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**□** ARM **☑** ENG **□** PAP **☑** Input

**□** DTEC **□** VTS **□** Information

Agenda item [[2]](#footnote-2) n.n

Technical Domain / Task Number 2 ………2.3.3……………

Author(s) / Submitter(s) ……China MSA……………………………

Proposal on amendments to G1066 Mooring Guidelines

# Summary

The Guideline G1066 on *the Design of Floating Aid to Navigation Moorings* only considers buoys connected by a length of chain to a sinker on the seabed，and does not consider buoys connected by a length of chain to a anchor instead. During ENG 17 and ENG 18 meeting, the task group discussed that the limitations of traditional mooring and believes, in some cases mooring by chain and  anchor can certain compensate such limitations, which should be added to the guidelines.This paper analyzes the advantages and disadvantages of different moorings, provides proposals on the revision of the new chapter-*Mooring Combination of anchor and chain* in the guidelines,and share the test-bed result of a new mooring.

## Purpose of the document

Through comparative analysis of anchor and chain mooring and sinker and chain mooring, this paper provides proposals for the revision of mooring guidelines, and solutions for buoy mooring under special conditions.

## Related documents

1. *G1066-Ed1.3-The-Design-of -Floating-Aid-to-Navigation-Moorings*
2. *R0107-E-107-suggests-Floating-Navigation-Mark-Anchor-System*

[3] *Report-of-the-18th-Meeting-of-ENG-Committee*

# Background

The main mooring method for buoys worldwide is sinker and chain mooring. During ENG17 and ENG18 section, participants realized that in some special waters, the traditional mooring method of the combination of sinker and chain has obvious defect. In order to fasten the buoy and prevent it from shifting in this area, people need to increase the weight of the sinker and result in the sinker buried by sand or mud. During the maintenance of the buoy, the gravity of the sinker and the viscous resistance of the sediment are too large, which makes the sinker and the chain difficult to be recovered.Therefore, the participants agreed that the guideline should not only provide guidance on mooring by sinker and chain, but also other types of mooring like a combination of anchor and chain, so that the guideline will be more comprehensive and instructive.

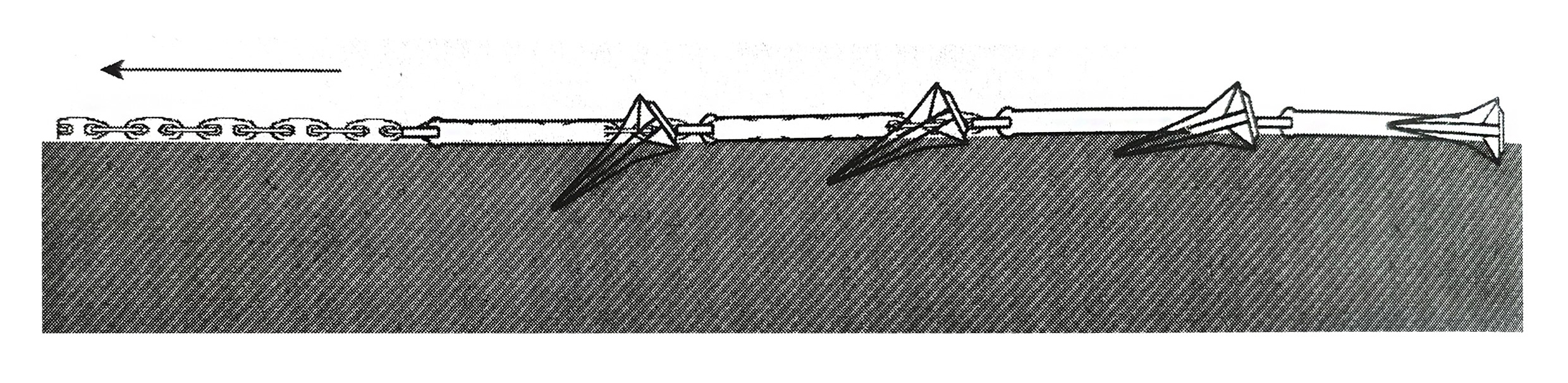
# Discussion

## Traditional mooring with anchor and chain

The mooring force of the anchor refers to the binding force on the buoy when it is in mooring state, which is also known as the anchoring force. It is composed of the holding force of the anchor and the holding force of the ground chain. The holding force of the anchor combined by the friction force between the anchor and the seabed and the viscous resistance of the anchor, which is related to the shape of the anchor and the seabed geology. The holding power of the chain is related to the geology of the seabed, the weight per unit length and the length of the ground chain. From the perspective of the characteristics of traditional anchor mooring, the mooring force mainly rely on the grip of the anchor, rather than relying on its own gravity like sinkers, so anchor is usually lighter than sinker under same condition, compared with the sinker, the weight of the anchor is usually one-tenth to one-twentieth of the weight of the sinker. For the same weight, the mooring force of traditional anchor is much stronger, normally is ten times as much as the sinker`s. Practically, anchor instead of sinker is used to solve problem that the submerged sinker is buried and cannot be recovered.Since the anchor must grasp the seabed before it can produce a firm mooring force, in the case of prominent changes in wind and wave force, the anchor direction would turn with the buoy causing decline of the mooring force, resulting in increase of risk of shifting. Due to the limitation of mooring with anchor and chain, such type of mooring may not suitable for use in waters where the tide causes the buoy to turn frequently.In general, mooring by anchor and chain can only be applied to rivers that are not affected by tides and are always in one direction.

## Requirement on buoy tender maneuvering and positioning accuracy for traditional mooring with anchor and chain

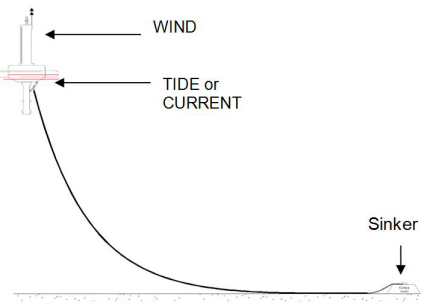
Due to the difference of mooring force between anchor and sinker, when setting buoy, stable mooring force is generated once the sinker set on seabed, while stable mooring force is generated until buoy tender drag the anchor to hold on seabed firmly. See figure 1. Firstly, it is difficult to predict the distance between the position of anchor reach seabed and the position of anchor hold on seabed firmly, which is directly related to the nature of seabed and buoy tender maneuvering, so the position accuracy is hard to determine.Secondly, it may be more difficult for the buoy tender to continue towing the anchor until the anchor completely grasps the seabed, or even cause the anchor to break the ground after the towing force is to much, meanwhile, because the chain of the buoy is all in water, it can not judge whether the anchor holds the seabed firmly through the state of the chain like the anchoring on ship,and can only be continuously observed from the state of the buoy, and the buoy tender need to stay on location for long time.These peculiarities make buoy tender more difficult to maneuver .



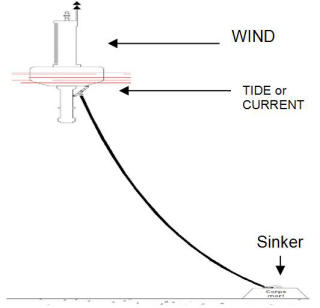
1. Traditional Anchor gripping process

## Disadvantage of traditional anchor in taut mooring

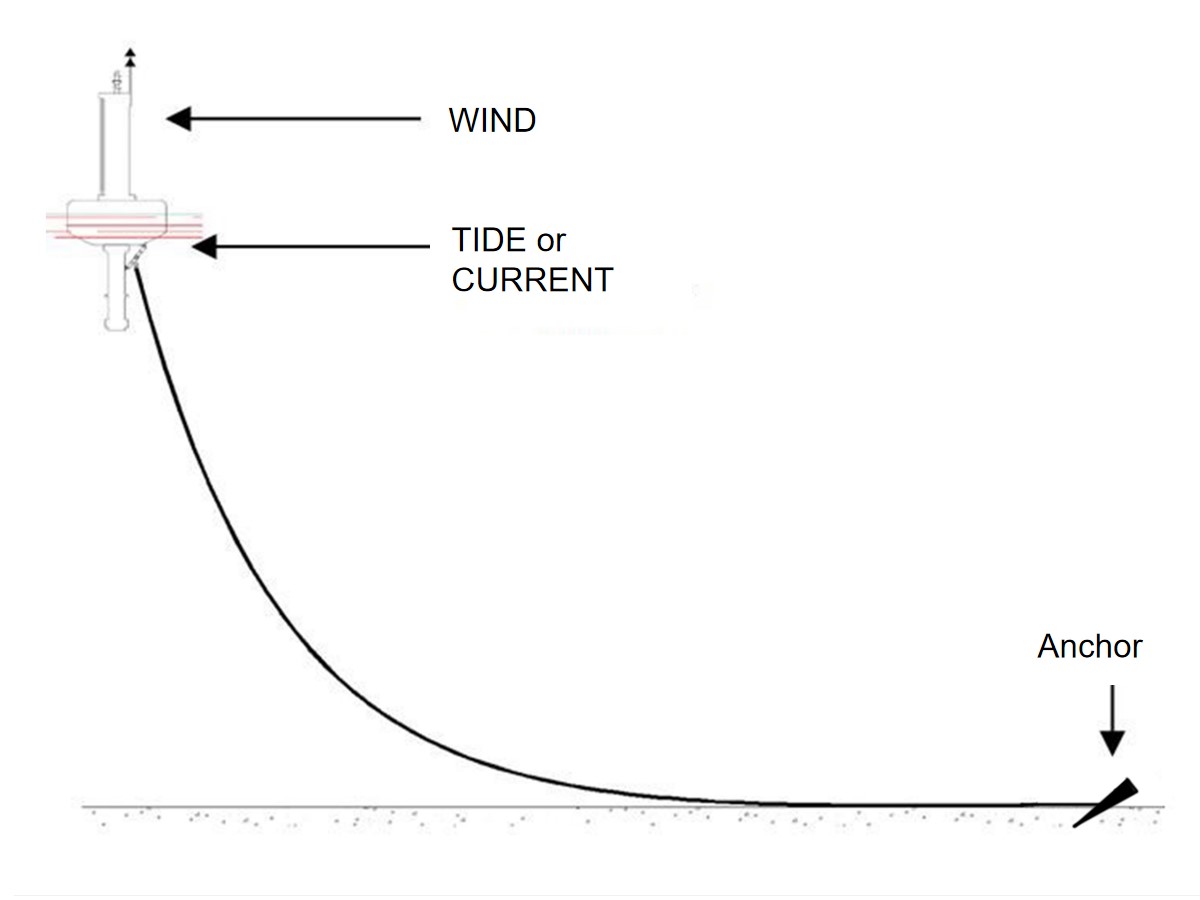
In general, slack mooring is adopted when designing buoy mooring, as shown in Figure 2. However, in some case, taut mooring is considered as well, as shown in Figure 3. Taut mooring can be used to minimize the swinging radius of the buoys and ensure accurate positioning of the buoys, to protect the seabed ecosystem and minimize ecological damage to the seabed, to reduce the entanglement and wear of chains caused by seabed rocks and minimize the impact of seabed rocks on chains. Usually, in order to meet navigational or special environmental requirements, we use sinkers and chains in the design of taut mooring. This is achieved by appropriately increasing the weight of sinkers and shortening the length of chains. However, when using anchor and chain for taut mooring, due to the fundamental difference between the anchoring force of the anchor and the sinker, if the length of the ground chain is zero, it will cause the chain to lift the anchor rod upwards, resulting in a sharp decrease in the anchor's grip. At the same time, the anchor may swing even more without ground chain to absorb energy. Experiments have shown that when the elevation angle of the anchor rod is 5 degrees, the grip coefficient decreases by about a quarter; When the elevation angle of the anchor rod is 15 degrees, the grip coefficient decreases by about half. Therefore, when using anchor and chain mooring, it is necessary to retain sufficient length of the ground chain. Therefore anchor and chain mooring is not suitable for taut mooring, and used for slack mooring only, See figure 4.



1. Slack Mooring(Sinker and Chain)



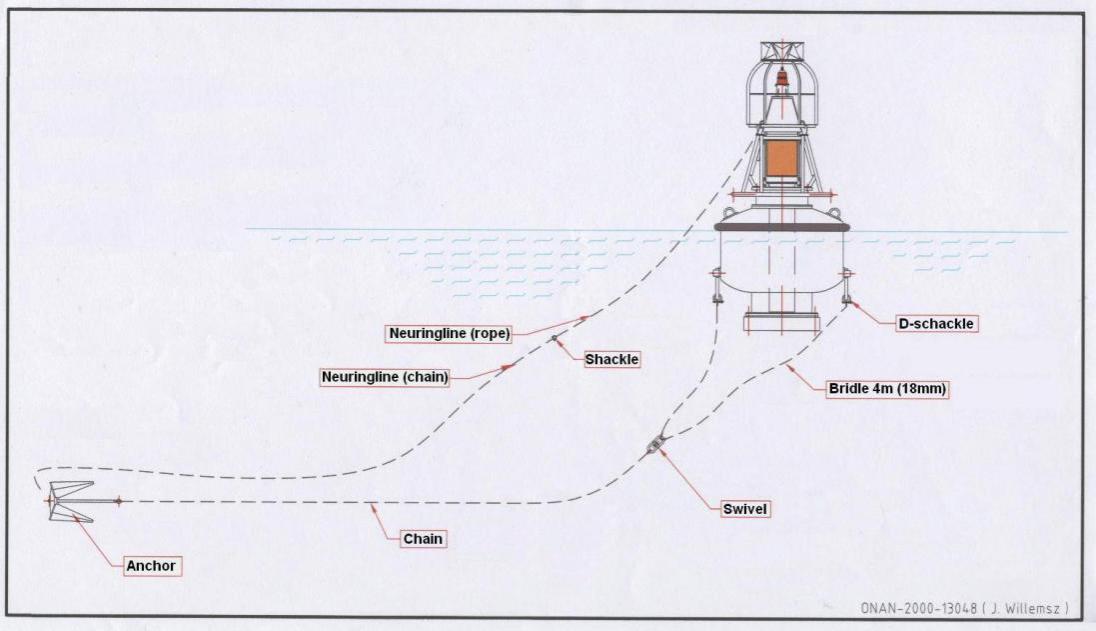
1. Taut Mooring(Sinker and Chain)



1. Slack Mooring(Anchor and Chain)

## The traditional mooring with anchor and chain can reduce reliance on buoy tenders

Since the sinker mainly relies on gravity to produce mooring force, weather suitable or not directly rely on the performance of buoy tender, which is not a small challenge for some areas where there is no appropriate buoy tender. In contrast, although traditional anchors is lighter, also can produce strong mooring force, and has unparalleled advantages in rivers not affected by tides. Below is a practical example, see figure 5. Anchor and chain mooring is adopted in the river with water depth 3 meters to 12 meters, current speed is 4 knots to 6 knots, the buoy is steel with diameter 2 meters, weight 2.5 tons, draft 1.9 meters, anchor weight 0.125 tons and the anchor chain is 22 mm in diameter. It is also equipped with a anchor line composed of a 10-meter chain at the bottom and a rope at the top. The boat can pull the rope to lift the anchor off the bottom, and then drag the buoy and anchor to the new position. As can be seen from the case, an anchor of 0.125 tons is adopted instead of a 3-ton sinker, which is only one twentieth of the weight of the sinker, and the whole buoy can be set up with a small boat, which can greatly reduce the dependence on buoy tenders.



1. Application of mooring with anchor and chain

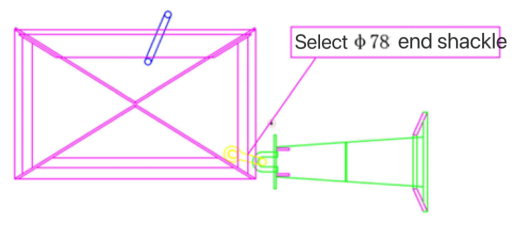
## Exploration of new mooring combination of anchor and chain

### **R&D Requirements**

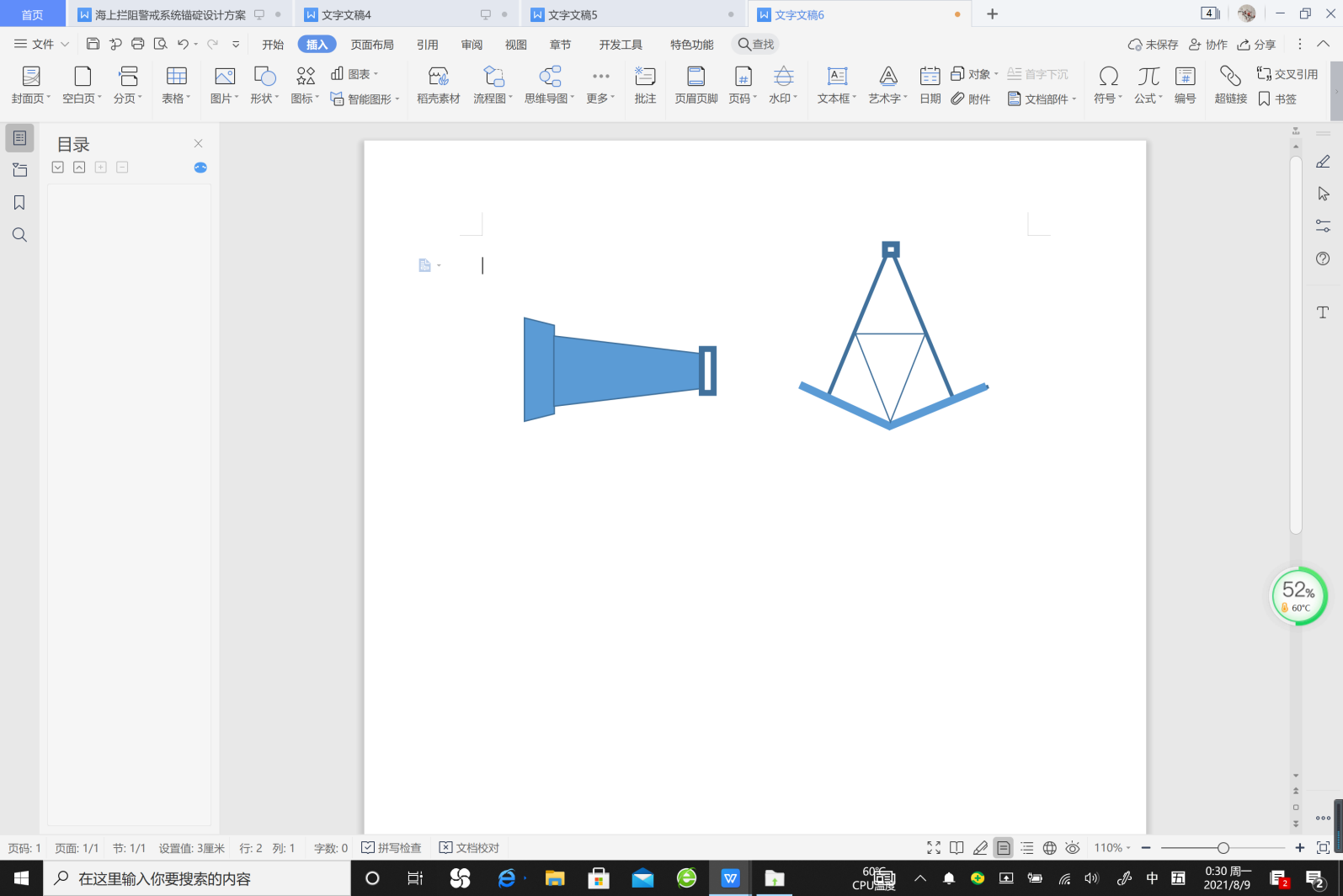
Near the estuary of the Pearl River in China, the seabed is silted and the current direction is changeable under the influence of tides, and flood and typhoon occurs frequently in this region. At the beginning, 5 tons of concrete sinker is used and the buoy frequently shifted much during the typhoon season, then the concrete sinker is changed to 5 tons of cast iron sinker. Although it is found that buoy shifting is reduced but a new problem occurs -that cast iron sinker buried in mud and can not be recovered. To solve the problem, China MSA noticed the limitations of sinker and chain mooring in this region, and try to developed a new type of combination mooring, and some meaningful work experience is gained.

### **Structure and specification of new** **combined mooring**

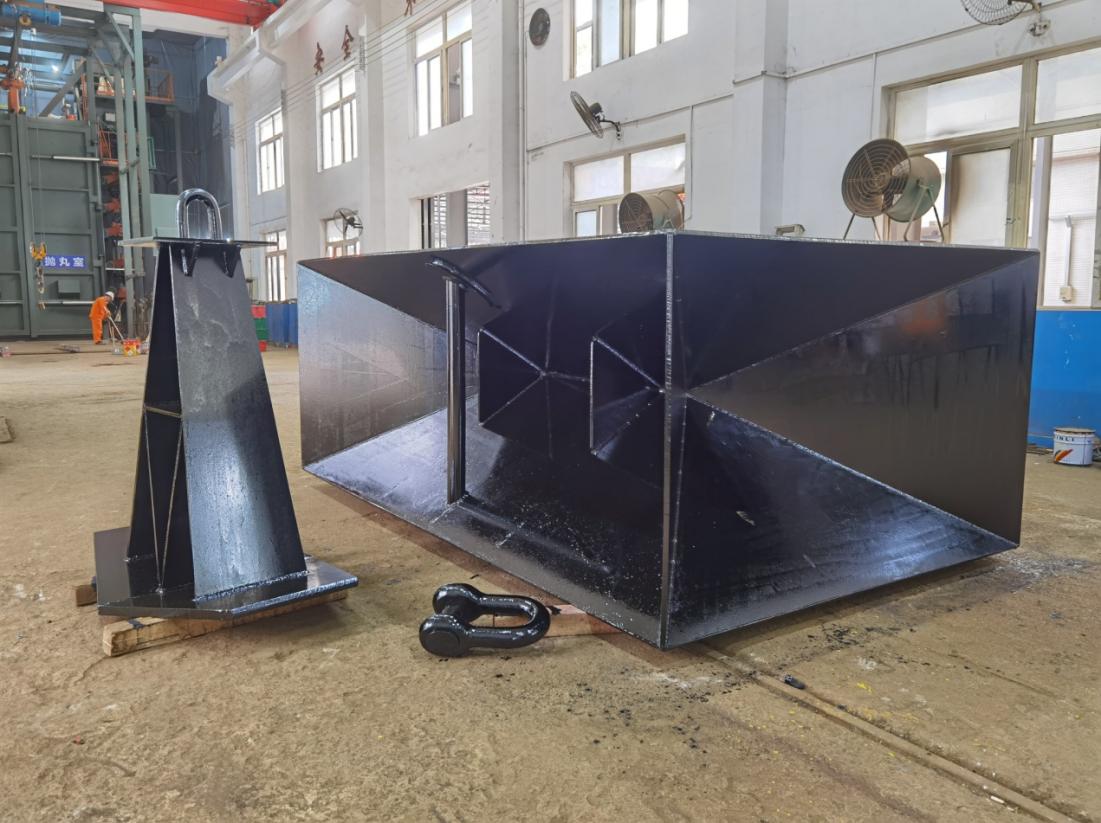
The new combination mooring is composed of steel cuboid and triangular claw, which are linked by shackles and chain. The size of the combined mooring is 2m\*1.24m\*0.76m for the steel cuboid and 1.6m for the steel triangular claw, the total weight is 0.98 ton. The mooring force of the new combined mooring is mainly composed of the resultant force generated after the cuboid steel structure is stabilized and the triangle claw is grabbed into the seabed. The groove of the cuboid steel structure will remove the water and mud inside to form a vacuum, and the sediment mixture at the bottom will produce non-Newtonian fluid effect under the instantaneous external force, resulting in a firm mooring force.



1. Schematic diagram of Steel Cuboid and Triangular Claw



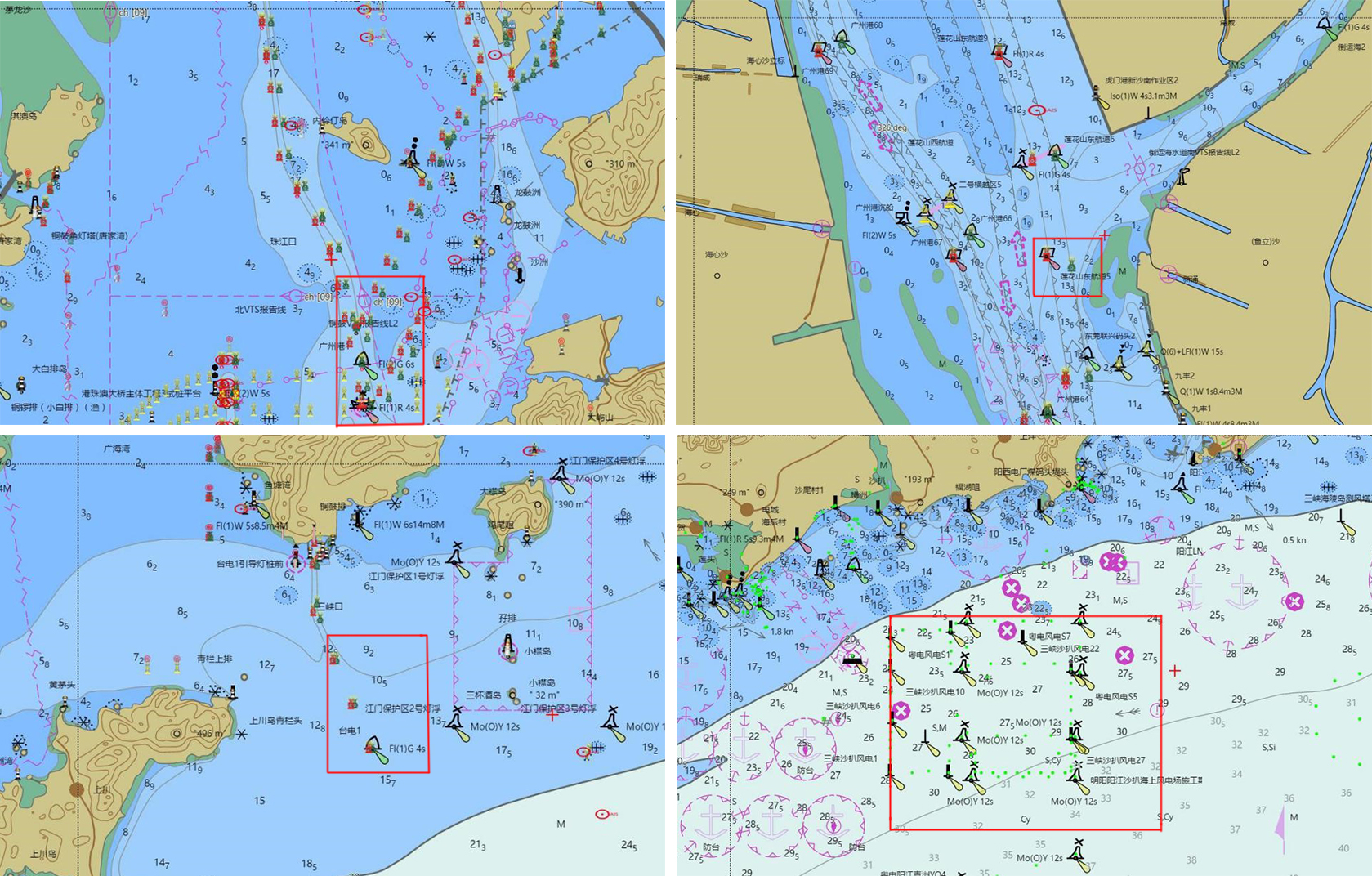
1. Schematic diagram of Triangular Claw



1. Picture of Real Steel Cuboid and Triangular Claw

### **Test result**

Test carried out in representative Pearl River estuary, Pearl River tributary inlet, open water artificial channel and offshore wind farms, respectively, as shown in Figure 9, and Table 1 for test result.



1. Test Region
2. Test Situation

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Number** | **Area** | **water characteristics** | **Mooring arrangement**  **(before)** | **Problem before test** | **Mooring arrangement**  **(after)** | **Test result** |
|  | Pearl River estuary | The sediment layer is shallow,  water depth 15-20 meters, current speed 3-4 knots, and it is affected by tides, floods and typhoons occurs frequently. | Steel buoy 2.4 meters in diameter, weight 5 tons, 2 cable of chains, 5 tons of cast iron or concrete sinker. | Bouy liable to shfting off position when use concrete sinker, or difficult to recover when use cast iron sinker. | Steel buoy 2.4 meters in diameter, weight 5 tons, 2 cable of chains, 0.98 tons of new combined mooring. | 13 bouys,test for 2 years, some buoys prone to shifting off positon during the flood season. |
|  | Confluence of Pearl River tributaries | water depth 10-15 meters, current speed 3-4 knots and changeable , narrow channel with depth drop,floods and typhoons occurs frequently. | Steel buoy 2.4 meters in diameter, weight 5 tons, 2 cable of chains, 5 tons of cast iron or concrete sinker. | Bouy liable to shfting off position no matter use concrete sinker or cast iron sinker. | Steel buoy 2.4 meters in diameter, weight 5 tons, 2 cable of chains, 0.98 tons of new combined mooring. | 2 bouys, test for 2 years, buoy position maintained stable |
|  | Open Water Artificial Waterway | water depth 15-20 meters, current speed 2-3 knots, floods and typhoons occurs frequently. | Steel buoy 2.4 meters in diameter, weight 5 tons, 2 cable of chains, 5 tons of cast iron or concrete sinker. | Bouy liable to shfting off position when use concrete sinker, or difficult to recover when use cast iron sinker. | Steel buoy 2.4 meters in diameter, weight 5 tons, 2 cable of chains, 0.98 tons of new combined mooring. | 5 bouys, test for 2 year,During the following typhoon season,other buoys in the same waters shifting far away. |
|  | Offshore wind farms | water depth 20-50 meters, current speed 2-3 knots, floods and typhoons occurs frequently. | Steel buoy 2.4 meters in diameter, weight 5 tons, 2 cable of chains, 5 tons of cast iron or concrete sinker. | Bouy liable to shfting when use concrete sinker, or difficult to recover when use cast iron sinker. | Steel buoy 2.4 meters in diameter, weight 5 tons, 2 cable of chains, 0.98 tons of new combined mooring. | 3 bouys, Slight or no deviation compared to other buoys in the same waters during the following typhoon season after trial. |

The test shows some positive result and some limitations as well. Since the gravity of the combined mooring is only one fifth of the gravity of a sinker, the buoy is easy to be push away by strong wind and current before it produces a firm mooring force, resulting in high requirements for deploy time. The new combined mooring is more suitable for waters with soft seabed but not for waters with a hard seabed. China MSA keeps cooperation with research institutions to improve the design in order to seek to a universal combined mooring.

In conclusion,sinker and chain mooring is the mainstream mooring method for buoys worldwide. The mooring force of sinker mainly relies on its gravity,the requirements for the seabed condition and setting time are not high, and its main disadvantage is that lifting or dropping sinker has relatively high performance requirements on the buoy tender,and in some areas, there is a risk that the sinker cannot be recovered easily. The mooring force of anchor mainly rely on the holding force to seabed, and the anchor is relatively lightter, the main disadvantage is is that it is difficult to accurately determine the time when it hold on seabed steadily , and mooring force is easy to be affected by wind and flow, anchor mooring can only be used in waters with soft seabed,and the requirements on the application location and timing are relatively high. Combined mooring by sinker and anchor has both advantages, and may have better effect in some case.

# References

1. *G1066-The-Design-of -Floating-Aid-to-Navigation-Moorings*
2. *ENG18-3.2.1.1-Application-of-a-Special-Structure-Combined-Anchorage*

# Action requested of the Committee

The Committee is requested to:

1. Take consideration to the limitations of the sinker and chain mooring, and add a section on "Mooring combination of anchor and chain" to the guideline G1066.
2. Notice the new combined mooring of sinker and anchor in China which can be used as an extension and supplement to traditional mooring, and the effort was make to provide solutions to the problems encountered globally .

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Leave open if uncertain [↑](#footnote-ref-2)