Shyue-Geng Liau and Chia-Lin Lee
Department of Marine Fisheries, Taiwan Fisheries Research Institute, Keelung 202, Taiwan.
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# A Mechanical Analysis of Mooring Lines on the Deployed Fish Aggregating Devices off Lutao


## Abstract

The main purpose of this study was to realize the drag force on the anchor and the tension of the mooring lines against the Kuroshio current with its velocity of 2.8 knots. Based on the static analysis of the mooring lines on deployed fish aggregating devices (FADs) at the depth of 440 meters with velocity of 2.8 knots of the Kuroshio current, the drag force on the device is 2,200 lb. With the angle of the mooring line against the horizontal at 30°, the tension of the anchor and of the device were 2,600 lb and 4,470 lb, respectively. Therefore, the drag force of the polypropylene synthetic ropes was calculated as 5,571 lb (2.35 tons) which is much lower than the breaking strength 78.93 tons of the rope. The drifting of the device may be attributed to the broken-end of the polypropylene rope with a very smooth incision, which might have been cut by a sharp axe.


**Key words:** Deployed fish aggregating devices, Mooring lines, Mechanical analysis, Lutao

The waters off Lutao is one the most important commercial demersal and pelagic fishing grounds adjacent to the eastern part of Taiwan. The Kuroshio current, with its sub-surface layer, brings much of the nutrients, therefore, greater production is expected within the study area.

Extension of the national economic exclusive zone to 200 miles may adversely affect the viability of our deep sea fleet unless new fishing grounds can be found[1]. Thus, the use of an improved fishing gear, such as giant concrete solid, bamboo raft or sunken vessel as artificial reefs or the FADs is becoming more important lure all kinds of fishes in coastal waters nowadays. FADs provide small fish habitats in the continental shelf, and helps to strengthen the evaluation and management of marine fishery resources.

Unfortunately, there are only few papers concerned about the deployed FADs in Taiwan[2,3], therefore, little is known especially regarding the dynamics of the mooring line. In Japan, experiments have been conducted to analyze the FAD's materials and mooring[4].

The mooring line is defined as the flexible mechanical component that connect and attach FADs structure to its anchoring points[5]. Mooring line usually get damaged or broken due to unknown factors and the connected body device drifts away along with the local current. Maximum tension obtained just before bottoming, if large enough, will sink the device. Considerable tangling is always present in a failed mooring, even breaking the mooring line that may cause the valuable equipment to be lost forever. Therefore, the main purpose of this study was to analyze the static stresses of the mooring lines and the tension and the drag at the anchor of the FADs off Lutao.

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## Materials and Methods

The deployed FADs (Fig. 1), used in this study called Sea Farming Type III[8] (Fig. 2), was cast at 22° 39′.2 N, 121°31′.8 E on 8 May 1998 (Fig. 3). The word "device" is often loosely used to describe both the float, anchoring line, and the device system can be divided into moored and free drifting systems, cast in the waters off Lutao with 3 ton weight of Danforth anchor and a 1.8 $m^3$ cubic concrete clump to decrease the fluke angle. It was settled by a set of mooring system which consisted of a 27.5 m length with its diameter of $\phi$=38 mm chain attached to the clump, a 375 m length with $\phi = 90$ mm polypropylene rope, a 350 m length with $\phi = 85$ mm acorn rope, and a 27.5 m length with $\phi$=38 mm chain attached to the devices. The forces considered for the study of mooring lines immersed in steady-state currents were gravity forces, fluid drag and line tension in a constant current situation. We also considered the devices with very simple configuration, one float, one line, one anchor, and some ancillary equipment. The elasticity of the mooring line was not considered.

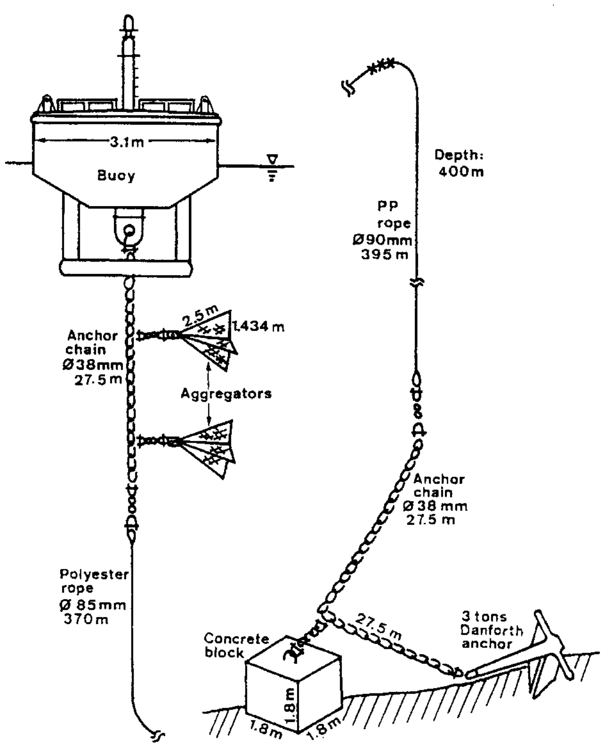


Fig. 1. The structure of the deployed fish aggregating devices used in this study.

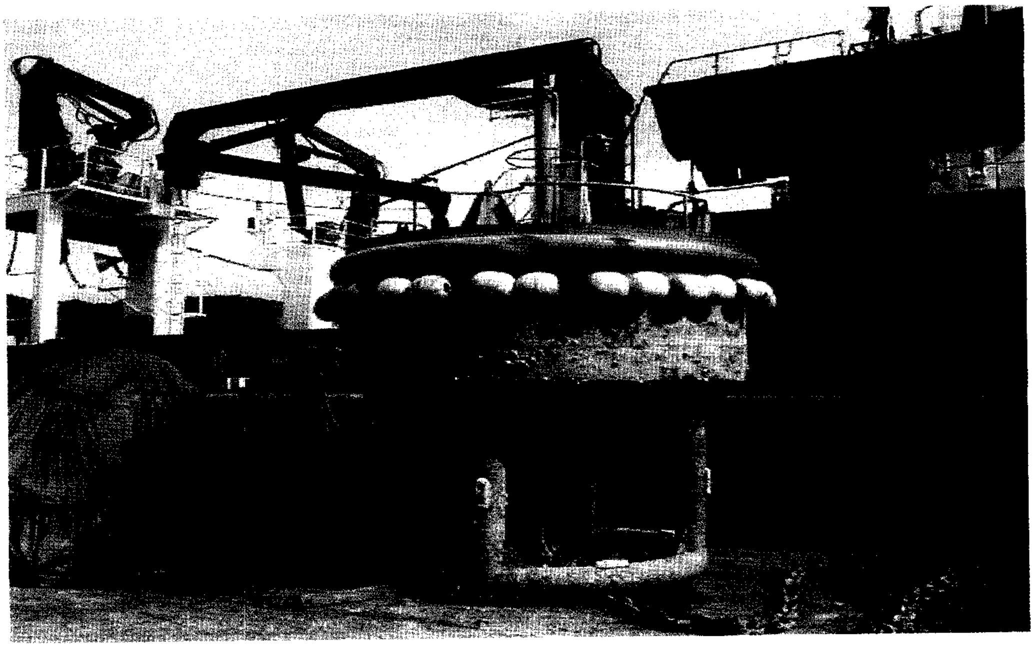

**Fig. 2.** Side view of the deployed fish aggregating device cast in the waters off Lutao.

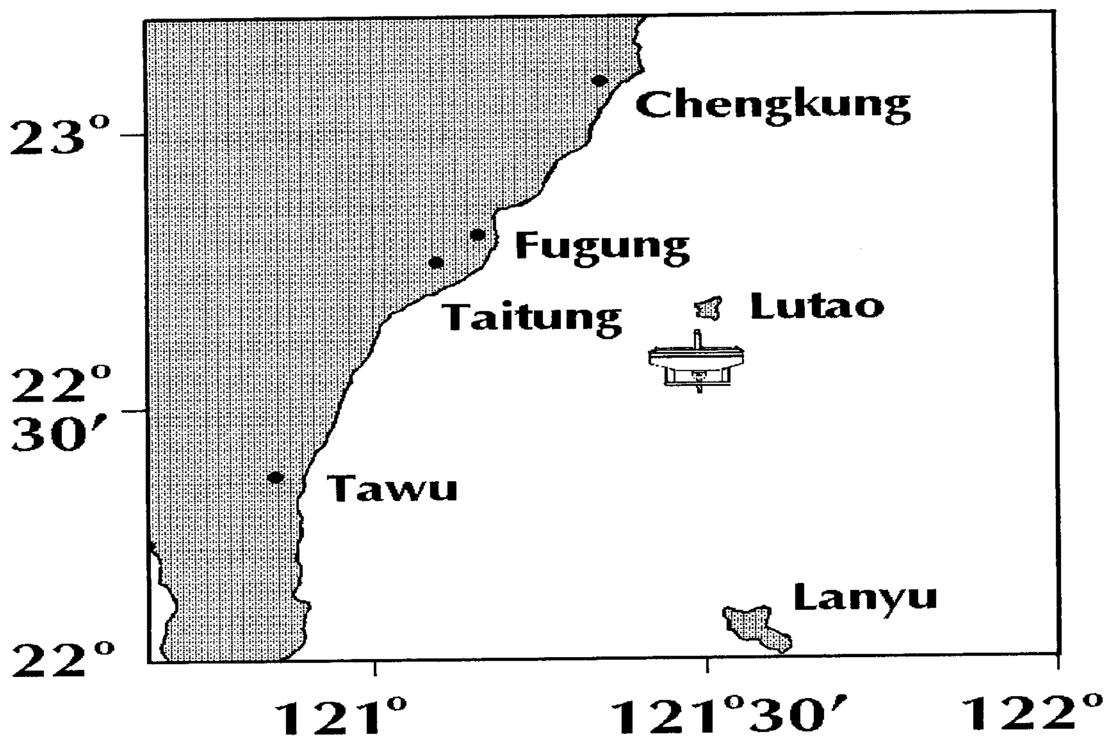


**Fig. 3.** Diagram shows the locations of the fish aggregating devices cast and settled in the waters off Lutao.

### *Equations of static equilibrium*

The static forces on a cable element of length are shown in figure 4. Under static equilibrium[5], the vector sum of forces must zero. Consider a short mooring line made of heavy material with a drag force applied at the device end only. In this case, the gravity force is predominant and the resistance terms of the cable equilibrium equation can be neglected. Therefore,

$\frac{dT}{T} = \tan\phi$, integrating from $\phi = 0$, $\phi = \phi$, yields

$$\ln\frac{T}{To} = \int_{\phi=0}^{\phi=\phi} \tan\phi d\phi = \ln\sec\phi$$

$$T_H = T\cos\phi = To = \text{constant} \quad \cdots (1)$$

$$\frac{To\, d\phi}{\cos^2\phi} = p\, ds$$

$$To\tan\phi = ps \qquad Tv = T\sin\phi = ps$$

$$T = (T_H^2 + T_v^2)^{1/2} = \left[To^2 + (PS)^2\right]^{1/2} \quad \cdots (2)$$

$$又\, dx = \frac{ds}{\sqrt{1 + (ps/To)^2}}$$

$$X = \int_0^{s=s} dx = \frac{To}{P}\sinh^{-1}\left(\frac{PS}{To}\right) \quad \cdots (3)$$

$$S = \frac{To}{P}\sinh\left(\frac{Px}{To}\right) \quad \cdots (4)$$

$$dy = \left(\frac{P}{To}S\right)dx \qquad dy = \sinh\frac{px}{To}dx$$

$$y = \int dy = \frac{To}{P}\left[\cosh\left(\frac{Px}{To}\right) - 1\right] \quad \cdots (5)$$

dT: Change of tension over cable element length (ds)
Dds: Normal pressure drag on cable element
Fds: Tangential friction drag on cable element
Pds: Gravity force per length (ds)
$\phi$: Angle with flow direction (V)
$d\phi$: Change in angle $\phi$ over cable element length
ds: Length of cable element
F: Normal drag force on cable element
V: Flow velocity
T: Tension

$$Td\phi = (D + p\cos\phi)ds = (R\sin^2\phi + p\cos\phi)ds \quad \cdots (6)$$

$P >> D$ or $P >> F$,

Expressions (6) and (7) are therefore reduced to

$$dT = (p\sin\phi - F)\, ds \quad \cdots (7)$$

$$Td\phi = p\cos\phi ds,$$

And

$$dT = p\sin\phi ds$$

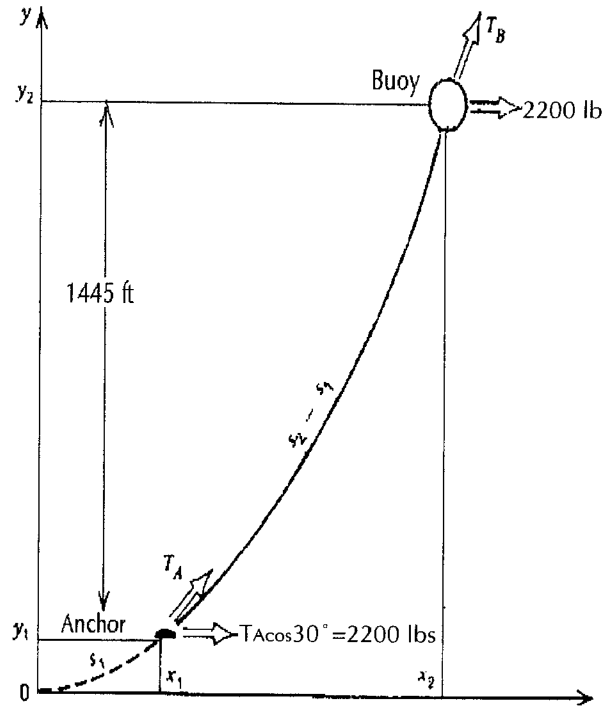


**Fig. 4.** Profile of the dynamics and static of deployed fish aggregating device[5].

## Results and Discussion

The drag force on the devices was estimated about 1 ton (2,200 lb) on the surface were the Kuroshio current velocity at 2.8 knots. If we used polypropylene rope with diameter 90 mm as a mooring line and a chain with $\phi$=38mm, and its angle of the mooring line with the horizontal at 30°, then the tension at the anchor and at the device were estimated as 2,600 lb and 4,470 lb, respectively[6] (Fig. 5). Therefore, the drag force of the polypropylene synthetic ropes was calculated as 5,571 lb (2.35 tons) which is much lower then the breaking strength of the rope 78.93 tons[7] (Table 1).

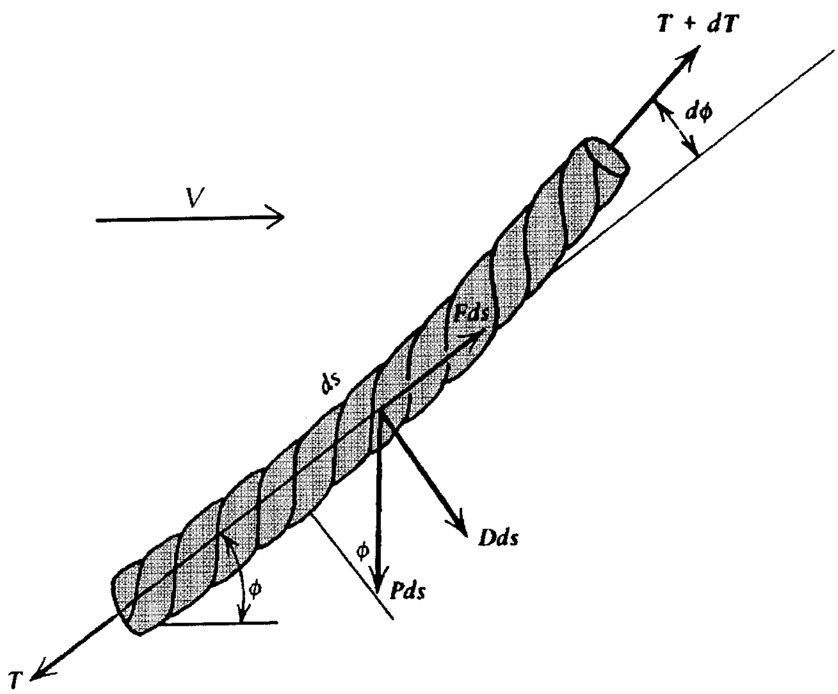


Fig. 5. Forces on cable element; T: tension; dT: change of tension over cable element length; Dds: normal pressure drag on cable element; Fds: tangential friction drag on cable element; Pds: gravity force per length (ds); $\varphi$ : angle with flow direction; V: flow velosity; $d\varphi$ : change in angle $\varphi$ over cable element length; and ds: length of cable element.

**Table 1.** Specifications of synthetic Polypropylene ropes (after Taito Seiko Co., Ltd.).

| *Dia. (mm)* | *Polypropylene* | | | |
|---|---|---|---|---|
| | *Multifilament* | | *Monofilament* | |
| | *Weight (kg/m)* | *Strength (ton)* | *Weight (kg/m)* | *Strength (ton)* |
| 10 | 9.9 | 1.40 | 9.9 | 1.30 |
| 20 | 39.0 | 5.07 | 39.5 | 4.76 |
| 30 | 87.5 | 10.74 | 88.5 | 10.13 |
| 40 | 156.0 | 18.28 | 158.0 | 16.47 |
| 50 | 243.0 | 27.76 | 248.0 | 26.35 |
| 60 | 349.0 | 38.65 | 356.0 | 37.21 |
| 70 | 476.0 | 51.43 | 485.0 | 49.41 |
| 80 | 621.0 | 65.89 | 634.0 | 63.44 |
| 90 | 730.8 | 81.87 | 770.0 | 78.93 |
| 100 | 905.0 | 99.58 | 955.0 | 96.01 |

The depth of casting devices near Green Island is 440 m, and based on the results of the equation (6) calculated, the theoretical length of the mooring line needed is 504 m. For more safety of the devices against the current, we used the length of polypropylene rope up to 725 m, and the tension of the anchor was 4,470 kg. Based on the chain with a diameter of 38mm, the estimated broken force was over 40 tons. Furthermore, the device did not drift away or changed its position even after several typhoons went through. Unfortunately, one of them drifted away and was found at coast waters of Okinawa, Japan in 1999. We inspected the lost device and found a very smooth incision, which seemed cut by a sharp knife or axe on the broken-end of the polypropylene rope (Fig. 6).

**Fig. 6.** The polypropylene rope at the broken-end with a very smooth incision seemed cut by a sharp axe.

The reasons that caused the devices to drift away may be summarized as the followings: (1) the rope was abraded by the rock in a long-term period, (2) the rope was cut with a sharp knife or axe, (3) surface motion may have induced repeated bending and torsion stresses in points of attachment of the mooring line as well as longitudinal cyclic tension stresses in the line itself, and (4) the steel wire or chain was corroded by galvanic, but its rate of corrosion is difficult to predict. In normal conditions, the corrosion rate of iron chain under sea water is 1.0 mm per year, and sometimes even up to 2-3 mm per year under an unusual circumstances[4]. Therefore, the chain 38mm in diameter in this study could not have been eroded by saltwater just in one year. Therefore, we may conclude that the rope was cut with a sharp knife.

Both static stresses, the tension at the anchor and at the device, the type and size of mooring line components, and large resonance related displacements effect can be very damaging for the mooring line.

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廖學耕，李嘉林
行政院農業委員會 水產試驗所 海洋漁業系
(2000 年 11 月 25 日接受)

# 綠島附近海域人工浮魚礁繫纜索之力學分析

## 摘 要

綠島附近海域因有黑潮主軸流經，表層海水含豐富的營養鹽，高經濟價值魚類的大量群聚，而為台灣沿岸海域的重要漁場之一。經研究調查結果發現，在黑潮流速為 2.8 N.M./h 的基礎下，當繫纜繩與水平線之角度成 30 度時，其位於錨碇處繫纜索之垂直張力與水平拉力分別為 2,600 lb 及 4,470 lb，繫纜索本身的拉力則為 5,571 lb，即約為 2,350 kg (2.35 ton)，然而，本研究所使用的繫纜索 (ϕ=90 mm) 之破斷力保守估計約為 78.83 ton，遠大於繫纜索本身的拉力。造成人工浮魚礁漂(移)流的因素很多，且大致可歸納以下幾個原因：(1) 人工浮魚礁之繫纜索與海底岩石的長期磨擦而斷裂，(2) 在正常的情況下，鐵鍊於海水中的腐蝕率為 1.0 mm/year，其最大值可達每年 2.0-3.0 mm 者，但本研究所使用的鐵鍊直徑卻高達 38.0 mm，因此，於一年內使鐵鍊完全腐蝕似乎不太可能，(3) 表層海水的運動，導致繫纜索與鐵鍊連接處或繫纜索或鐵鍊自身因水流運動與張力作用所造成的長期彎曲變形而斷裂，(4) 經由繫纜索斷裂處推測，似乎以人為的外力因素導致繫纜索斷裂的成份較高。

**關鍵詞：**人工浮魚礁，繫纜索，應力分析，綠島

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