the largest vessel and not less than 40 m, exceptionally for extra small boats of up to 20 m.
   - The field should be divided into groups according to the length of vessels, e.g., LOA to 10 m, from 10 to 15 m, from 15 to 20 m, etc.
4. Safety distances

- The distance between buoys in single buoy mooring should be determined so that the swing circles do not overlap. The calculation should be based on the length of the largest vessel for which the mooring is intended, taking into account extreme water levels. Average distance may be expected between 3 and 4 lengths of the vessel, for minimal tide range;
- The calculated swing radius should be increased by 10% of the vessel length, but not less than 1 m (smaller boats), (according to Pianq: for standard anchoring: minimum 20 m, for fishing and pleasure craft it may be reduced to 5 m);
- For multi-buoy mooring (forward and aft) minimal (transversal) distance between buoys should not be less than 2 to 3 breadths of the vessel;
- The distance between mooring field boundaries and the coast (danger) should not be less than the length of the largest vessel, and not less than 20 m;
- In case of the transit traffic vicinity, the distance from the shoreline (safe isobath), should not be less than double length of the largest vessel and not less than 40 m;
- In the nautical mooring area towards the shore and 150 m from the nautical mooring field towards the open sea there should not be any other artificial installations nor objects, including moorings or maritime traffic control measures;
- The distance from the beach should be more than 100 m;
- The area should be deep enough, making sure that during the lowest tide the depth should never be less than 1 m more than the expected vessel draft.

5. Type of anchor
   - Strive to modern anchoring techniques, like helical anchors, to avoid destruction of reefs, seagrass meadows and the benthic ecosystems in general;
   - For standard anchoring the scope can reach 5 and more, for concrete anchors it should be between 2.5 and 1, and for helical and similar embedded anchors between 1.5 and 1.

The risk assessment for mooring/departing and staying at the buoy/anchoring is usually based on the period of use of mooring, and the worst-case scenario should be considered for this period. The installation of a year-round mooring is always more demanding. For seasonal (tourist) use, usually during the summer months, more favourable hydro meteorological factors prevail, but the worst case should always be assumed.

7 CONCLUSION

In determining size, shape, and outer borders of a mooring area, it is essential to take into account the accommodation capacity, and that is primary number and size of vessels. If these capacities are not known, they can always be estimated from practice, statistics, or expectations regarding the location of the anchorage. Nautical anchorages are primarily intended for smaller vessels, and practice shows that these vessels are usually up to 20 m in length. Accordingly, the distance between buoys (their anchors) is usually chosen conforming to vessels whose length is between 10 to 20 meters. Therefore, when planning the field, it is always recommended to draw a series of swing circles based on known or estimated vessel sizes and define the field boundaries as tangents to the drawn circles. Smaller vessels should be closer to shore, larger vessels closer to the open sea. As for the shape of the fields, simple geometric shapes (square, rectangle, trapezoid, ...) should be aimed for, which should also follow the coastline as much as possible..

The distance between buoys, i.e., their anchor pins, should allow the vessel to turn free of all hazards. This is a basic recommendation, the application of which is unproblematic in practice for larger vessels. However, for smaller vessels, especially tourist ones and boats in general, there are deviations, or more precisely, situations where theoretically swing circles can overlap. This is the case when simpler calculation models are used, such as determining the distance between buoys based on increasing the length of the largest vessel by a certain percentage, usually 2 to 3 times the length of the largest vessel. It should be emphasized that the key element in risk assessment is the accurate calculation of the swing radius and its non-intersection with the swing radii of other vessels or other hazards. Overlapping of the swing circles should be avoided, although at small percentages of overlap, up to 20 - 30% of the swing radius of the largest vessels for which the field is designed (and for the worst scenario), the probability of contact is very small. Even if contact does occur, the probability of consequential damage is minimal due to the low approach speeds.

If there is not enough mooring space, it is generally recommended that other mooring techniques be used, such as Fore and Aft mooring. Of course, always make sure that the location of the mooring field provides sufficient protection from external factors and minimises the impact on the environment. In that respect avoid ecologically sensitive areas and use modern mooring solutions that are based on drilling, i.e., firmly anchored in the seabed. In addition, mooring areas should be located at a safe distance from facilities, installations, beaches, hazards, common routes of other vessels, and should be of an appropriate size so as not to impede transit or access to the coast in general.

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