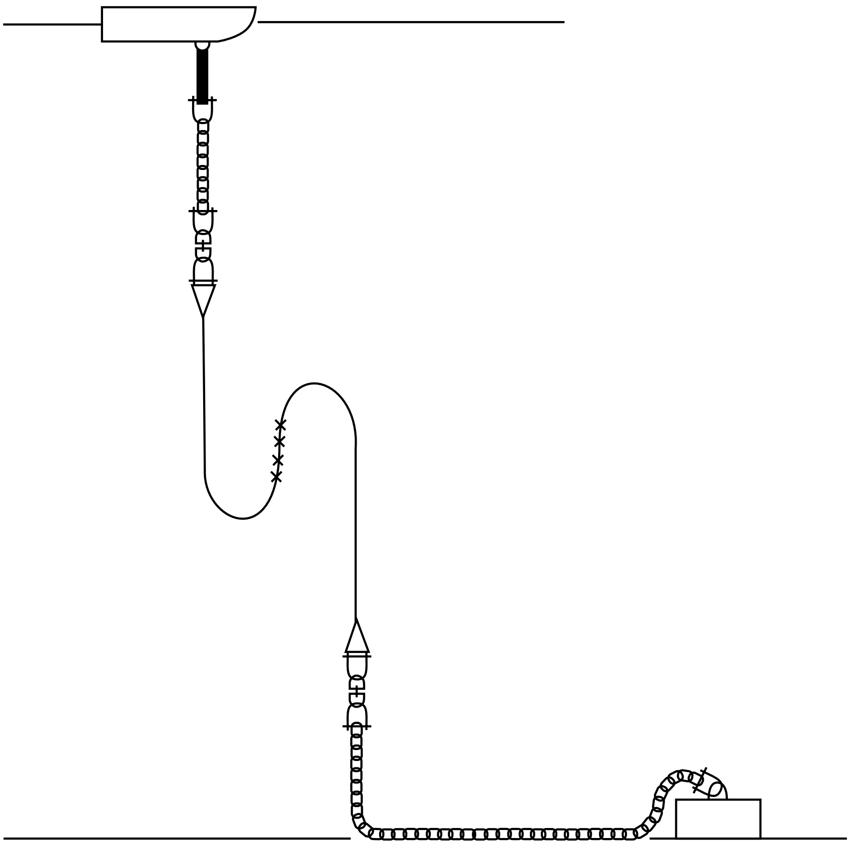
HANDBOOK No. 24 (1984)

DESIGN IMPROVEMENTS TO FISH AGGREGATION DEVICE (FAD) MOORING SYSTEMS IN GENERAL USE IN PACIFIC ISLAND COUNTRIES

R.L. Boy and B, R. Smith



SOUTH PACIFIC COMMISSION
NOUMEA, NEW CALEDONIA

Handbook No. 24 (1984)

DESIGN IMPROVEMENTS TO FISH AGGREGATION DEVICE (FAD) MOORING SYSTEMS IN GENERAL USE IN PACIFIC ISLAND COUNTRIES

R.L. Boy*
B.R. Smith**

This handbook reports the results of the South Pacific Commission design study of fish aggregation device systems in current use in Pacific Island countries. It was presented as a working draft (Working Paper 2) to the Fifteenth Regional Technical Meeting on Fisheries, 1–5 August 1983, entitled ‘An improved FAD mooring line design for general use in Pacific Island countries: a report of the SPC design study of fish aggregation devices’. The manuscript has been substantially revised to take account of comments and suggestions from delegates to the above meeting.

* Buoy Systems Engineer,
NOAA National Data Buoy Center,
NSTL, Mississippi 39529, United States of America

** Fisheries Adviser, South Pacific Commission,
Noumea, New Caledonia

South Pacific Commission
Noumea, New Caledonia
April 1984

Original text: English

This handbook was prepared and published
with the financial support of
the Australian Development Assistance Bureau.

Prepared for publication at
South Pacific Commission headquarters, Noumea, New Caledonia
and printed at Imprimeries Réunies de Nouméa, New Caledonia, 1984

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This study drew extensively on the accumulated knowledge and experience of fisheries personnel throughout the region, and we are very grateful to the many people who gave generously of their time and information. A number of people whose encouragement and assistance were instrumental to the success of the project include Mr Richard Shomura, Mr Harry Sperling and Dr Jerry McCall. The NOAA National Data Buoy Center provided the services of buoy systems engineer Lt. Richard Boy and made available the facilities of their engineering division as required. In this regard, particular thanks are due to Lt. Gerald Timpe for his technical assistance. This design study was funded by a grant from the Australian Development Assistance Bureau.

I. INTRODUCTION

The use of anchored rafts or fish aggregation devices (FADs) to attract and hold schools of both surface and deep-swimming pelagic fish species is one of the most significant developments in Pacific Island fisheries in recent years. Such devices have demonstrated their effectiveness in augmenting catches from both commercial and artisanal fisheries, and their use is rapidly changing the pattern of fishing activities throughout the area of the SPC, and indeed worldwide. While regionally and in many of the larger resource-rich countries, the greatest benefits in economic terms will come from their use in commercial fisheries, in the smaller countries, with limited coastal resources, the greatest impact of fish aggregation devices will be in the artisanal sector. Fishing around FADs has been shown to produce increased and more consistent catches, reduce search and travel time, thereby conserving fuel, and to increase the safety factor for small-boat operation. Their introduction has made it possible for village fishermen to harvest economically the offshore tuna resources on a more regular basis, thereby relieving pressure on overfished reef and lagoon stocks.

Premature loss of such high cost items has proven to be a major problem with designs in current use, with over 80 per cent of all FADs deployed in the last three years reported lost, the majority within 12 months of being anchored. The average life expectancy regionwide would approach 9–12 months, with no reported survivals beyond two years. For the smaller countries in particular, such severe early losses have had a debilitating effect on artisanal fishery development projects employing FADs, and in some cases have led to the deferment of planned activities, pending the development of a more satisfactory, longer-lived design. While FADs are very effective in generating increased catches and revenues back to the fishermen, replacement costs must generally be met by the government concerned, and constitute a major drain on often limited development funds which these countries can ill afford. Such considerations are of lesser importance where FADs are deployed to service industrial fisheries.

Considerable improvement in the basic design has been achieved over the last three years, largely by trial and error, as individual fisheries officers have attempted to overcome problems in design, fabrication, and component availability, using their own experience and what limited specialist advice may be available. Remedial action has too often been based on technology or experience applicable to shallow-water moorings, contributing to the repetition of costly errors from country to country, and the resultant wastage of scarce resources.

Discussions during both the 1981 and 1982 SPC Regional Technical Meetings on Fisheries highlighted the shortcomings of existing designs and stressed the urgent need for marine engineering expertise to improve current FAD technology. The present study was initiated to meet this need, and has drawn heavily on the combined experience and practical understanding of fisheries officers in the field, published and unpublished documentation on individual country FAD development programmes, and the ocean engineering expertise of the NOAA National Data Buoy Center. FADs in current use are critically reviewed with a view to identifying problems in design or fabrication which contribute to premature failure of the mooring. The results of this analysis provide the basis for the development of a recommended FAD mooring line design which eliminates or accommodates many of the problems associated with failure of early designs, and which, in consequence, should have a significantly improved effective life.

II. SPECIFIC OBJECTIVES OF THE STUDY

(i) To conduct a thorough study of current FAD designs as well as construction and deployment techniques which have been developed semi-independently by a number of Pacific countries, with a view to identifying (a) those designs and techniques which have been proven most effective, and (b) problem areas where improvements can be made.

(ii) In the light of recent developments in deep sea mooring technology, and insights gained from the above study, to draw up cost-effective generic FAD designs which would be suitable for broad application throughout the SPC region and which satisfy the following design criteria:

– working life expectancy of more than two years

– unit cost within present range (US$3000–4000)

– capable of deployment from small vessels (30–60' length).

(iii) To prepare guidelines, based on regional and international experience, for the deployment and maintenance of FADs.

III. REVIEW OF COUNTRY EXPERIENCE WITH FADs

A. Background

The reported success of experimental FAD deployments in Hawaii by the National Marine Fisheries Service in 1979, created considerable interest throughout the region, and paved the way for their rapid introduction into other Pacific Island countries. Twenty-three Pacific basin countries and territories have current or planned FAD development programmes, with over 600 units deployed to date and a conservative estimate of 300 units planned for deployment within the next twelve-month period (Table 1). At an average cost of US$3000 per unit, this represents a regional investment in excess of US$2.5 million, and highlights the importance of FADs in the development of fisheries in the South Pacific region.

B. FAD systems in current use

Brief summaries of country experience with FAD development programmes including descriptions and schematic drawings of designs in current use are presented in Appendix I for each of the countries visited during this study (Fiji, Cook Islands, American Samoa, Western Samoa, Vanuatu, French Polynesia and Hawaii). The twin constraints of time and aircraft schedules precluded visits to all countries in the SPC area and we have relied on personal communication and published documentation for information on developments in other countries.

Various modifications of the slack, buoyant rope with counterweight FAD mooring system (Fig. 1) have been adopted or developed in most countries of the region, with variations in local conditions and availability of component materials dictating the final design. Hawaii, however, has recently introduced a slack, reverse catenary composite nylon/polypropylene mooring line which is similar to the generic design recommended in this report.

Table 1: Summary by country of FADs deployed, reported or presumed lost, and planned, with estimated average cost/unit (figures as of March 1983).

COUNTRY	FADs			
	Deployed	Lost	Planned	Approx. Cost/ Unit US$
American Samoa	22	20	4	5000
Australia	10	4	N/A	various
Cook Islands	6	4	20	3000
Fiji	208	182	175	1000–1500
French Polynesia	11	8	19	5500
Guam	10	9	–	4500
Hawaii	59	4	39	4500
Kiribati	5	3	N/A	600
Northern Marianas	5	5	–	N/A
New Caledonia	6	N/A	N/A	N/A
Niue	5	0	N/A	3000
Palau	6	6	6	3600
P.N.G.	76	76	N/A	N/A
Solomon Islands	132	88	20	2000
Tokelau	1	1	N/A	N/A
Tonga	2	2	2	3000
Tuvalu	–	–	2	N/A
Vanuatu	3	–	N/A	N/A
Western Samoa	37	22	Replacement Only	3000
TOTAL	604	434	287	3000

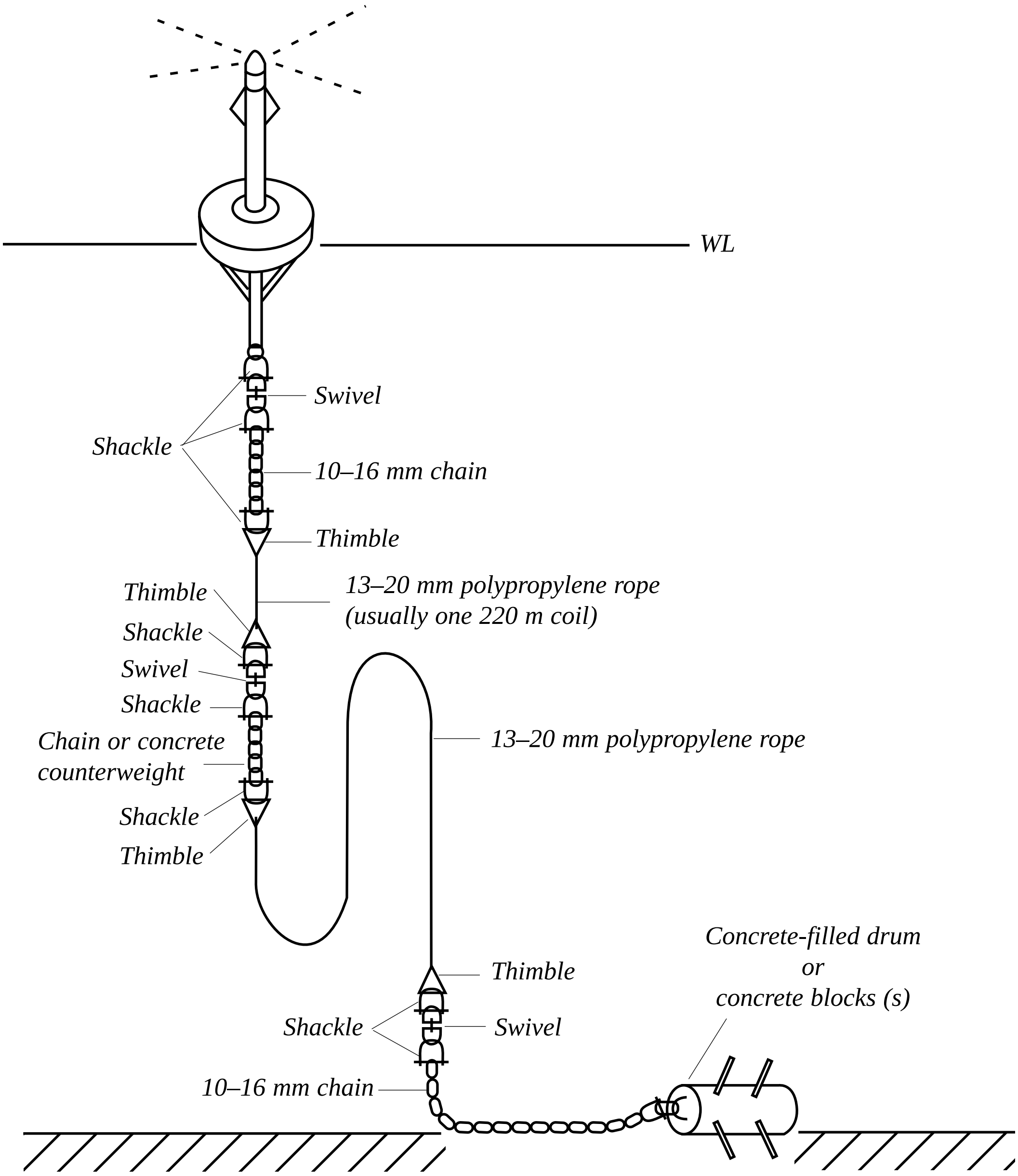


Figure 1: General configuration of FAD mooring line system most commonly deployed in Pacific 1sland countries—a slack buoyant synthetic line with counterweight.

1. Mooring line system or tether

Most FAD failures are directly attributable to deficiencies in mooring line design, and the slack, buoyant synthetic rope with counterweight system in general use in the region is not considered suitable for deep mooring application. Some general comments on this system are noted below, with a more detailed discussion of marine mooring components presented in Section IV.

(i) *Rope*: polypropylene rope (18–22 mm diameter) is the most common synthetic rope used: it is of low cost, adequate strength, and has suitable characteristics for mooring use. Polyethylene rope, used in some countries, is unsuitable for marine mooring applications and should not be used.

(ii) *Marine hardware*: much of the marine hardware in current use is unsuitable or inadequate for use in long-term marine moorings. Stainless steel connectors should not be used in marine moorings unless unavoidable. In this case special precautions will be necessary to prevent accelerated corrosion of other components.

(iii) *Scope*: there has been a general trend to reduce the scope of moorings, from 1.5 or 1.4:1 in early deployments to 1.2 or more usually 1.1:1 in later generation FADs. This has produced savings in rope costs and has reduced the watch circle of the raft, making it easier for fishermen to locate in the critical predawn period.

(iv) *Counterweight*: the use of a counterweight, usually a chain insert, to prevent excess buoyant mainline reaching the surface during slack current/low wind periods, introduces additional linkages and rope terminations into the line, and creates a major source of line chafe. It is considered one of the main causes of failure with this design.

2. Anchors

A variety of clump anchors have been used, the most common of which were concrete-filled oil drums (200 litres) or reinforced concrete blocks, with additional weight provided in some cases by the inclusion of surplus steel.

(i) Concrete-filled drum (Fig. 2)

Oil drum anchors are inexpensive, easy to form and deploy, but have a limited drag resistance which increases the tendency to roll about on the seafloor. Steel reinforcing bar protrusions, commonly used to increase the drag resistance of the drum, also increase the likelihood of entanglement and possible wrap-up of the anchor chain, with attendant increased potential for rope chafe. Preston (1982) indicates the weight in air of the Fiji drum anchor to be about 480 kg (1100 lb). For most locations it would be necessary to use two such drums to ensure sufficient holding power on the bottom, thus

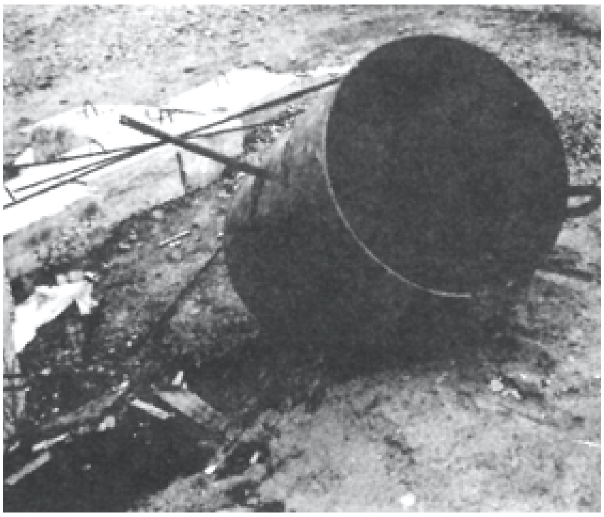


Figure 2: Oil drum with reinforcing ready for concrete filling (Fiji)

further increasing the chance of anchor chain entanglement.

(ii) Concrete block (Figs. 3, 4)

Single blocks of reinforced concrete, in sizes varying from 545 kg (1200 lb) to 1300 kg (2860 lb), have proven effective anchors for most locations. Primarily to overcome problems encountered in deploying a single massive block for a small service vessel, some countries have opted for multiple blocks of a smaller size, usually two but up to 8 or 10 in Fiji. Multiple blocks tend to form a tangled mass and "walk about" on the bottom. Where multiples are used, the individual blocks should be tightly shackled together to form a compact mass. Surplus steel is often added to the concrete mix to increase the weight/size of the block. Too much steel and insufficient concrete will weaken the block to a point where it could possibly fracture on impact with the seafloor. The shock of impact on a hard bottom is quite severe.

Figure 3: Shaped (545 kg) concrete clump anchor (Western Samoa)

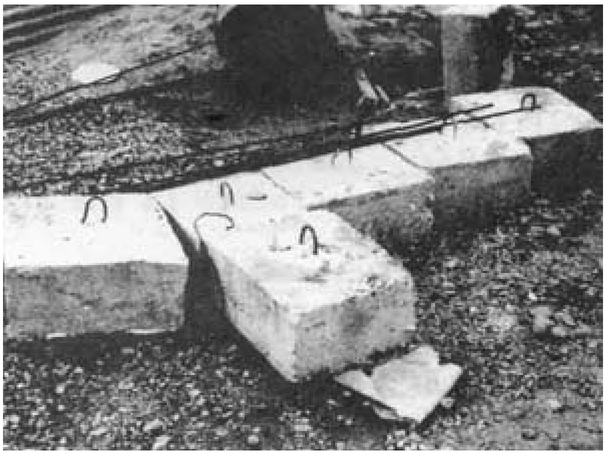


Figure 4: Small concrete blocks (180 kg) linked to form multiple clump anchor (Fiji)

(iii) Others (Fig. 5)

Surplus steel (railway wheels, ship's anchors chain, etc.) can make a very effective anchor. Protrusions which may entangle or abrade the anchor chain should be avoided.

Figure 5: Surplus steel anchor – railway wheel (American Samoa)

3. Rafts or buoys

With the exception of some simply constructed expendable designs, most rafts in current use are effective surface platforms for supporting their moorings and appendages.

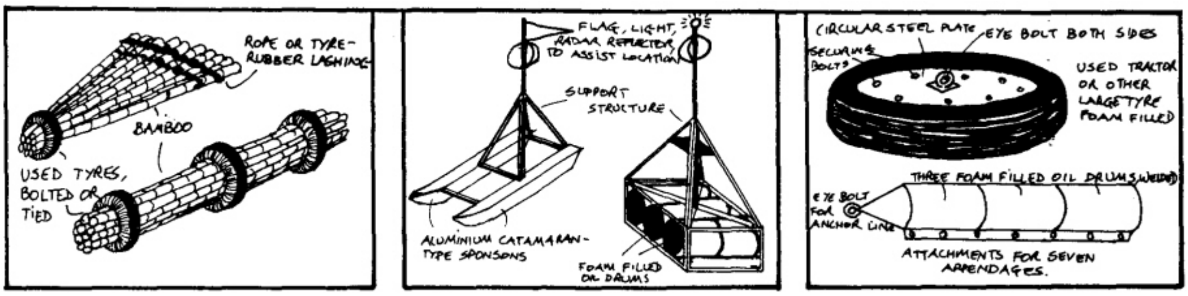


Figure 6: FAD raft designs tested in Fiji waters (from Preston 1982).

Figure 6 illustrates the types of FAD rafts tested in Fiji waters which are representative of the more common designs used throughout the Pacific. A disproportionate effort has been directed towards raft design relative to other components, and this has resulted in a variety of ingenious designs which were developed to take advantage of locally available materials, fabrication facilities and skills, and a number of other considerations which include :

- Life expectancy
- Cost limits
- Type of fishing in vicinity/user group
  - Purse-seining-Pole and line
  - Trolling/artisanal or sports fishing
  - Other, e.g. trawling, longline
- Anticipated possibility/desirability of small fishing boats tying up to raft
- Visibility for the mariner
  - Dayshapes
  - Lights/light reflectors
  - Radar reflectors
- Compartments
  - Floatation
  - Battery containers
- Support for aggregation appendages
- Survivability.

Some of the above considerations are required by law and international agreement while others are determined by local authorities and conditions. General comments on some of the more commonly used raft designs, which have given satisfactory service, and which were examined during the present study, are presented in Appendix II, together with suggested modifications which should improve their overall effectiveness.

(i) Lights/radar reflectors/dayboards

All rafts near shipping lanes or harbour entrances should be lighted for the protection of the buoy and passing vessels. In most countries where light specifications are not controlled by regulation or where existing regulation is not enforced, lights have been attached to the FADs primarily to assist fishermen to locate the buoy at night. A wide variety of lighting systems has been used, most of which have suffered from limited battery life. One unit in widespread use is a Canadian-produced plastic flashing net light powered by four D cell batteries; it is inexpensive and reasonably effective but has some serious defects—a short battery life (3 weeks approx.), lacks a fresnel lens, and has a limited visual range, particularly on moonlight nights. The battery life could be extended considerably by the use of alkaline batteries. Long-life solar powered units are now under test or consideration by a number of countries, and while expensive, it is likely that they will attract increasing interest once premature loss problems are resolved when the improved longevity of the FAD system could justify the additional expense.

Every raft should be adequately visible to avoid collisions and allow fishermen to find them. Radar reflectors can be built as a day shape or can be attached to dayshapes. The reflectors can be very small yet effective if vertical and horizontal planes are at 90 degree angles. Light-reflecting tape on the radar reflector or dayboard is an expensive but very effective way to improve the visibility of rafts at night.

4. Appendages

It is widely but not universally agreed that appendages streaming below a raft increase its effectiveness in attracting and holding schools of pelagic fish. This has yet to be scientifically substantiated, but is supported by the largely anecdotal accounts of country experience with the utilisation of FADs.

A non-exhaustive list of comments on the effectiveness of appendages includes:

– they increase the number and size of schools in temporary residence;

– appendages increase the rate at which fish schools accumulate around the FAD; and bring it into production within a shorter period of time;

– the loss of the appendage (e.g. after a storm, etc.) is followed by a rapid drop in fish sightings and catches around the FAD;

– the appendage acts as an underwater rudder, and dampens the tendency of raft the to twist or spin.

Reasons advanced for the attractive effect of appendages include:

– appendages provide shelter, allowing a build-up of prey species which provide a strong visual stimulus to predators. It is unlikely that the generally small quantities of bait available could provide adequate food reward to account for the accumulation process. In Fiji, it is reported that FADs "seeded" shortly after deployment with a few scoops of broadcast baitfish, generally reduced the time required to produce commercial catches of tuna;

– they increase the underwater size of the FAD, increasing the visual target size; the light-sheltered or shaded area is also increased;

– they provide a medium for marine growth, producing a further link in the food chain, and increase the “odour” emanating from the raft.

There is considerable variation in opinion as to the most effective type of appendage. While a wide variety of materials and configurations have been tested, most countries have opted for very simple configurations of synthetic materials which are more durable, and easy to fabricate and deploy. Comments on the more common types in use are as follows:

(i) Coconut fronds

While cheap and effective, they deteriorate quickly and must be replaced every 3 to 4 weeks, and are not widely used for this reason.

(ii) Plastic strapping material

Usually deployed as streamers woven into vertical mooring chain or chain-weighted ropes (usually 6 or more ropes; each 12—18 m long). Widely used and considered very effective in most countries. More complicated arrangements have generally been less successful.

(iii) Tyres

Strung (wired) onto a loop or single length of chain suspended below the raft; tyres are usually cut in half to reduce drag (Western Samoa). In some cases they have been strung vertically on a weighted rope (Fiji) or encased in cargo netting (American Samoa).

(iv) Netting

A variety of netting has been used, most often old purse seine webbing. Netting has a tendency to gill small fish leading to shark damage, and will collapse and tangle with time.

C. Life expenctancy

Recorded FAD longevity in the region has varied from a few minutes (lost during deployment) to 22 months (Western Samoa), with most lasting from 6 to 12 months, and very few surviving beyond 18 months. The estimated average life expectancy regionwide approaches 9 months. Table 2 summarises available information on FAD attrition rates in some Pacific Island countries, and, while covering a limited number of countries and less than 25 per cent of total reported or presumed losses, it is indicative of FAD loss rates experienced in most other countries.

Table 2: Summary of available information on FAD attrition rates in some Pacific Island countries*

FAD Life in Months	American Samoa	French Polynesia	Cook Islands	Western Samoa	Fiji	Guam	TOTAL
1	4	2		2	3	2	13
2	2				14		16
3	2	2			19	3	26
4					14		14
5		1	1		1	1	4
6					1		1
7							
8				6		2	8
9							
10		1		2			3
11	1		1	1			3
12				4			4
13		1		7			8
14							
15				1			1
16				2			2
17				1			
18	1	1		1			3
19							
20			1				1
21			1			1	2
22				1			1
23							
24							
TOTAL	10	9	4	22	54**	8	111
CONTINU-ING (9+MTHS)	2		2	5		1	10
INFO. N/A	10			2	128	1	141

* Figures as of March 1983 and include existing FADs deployed for more than 9 months.
** All expendable bamboo design and only proportion of total losses in Fiji (Preston 1982).

D. Failure analysis

The analysis and understanding of FAD mooring failures provides essential feedback on component performance, and by identifying weak points, facilitates continual improvement of the design. The information presented in this section has been drawn from examination of FAD systems in current use in the countries visited during the study, as well as anecdotal and published information supplied by fisheries officers throughout the region. The speculated failure analysis is based on practical experience gained from the mooring of oceanographic and meteorological platforms in deep oceanic waters, along with the application of basic engineering principles.

The most useful source of failure information comes from examination of the actual failed mooring. The NOAA National Data Buoy Center (NDBC) has recovered virtually 100 per cent of its failed buoys, 50 per cent of which readily show the failure source. For the countries visited during this study, less than 20 per cent of their failed FADs have been recovered, and in many cases the primary cause of the failure was not readily apparent, or the system was not scrutinised by a trained eye. Where the source of failure was obvious, very often the mooring remnants were discarded or re-used. The remnants should always be closely examined for wear and tear so that the next most likely causes of failure can be identified and corrected.

Available information on known or probable causes of FAD loss for some Pacific Island countries is presented in Table 3. Such statistics, while of limited value, are indicative of the relative importance of the various failure source categories.

Table 3: Known or probable causes of FAD loss in some Pacific Island countries (figures as of March 1983).

	FADs			KNOWN OR PROBABLE CAUSES OF FAILURE							
	Set	Lost	Recovered	Mooring Line Failure	Storm/ Cyclone	Hardware Failure	Man-bite	Unsuit. Site	Fish-bite	No Raft Break-up	Information
American Samoa	22	20	10	3	–	2	2	2		2	9
Cook Islands	6	4	2	2		1				1	
Fiji	208+	182+	11+	6*	17+*	*			1	*	158+
French Polynesia	11	8	6		3	3	1	1			
Guam	10	9	2	1		1	1	1			5
Hawaii	59	5	19	37	2		2	3	1		
Kiribati	5	3	–		2		1				
Solomon Islands	152	78	N/A	*		*				*	78
Toonga	2	2	1		1		1				
Western Samoa	37	22	13	11		6	3		2		
TOTAL	512	373	64	60	25	13	11	7	4	3	250

* Reported probable major causes of loss—little or no detailed information available.

The major confirmed as well as probable causes of FAD mooring failure are discussed briefly below.

(1) Mooring line failure

Most mooring line failures can be attributed to one or more of the following factors: synthetic line chafe on hardware components or the sea bottom, splice failure, poor hardware selection or failure, fishbite and manbite (vandalism, vessel damage). Overloading to the point of failure is unlikely with the polypropylene and nylon sizes in general use. The use of polyethylene rope is not recommended for FAD application; while inexpensive, it has very poor resistance to repeated loading and will fail at loads considerably below rated break strength. More detailed comments on rope characteristics are presented in Section IV.A.

(i) Line chafe

Chafe of the synthetic rope on the intermediate counterweight or sinker and other hardware inserts in the line (swivels, shackles, etc.) is considered a major cause of failure with most current FAD designs. The potential for tangling of the rope and subsequent chili problems caused by the use of a counterweight is discussed in Preston (1982) and illustrated below.

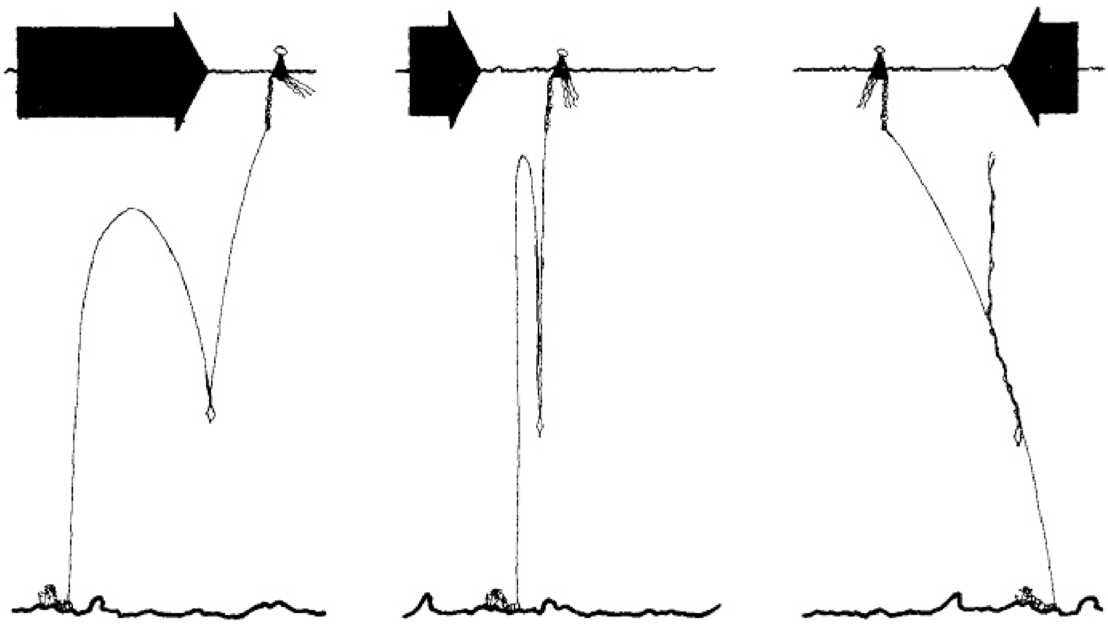


Figure 7: Tangling of the mooring line caused by the use of a counterweight (from Preston 1982).

A similar problem is encountered where the scope allows the buoyant rope to chafe on top hardware and appendages. Chafe on the seabed would be a problem where the anchor design permits wrap-up of the anchor chain, bringing the lope into contact with the bottom, or in a steep slope or broken bottom situation where the mooring line can often abrade against an underwater ledge.

(ii) Splicing technique

Splice failure was considered a significant problem in some countries. Splicing is the safest method of joining two coils of rope for use in marine moorings, and it is suspected that some of the reported splice failures were caused by chafe problems associated with the use of wire rope thimbles, or chafe on other hardware components. Splices should be smooth and tapered to avoid fatigue areas in the line. (Recommended splicing techniques are illustrated in Appendix III.) Knots of any form will reduce line strength, in some cases significantly, and should not be used in mooring lines.

(2) Hardware selection/failure

The selection and use of hardware components of a design or quality unsuitable for marine moorings is a primary cause of FAD mooring line failure. The components most commonly implicated are mentioned briefly below, while a more detailed discussion of this topic is presented in Section IV.B.

(i) Screw pin shackles

The most commonly used shackle—major problems include pin loss through failure to weld shut or properly tie or mouse with stainless wire, and thread corrosion which loosens and weakens the pin and contributes to early failure.

(ii) Wire rope

The use of galvanised wire rope pennants proved a major cause of failure with many early FAD designs. Deployment problems, corrosion, kinking and termination problems make wire rope unsuitable for use in long-term moorings. Stainless steel, torque-free wire rope is used extensively in oceanographic moorings, but design considerations which apply for this specialized usage (usually short-term, taut line moorings which incorporate expensive instrument packages) cannot be directly applied to FAD systems. The hardware required is expensive and precise siting conditions must be determined prior to fabrication and deployment.

(iii) Wire rope thimbles

As the name implies, these were designed for use with non-stretch wire rope and are not suited for use with synthetic rope. Most problems are caused by rope stretch which allows the thimble to work out of the eye splice, or rusting of the inner rope bearing surface which causes abrasion of the line. Where more suitable thimbles are not available (Section IV.B), the wire rope thimbles should be whipped onto the rope to limit thimble movement.

(iv) Swivels

While most of the forged designs examined were adequate, a few were poorly fabricated and would have a tendency to bind up under load. A smooth turning action when twisted between the hands usually indicates adequate quality: experience and, more importantly, adequate maintenance, will ensure early detection of defective hardware. Fouling of the primary swivel with the appendages was another common problem. Ball-bearing swivels are expensive and are not suitable for long-term use in sea water; the grease seal breaks down, allowing water penetration and corrosion due to the many different grades of steel within.

(v) *Stainless steel connecting rings, shackles, etc.*

These will cause accelerated corrosion problems where used with dissimilar metals, and should be avoided.

(3) Fishbite

Fishbite is a generic term used to describe any damage inflicted on mooring lines by free-swimming marine animals. While fishbite, and sharkbite in particular, is considered an important cause of severe damage to deep water moorings in some parts of the world, there is very little evidence to implicate it as a serious cause of FAD loss in this region. The most often cited source of information is the NOAA National Data Buoy Office,(NDBC) report Deep sea lines fishbite manual (Prindle and Walden, 1976). The majority of data included in this and subsequent reports refers to reported attacks on oceanographic moorings in the Atlantic Ocean, and applicability to the tropical western Pacific is questionable. Also, most such moorings are small diameter (13—16 mm diameter), taut line instrument supporting systems which are very different to the larger diameter slack line FAD moorings currently in use. The taut line mooring is more prone to strumming, considered a possible "acoustic attraction factor" for sharks, and being of smaller diameter and under tension, is more vulnerable to the cutting action of fish or shark teeth.

Each country must determine the scope of confirmed fishbite problems in its own area and decide on the degree of action necessary, if any, to counter it. While no system has been devised which can completely eliminate fishbite damage, rope armoured with hard plastic retains reasonable handling characteristics, and has increased resistance to fish attack.

More importantly, teeth marks can be more easily identified and on recovery, would provide valuable information on the extent of the fishbite problem. When design, hardware and other major problems experienced with current designs have been identified and eliminated, minor and more variable causes of failure, such as fishbite and vandalism, can be more readily identified and understood and any necessary remedial action determined.

(4) Manbite

(i) *Vandalism*: is a local problem, rarely of major proportion, and is often related to user conflict. In a number of countries, early problems were eliminated through publicity and extension programmes aimed at greater community awareness of the benefits of the FAD programme. Petty pilferage can often be obstructed if not eliminated by careful design.

(ii) *Vessel damage*: propeller damage to mooring lines floating on the surface was a problem with early designs. Rafting up to the buoy by fishing boats can cause damage to the raft, and will strain the mooring line in rough weather, sometimes to failure. Where there is a possibility that this will occur (even if prohibited), the FAD system should be strengthened to accommodate the additional strain (see Section V).

IV. GENERAL DISCUSSION OF MARINE MOORING COMPONENTS

A. Synthetic ropes

1. Introduction

As the name implies, synthetic ropes are fabricated from man-made materials. For marine application, the most widely used synthetic materials are Nylon (polyamide), Dacron (polyester), polypropylene, and polyethylene. Blends of exotic materials are becoming increasingly common in custom moorings but are too expensive and specialised to warrant attention in this report. Rope construction can be very important depending upon the use and desired characteristics of the rope.

2. Characteristics of main types of ropes used

(i) Materials

In Table 4 the average characteristics of the main types of synthetic rope used in marine moorings are compared, and their suitability for use in this application is discussed briefly below.

(a) Nylon (polyamide): Nylon is the most widely used synthetic rope. It has excellent strength to weight and elastic properties while weighing very little in seawater. New Nylon is very flexible, elastic, and easy to splice although it will stiffen with exposure to the elements. Some nylon ropes will stretch up to 50 per cent before breaking giving them excellent shock absorption capabilities. Properties to be wary of are moderately high cost as well as shrinkage and loss of strength (approx. 10%) in seawater. Nylon has an internal abrasion problem when used in seawater, but experience shows this not to be significant over the normal life of a particular buoy mooring.

(b) Polyester (Dacron): Polyester is similar in appearance and handling to nylon. It has excellent all-around properties but is slightly more costly and less elastic than nylon. It does not experience a loss of strength in seawater, but it is heavier than nylon. Polyester is not widely used for buoy mooring application mainly because of its higher cost and limited availability in the sizes required.

(c) Polypropylene: Polypropylene is the most widely used material where buoyant rope is required. It is relatively inexpensive and moderately strong. Unlike nylon, it is actually stronger wet than dry (over 5% increase). It has good energy absorption properties and excellent resistance to abrasion. Due to its slippery nature, extra care must be taken and extra tucks must be made when splicing polypropylene. Other properties to be cautious of are its deterioration in sunlight and its low resistance to plastic flow. Polypropylene should not be stored in direct sunlight. The fibres become very brittle and strength degradation is rapid. Dark-coloured rope has been developed with increased resistance to UV degradation and is recommended where moorings are deployed in very clear water. Polypropylene will actually stretch to failure at forces much less than its break strength. More analysis is needed to determine strict guidelines for use in deep water moorings, but it appears that with the rope sizes used this will not be a significant factor over the normal life of a FAD.

(d) *Polyethylene*: Although inexpensive, polyethylene has poor characteristics in all categories of performance. It is slightly buoyant and similar in appearance and handling to polypropylene, but due to its other properties, polyethylene is not recommended for use in long-term buoy moorings.

Table 4: Comparative table of average synthetic rope characteristics (figures given for 20 mm diameter rope).

Type of material	Nylon	Dacron	Polyethyelene	Polypropylene
Dry weight of 220 m of rope (kg)	57	70	44.9	39.5
Specific gravity of fiber	1.14	1.38	0.94	0.91
Immersed weight as a percent of dry weight	12.3	27.6	–5.3	–9.9
Breaking load(kg)	8300	6350	3450	5330
Wet strength compared to dry strength	90%	100%	100%	105%
Endurance to cyclic loading	Good	Excellent	Fair	Excellent
Buoyancy	Negative	Negative	Positive	Positive
Elasticity-Elongation at 20% of unltimate strength	17%	7%	6%	10%
Water absorption in % of rope dry weight	9%	1%	0%	0%
Resistance to internal chafing(wet)	Good	Excellent	Fair	Good
Resistance to plastic flow	Good	Excellent	Poor	Fair

* Data supplied by Donaghys Industries Ltd.
** After first loading to 50% of tensile strength.

(ii) Construction

The three basic constructions of fibre rope are twisted, plaited, and braided.

(a) *Twisted*: 3-strand is the most common construction with strands twisted together either in a left-handed (S twist) or right-handed (z twist) direction (see Fig. 8).

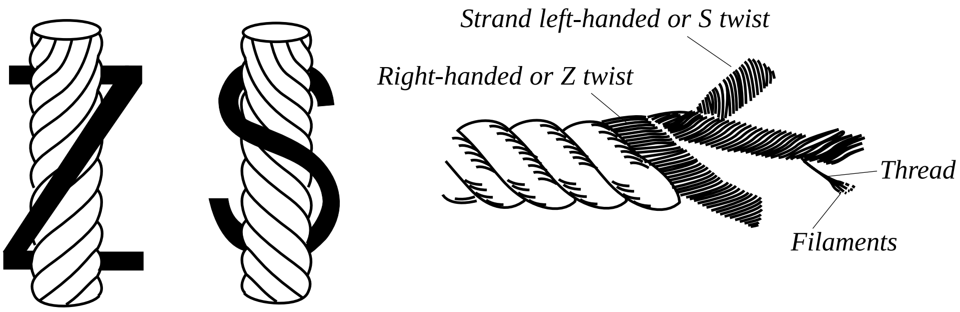


Figure 8: Z-twist and S-twist stranded rope construction.

It is readily available in all sizes and has very good strength and handling properties. Under load, twisted construction rope tends to unlay, causing a torque on the ends. Under cyclic or intermittent loading caused by the sea keeping motion of the raft or varying currents, this can cause increased fatigue on all components and can produce hockles or kinks in the rope. For this reason, it is not recommended for general use in FAD moorings. Great care must be taken when uncoiling or unreeling the rope to avoid adding or removing twists from the rope. Hockles or kinks can reduce the strength of a rope by one-third or more. When using twisted construction in moorings, an added safety factor should be used as well as good quality swivels. These steps will help to reduce the torque and prevent transfer of twist to other mooring components.

(b) *Plaited*: made from an even number of strands plaited in pairs of opposite direction: 8-strand, the most common plaited construction, consists of four left-hand strands and four right-hand strands plaited or twisted in pairs to produce a torque-free or tol-que-balanced rope. The rope will actually absorb many twists without losing its shape and will not twist under load. It is very flexible, easily handled and the construction allows for a great deal of elasticity. Splicing is slightly more difficult than 3-strand twisted but even fair splices have excellent holding power. Plaited construction has the same strength, weight, and cost as twisted construction, but is more difficult to find in the smaller sizes. l2-strand hollow plait which has been introduced only recently, is slightly more expensive but stronger and more readily available in smaller, sizes than 8-strand.

(c) *Braided*: a more complex construction made of a great number of equally distributed left- and right-hand yarn. Single braided (hollow core) construction is very similar to plaited rope as it is very pliable, easily handled and very elastic. It is usually only

produced in the smaller diameters. Splicing is more difficult and does not hold up as well under cyclic loading. Larger sizes are made in double braid construction, which consists of an inner core with an outer cover, and is both the strongest construction of rope and the most expensive. Splicing is difficult as technique is critical, and attempts to moor buoys with double braid have been less than successful. Examination shows that under cyclic loading, the inner and outer braids do not evenly distribute the load due to friction. This causes failures at less than expected loads. Double braid is usually only found in nylon or polyester.

3. Rope connections

Ideally, a mooring should consist of one continuous length of rope, free of knots, splices, or anything to decrease its overall strength. However, even for this ideal situation end terminations will still be required. Except under extreme circumstances all end terminations should be eye splices. These should be made using the proper thimble (see hardware section) and splicing techniques (see Appendix III). Without proper thimble protection, the rope will be subject to abrasion and fatigue causing premature failure. Where multiple coils are used, they should always be spliced using the proper techniques. The use of knots, cable clamps, and other devices anywhere on the rope should be avoided as they will reduce rope strength and result in premature failures. Twisted and plaited ropes will rarely fail within a splice when strength tests are performed. Even poor quality plaited splices still retain a tremendous amount of their strength.

4. Products to improve rope performance

Many manufactured products are available which were developed to improve the performance of synthetic ropes for oceanographic moorings, and may be applicable to FAD usage as well.

(i) Coatings

Coloured, abrasion-resistant coatings have been developed which do not reduce the strength of the rope, and still allow splicing after the coating has been applied (usually at the factory). These coatings will help reduce abrasion on the rope both during deployment, from boat deck fittings etc., and after deployment, from fishing gear or appendages. A dark-coloured urethane rope coating is being used in Hawaii to provide added protection against fishbite. Coatings also offer protection from sunlight damage.

(ii) Fairings

Ropes can be faired using small streamers which are attached during the manufacturing process (Fig. 9). These have been developed to reduce strumming or vibrations caused by current moving past the rope. The strumming has serious effects on the rope, and can greatly increase drag on the mooring. NDBO points out that the theoretical frequency of vibration of 13 mm (1/2") rope, the size commonly used for oceanographic moorings, is most attractive to sharks (Prindle and Walden, 1976). In addition to being used to reduce drag on FADs moored in steady currents and eliminating a possible cause of shark attack, fairings can be used as appendages to attract fish. The length, density, and location of the streamers can be varied during fabrication to individual specifications. This may eliminate the need for hanging appendages below rafts and allow for a greater variety of raft shapes and sizes to be used.

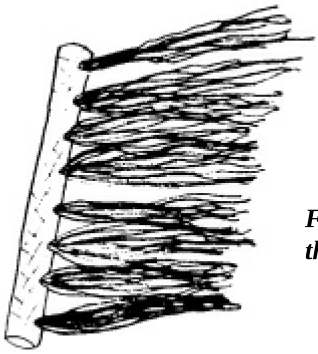


Figure 9: Plastic ribbons or strapping attached to the mooring line to reduce line strumming.

B. Marine hardware

1. Introduction

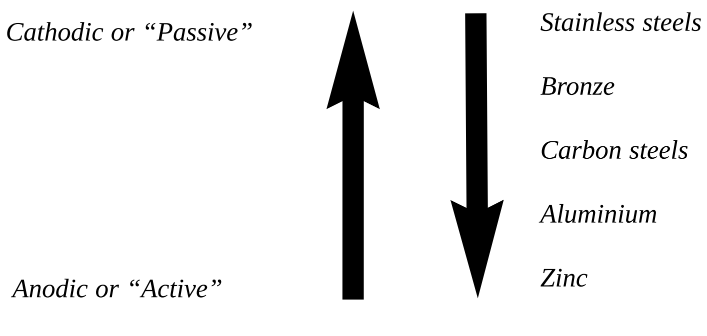
A good working knowledge of marine hardware is essential for designing and building buoy mooring systems. As with synthetic ropes, proper selection of materials and construction are very important; they affect the cost, characteristics, and longevity of the mooring.

2. Corrosion prevention

Corrosion is a very familiar problem when dealing with hardware in a marine environment, and lately, much attention has been focused on the topic. Although textbooks can open one's eyes to potential problems, the best understanding of corrosion, both on buoys and underwater moorings, comes from experience. The following are some rules of thumb for dealing with marine corrosion:

(i) Dissimilar metals

In virtually all cases where two different metals or metal alloys are in contact in seawater, accelerated corrosion will occur. This is caused by differences in their electrochemical potentials, the latter often depicted as a Galvanic Series, which lists metals in order of decreasing activity. A simple table for metals commonly used in FAD hardware would be as follows:



Commonly, the passive metals will cause accelerated deterioration of the more active metals when in contact. Practical measures which can be used to prevent or reduce deterioration caused by corrosion include the following:

- *Sacrificial anodes*: Zinc and aluminium are used to protect more passive metals from corrosion by "sacrificing" themselves. These can be found in clumps physically attached to cathodes or as paints used to coat the cathodes. The sacrificial material must be in electrical contact with the metal being protected.

- *Exposed areas*: The “Law of Areas” has an effect on corrosion activity. A relatively small cathode or passive area in contact with a large anode or active area, e.g. a stainless steel pin in a carbon steel safety shackle, will exhibit very little activity, while a large cathode will quickly deteriorate a small anode. For this reason it is not good practice to coat an anode such as an aluminium buoy. If the coating is chipped or worn away, it will expose a small anodic area to a large cathodic one, with resultant rapid corrosion in that area.

- *Isolation*: The metals can be electrically isolated with non-metallic bushings (commonly Delrin or Phenolic), synthetic ropes, or by coating the cathode with inert paints or epoxys.

(ii) Stress corrosion

Certain metals, such ashigher strength carbon or alloy steel, are highly susceptible to accelerated corrosion due to stress. This is most often seen in threaded bolts and pins. The areas of the threads under constant stress (caused by tightening the bolt or pin) will rapidly deteriorate.

(iii) Oxygen depletion

Stainless steels commonly show this type of corrosion as they rely on oxygen to maintain a protective coating. Areas or conditions which do not permit a flow of oxygenated water, such as under clamps and bolts or where the metal is covered by bottom sediment or fouling organisms, will cause the stainless steel to become active. Crevices and pitting will soon follow in the stainless steel with resultant loss of strength.

(iv) Rules for usage

Some common hardware alloys and combinations, which have the least problems with corrosion:

- *Stainless steel*: The law of areas is important with stainless steel. Stainless cotter pins are excellent replacements for the steel pins normally supplied with carbon steel safety shackles. Stainless bolts and hatch dogs are recommended on above-surface buoy fittings. Avoid large stainless bridles on buoys as isolation becomes a problem with the buoy and mooring. The best alloy for marine use is Series 316. Stainless steels which are magnetic are to be avoided in seawater. Stainless swivels and cables are not worth the expense considering the dissimilar metals and oxygen depletion corrosion problems.

- *Bronze*: Bronze thimbles have been effective when used with long lengths of mooring chain, where the area of exposed bronze is small relative to the more active metal (steel). The reverse is true where the area of exposed bronze is relatively large and can cause accelerated corrosion of the anodic metal, e.g. two bronze thimbles connected by a carbon steel shackle will often result in severe corrosion of the shackle.

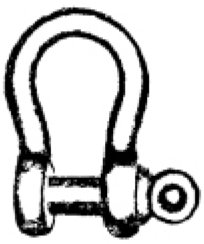
Epoxy coatings have been used with some success to reduce the cathodic action of the bronze, but wear is a consideration.

- *Carbon steels*: Low carbon steels are used extensively in the fabrication of buoys and moorings. Avoid high carbon steel which is subject to severe pitting problems, crevice corrosion, and is usually more expensive. Steel buoys should have sacrificial paint or anodes for longer service. Back up shackle pins with stainless wire or cotter pins because of stress corrosion. Be cautious of areas or situations which may abrade the protective rust coating off mooring components. The splash zone on buoys will have the most extensive rust problems if adequate protection is not provided.

- *Aluminium*: Aluminium is usually only found on the buoy itself. Generally, marine grade alloys are magnesium alloyed (U.S.5000 Series i.e. 5454, 5456, 5086). This is the preferred alloy as cheaper heat-treated magnesium/silicon alloy (U.S. 6000 Series) is subject to pitting along the weld areas and is weaker where it is welded. Unfortunately, marine-grade aluminium is more expensive and not as readily available. Painting is not recommended, except where a colour coding is required under existing maritime regulations. Aluminium creates a very good oxidised protective coating.

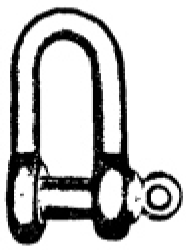
3. Shackles

Shackles are the recommended means for connecting mooring hardware components, being both simple to use and very secure. Shackles are sized according to the diameter of the bow. The pin is usually the next size larger for strength. There are two basic configurations:



(i) Anchor shackles

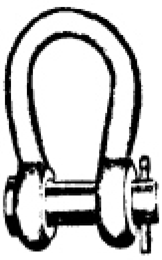
Anchor shackles are used to connect the buoy to the mooring and the mooring to the anchor. They are also used with thimbles and larger shackles where the large inside diameter of the bow is an advantage.



(ii) Chain shackles

Chain shackles are used to connect two segments of chain together and are sized equal to the chain diameter. Often two shackles are necessary due to chain link dimensions. Chain shackles are also used with swivels, anchors, and buoys depending upon fit.

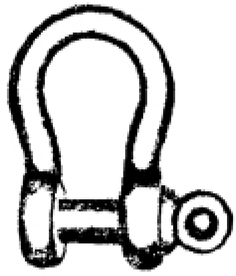
In addition to two bow configurations, there are three basic pin styles:



(iii) Roundpin

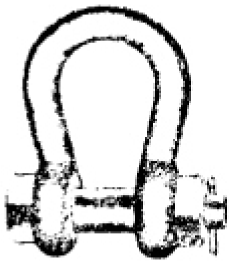
Round pin shackles utilise a cotter pin only to prevent the shackle pin from falling out. This is not very secure and should not be used for long-term buoy moorings. If used in short-term moorings, the pin should be welded and a stainless steel cotter pin inserted.

(iv) Screwpin



Screw pin shackles are not very secure for buoy moorings. Many FAD mooring failures can be directly attributed to the use of screw pin shackles. The pin must be carefully "moused" with stainless wire and should be welded for added security. Failure to do so will result in early loss of the pin and thus the mooring as well. In addition, the threaded portion is subject to stress corrosion. The pin thread is one of the main load-bearing surfaces and thread corrosion will directly reduce the overall strength of the shackle.

(v) Safety shackles (bolt-pin type)



Safety shackles utilise both a bolt-pin and a cotter pin for security. This is the recommended shackle for FAD moorings. Although the threads are subject to stress corrosion, they are not on a load-bearing surface, and the overall shackle strength is maintained. A stainless cotter pin is necessary to prevent the nut from working loose and falling off. Welding the bolt and nut to the shackle bow is recommended for long-term mooring applications.

4. Thimbles

The use of wire rope thimbles with synthetic rope is not advisable for marine moorings, as unlike wire, synthetic ropes will stretch. Wire rope thimbles have been shown to fallout of synthetic rope eyes and then act as an effective cutting surface with the shackle against the rope eye. In addition, the working motion of the rope on the steel thimble causes abrasion on the rope eye, a process accelerated by rust formation on the inner surface of the thimble. Wire rope thimbles can be made more secure by splicing the eye very tight and then whipping the base of the thimble securely. Nylon thimbles are available in smaller rope sizes but are not very strong and are not suitable for long-term moorings. Two approaches to synthetic rope terminations suitable for FAD moorings include the following:

(i) Nylite rope connectors (Fig. 10)

Samson Ocean Systems has developed this type of thimble. It uses a smooth, lightweight nylon spool with a flexible shield. It is held in place with the connecting shackle and can be assembled and taken apart without disturbing the eye splice. The Nylite connector is non-metallic and is very useful to isolate dissimilar mooring components. The shield reduces the chance of abrasion on the outside of the rope eye. Overall strength is equal to that of the rope it is connected to, and, while expensive, is the preferred thimble for FAD moorings.

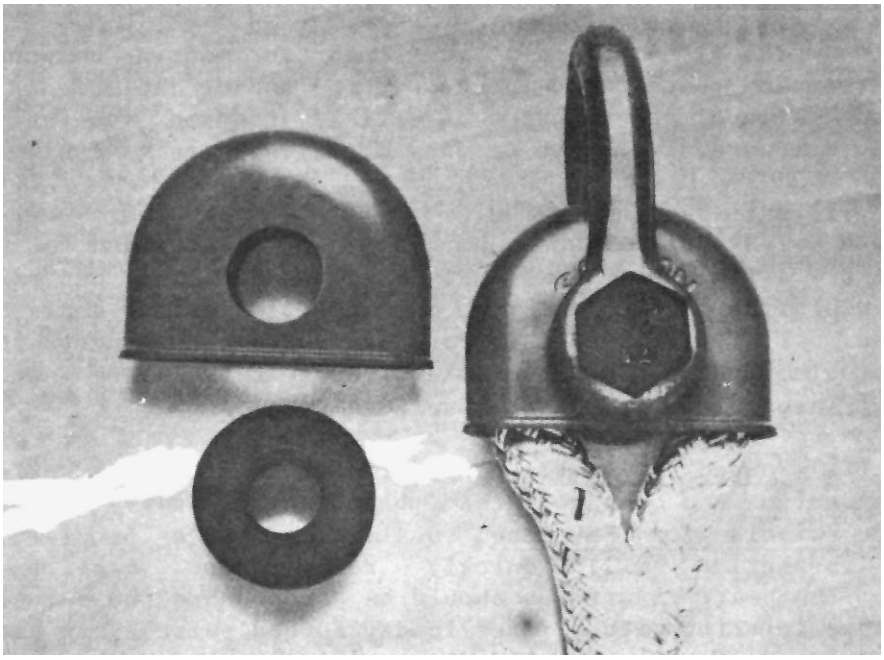


Figure 10: Nylite rope connector.

(ii) Newco thimbles (Fig. 11)

Newco is a trade name for a cast bronze (also available in steel) thimble similar to the wire rope thimble, with modifications to prevent it from working out of the rope eye as the rope stretches. It also allows for looser fitting eyes, thus easier splicing. Bronze provides a smooth surface for the rope and it does not rust like steel. However, it can cause corrosion problems where the area of exposed bronze is large relative to the exposed area of a linked, more active metal component. It has been used satisfactorily to connect rope to long lengths of steel chain, e.g. top chain or anchor pennant.

Figure 11: Newco bronze thimble.

5. Swivels

A good working swivel is a very important mooring component. Torque from buoy rotation, and twist induced during anchor deployments can cause hockling and failure of the rope as well as tension and fatigue problems with mooring hardware. Two basic designs of swivels are as follows:

(i) Ball-bearing swivels

Ball-bearing swivels were developed for use with wire rope cranes and are not recommended for use in FAD moorings. A new swivel works extremely freely under load, but experience has shown deterioration in seawater to be rapid. The grease seals degrade with time and the different alloys used for the swivel components set up severe corrosion problems. When used underwater, these swivels are not subject to the frequent inspections common to "surface" uses.

(ii) Forged swivels

Forged swivels are very effective, much simpler in design and cheaper than ball-bearing swivels, and are the recommended swivels for FAD use. Quality can be a problem, but visual "hands-on" inspection will quickly reveal poor quality designs or workmanship. The bearing surfaces should be smooth and the swivel should not bind up while twisting with off-set loads. Forged swivels can have any fair combination of end fittings including jaw (clevis) ends, eye ends, and chain ends (Fig. 12). "Eye and eye" swivels offer the most versatility, while swivels with jaw ends often have round pins which are not suitable for FAD moorings. Swivels should be located on moorings where they will be free from any possible entanglements. One good working swivel is sufficient, but they can be used in pairs for added insurance.

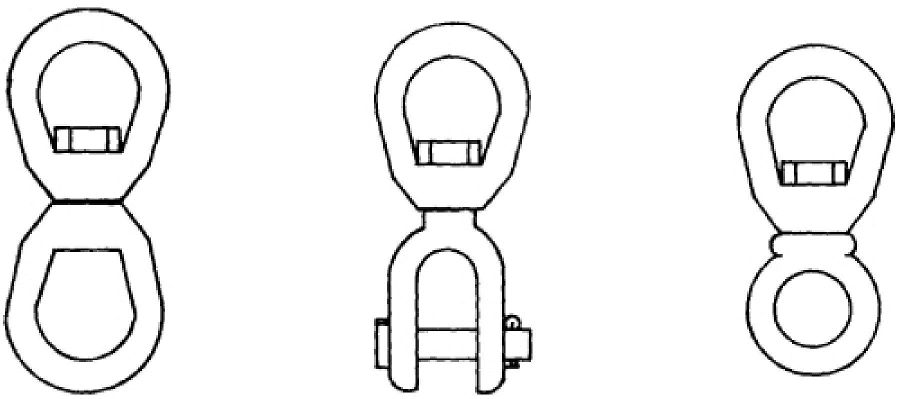


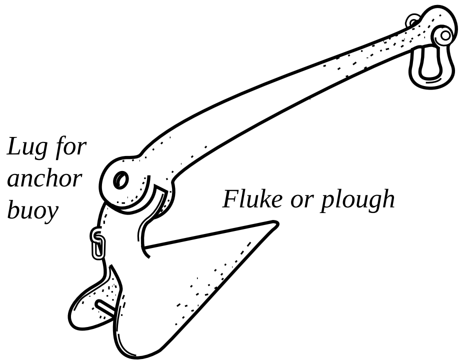
Figure 12: Forged swivel designs.

6. Chain

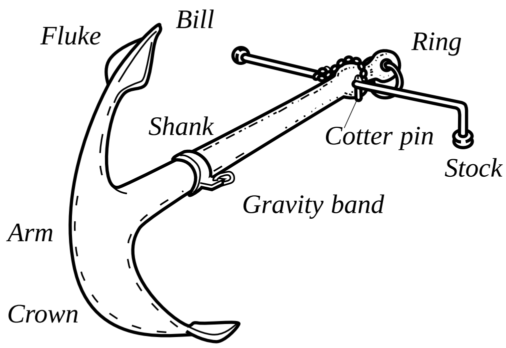
Chain quality and construction are not as critical as the previously mentioned items but are still very important. The statement, "a chain is only as strong as its weakest link", is true for both the chain as well as the entire mooring system. A chain forged from low carbon steel according to industry standards should be adequate for any FAD mooring. Look for good welds on uniform size links and documentation proving that quality assurance testing has been performed on the lot. Avoid "High-Test" (high carbon steel) chain as it is expensive and will not perform well in seawater.

7. Anchors

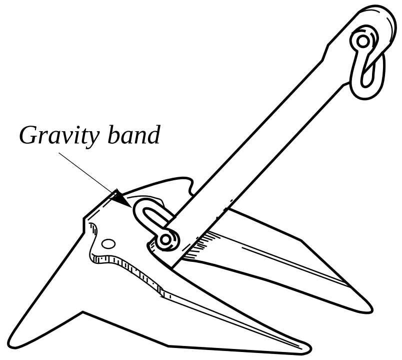
The most common anchor designs are shown in Figure 13 together with typical holding power ratios. Clearly, the most cost-effective design is the Danforth anchor. If a sandy bottom is present, this is the recommended anchor for FAD moorings. In most SPC areas, the bottom is presumed to be rocky where a concrete clump or oversized chain would be most effective. The types in common use are discussed in Section III.B. When sizing a clump anchor, the maximum forces the buoy and mooring rope will place on the anchor and bottom chain must be estimated. Given these forces, determine if it is more beneficial to have the anchor hold firmly, and risk parting the mooring, or to have it give a little, and move from its deployed location. (See Section V, Recommended FAD mooring design, for suggestions.)



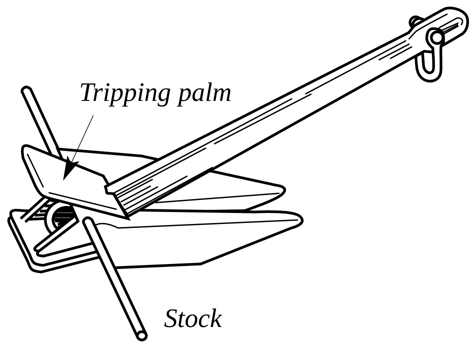
CQR (PLOW)/8:1



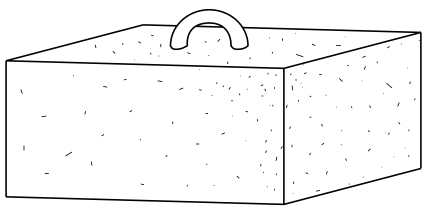
Fisherman's (Kedge)/5:1



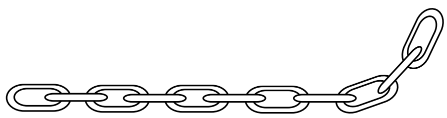
Stockless/6:1



Danforth/10:1 (mud)
18:1 (sand)



Concrete.1/2:1



Chain. 3/4:1

Figure 13: Anchor types with typical holding power.

V. RECOMMENDED FAD MOORING DESIGN

A. Introduction

The following discussion presents the FAD mooring system design recommended for the SPC region. This generic design is adaptable to most anticipated deployment locations and should have broad application throughout the Pacific Islands. The design expertise is drawn from experience with NDBO moorings, discussions with the oceanographic community, and local knowledge and experience passed on by fisheries personnel. The elements of the mooring system are specified in detail below, and instructions given where necessary to enable fisheries officers and other user groups to custom-tailor the design to meet variable deployment site conditions and individual country requirements.

B. Design criteria

Although often overlooked, putting the design objectives on paper is an important first step in the development of an effective FAD mooring system. It forces the designer (user) to answer critical questions about the FAD system and then to temper the design to meet those specific objectives. The following parameters should satisfy design criteria for most countries/locations in the SPC area.

- Life expectancy: 2+ years (to be extended with scheduled maintenance)
- Low cost: approximately US$3000/unit
- Deployment vessel: small Government or private vessel 30'—60' LOA
- Environment:
  - Moderate weather
  - Moderate seas and currents
  - 1600—2000 m (800—1000 fath.) depths
- Rough rocky bottom, some steep slopes
- Utilisation: fish aggregator for small trolling vessels, independently operated.

C. Description

1. General

The recommended FAD mooring configuration utilises an inverse-catenary synthetic rope design, chosen because it allows for large depth variation and a relatively small raft or buoy. The figured generic design was developed for the design parameters listed above, and as these vary from country to country and location to location, detailed instructions which enable the design to be modified to satisfy the different parameters which apply are presented in a later section (Section V). The objective of each user or user group should be to develop a uniform mooring design which is cost effective under local conditions and which eliminates critical weak links in the system.

The generalised mooring design (Fig. 14) is drawn as it will look in the water (heavy objects sink, buoyant rope will float and support a certain amount of hardware, etc.). This accuracy is important and will pinpoint problems which may otherwise be overlooked. The following detailed description of the components of the recommended mooring system will provide for a better understanding of the concept. It should be noted that these are recommendations only, and such factors as hardware availability, skill levels, and decisions based on previous experience, may preclude the exact use of the design as detailed. The synthetic rope information has been provided by Donaghys as they are the major supplier in the area. Other hardware suppliers vary, therefore the characteristics are based on industry standards.

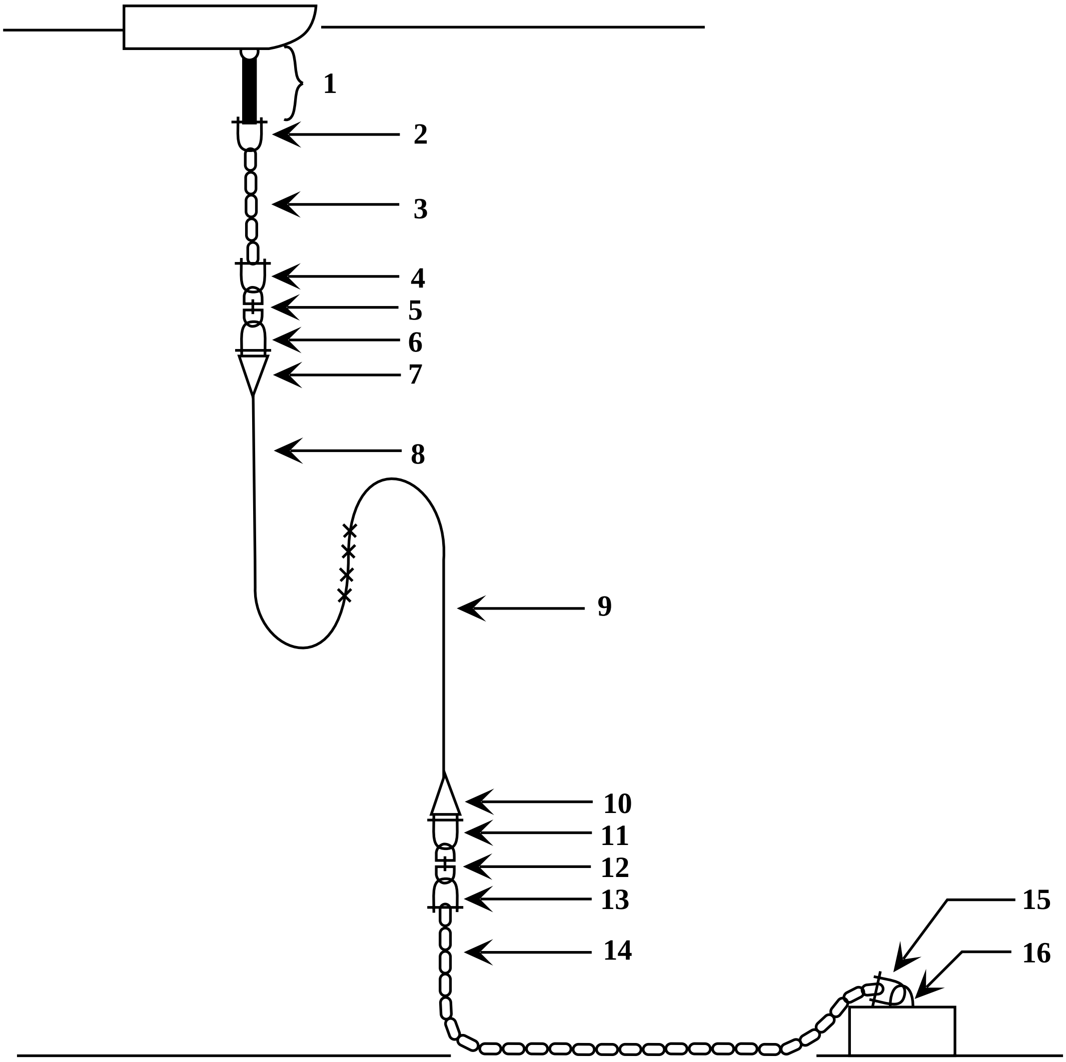


Figure 14: General arrangement—recommended FAD mooring design.

2. Components

The individual components of the FAD system are labelled in Figure 14 and will be discussed in numerical order. Table 5 details a bill of materials specific to this design.

Table 5: Bill of materials specific to generalised mooring design (Fig. 14).

Item	Quantity	Size	Description	Material	Break strength
1			Buoy hull and mooring bridle		
2	as req'd	to fit	Safety shackle(s)	Carbon steel (CS)	
3	45 ft	13 mm (1/2")	Open-link chain	CS	6 820 kg 15 000 lb
4	1	16 mm (5/8")	Safety shackle	CS	10 050 kg 22 100 lb
5	1	16 rnrn (5/8")	Swivel (eye & eye or chain)	CS	10 640 kg 23 400 lb
6	1	19 mm (3/4")	Safety shackle	CS	14 460 kg 31 800 lb
7	1	2" circ.	Thimble, synthetic rope type (Newco or Samson)	Bronze or nylite	
8		16 rnrn (5/8"D/2"C)	Rope, 8-strand plaited	Nylon	5 320 kg 11 700 lb
9		20 mm (13/16"D/ 2.1/2"C)	Rope, 8-strand plaited	Polypropylene	4 500 kg 9 900 lb
10	1	2.1/2" circ.	Thimble, synthetic rope type (Newco or Samson)	Bronze or nylite	
11	1	19 rnrn (3/4")	Safety shackle	CS	14 460 kg 31 800 lb
12	1	16 rnrn (5/8")	Swivel (eye & eye or chain)	CS	10 640 kg 23 400 lb
13	1	19 rnrn (3/4")	Safety shackle	CS	14 460 kg 31 800 lb
14	100 ft	19 mm (3/4")	Open-link chain	CS	14 550 kg 32 000 lb
15	1	19 rnrn (3/4")	Safety shackle	CS	14 460 kg 31 800 lb
16	1	900 kg (2,000 lbs)	Anchor; concrete block	Composite	

Item 1: Most of the raft designs discussed in Appendix II have proven effective FAD mooring platforms and should be suitable. Some of the small spar buoys may lack sufficient buoyancy or survivability for a two-plus year deployment. The mooring attachment should be non-metallic or low carbon steel. Bi-metallic insulation (if required) is more effective at the buoy/bridle interface. Use oversize materials in the mooring attachment area for sufficient strength after two-plus years of corrosion and wear.

Item 2: A safety shackle larger than 19 mm (3/4") is recommended as this will be a significant wear point. An additional safety shackle may be necessary to fit the larger one to the chain below.

Item 3: 14 m (45 ft.) of good quality open-link chain is recommended here. With connecting hardware, it will provide approximately 45 kg (100 lb) of counterweight to the raft. Most rafts will need some weight for stability. To vary the weight, vary the size or length of the chain as necessary. For abrasion resistance, the chain must be longer than any FAD appendages which may be suspended from the raft. It should also run deeper than trolling lines or any other gear from fishing boats which may foul the mooring. This protection should not be overlooked. Any chain smaller than 13 mm (1/2") will probably not last the required two-plus years.

Item 4: A 16 mm (5/8") safety shackle is recommended here. A 19 mm (3/4") shackle would be desirable to standardise all the shackle sizes, but it may not fit the 13 mm (l/2") minimum chain size specified above. A 13 mm (l/2") shackle has sufficient initial strength but may not hold up well after two years without maintenance.

Item 5: A 16 mm (5/8") swivel is sufficient here. The “eye and eye” or chain types are the most suitable. It is important to have the swivel inserted well below any appendages and at a depth where it would not normally be fouled by fishing lines.

Item 6: The 16 mm (5/8") safety shackle is sized to fit the thimble below. See manufacturer’s recommendations for proper fit.

Item 7: The thimble should be designed for synthetic rope use. The eye must not collapse under strain and should protect the rope from abrasion. A Samson “Nylitel”, Newco bronze or similar type of synthetic rope thimble is highly recommended. These thimbles are sized according to the rope diameter and circumference respectively.

Item 8: 16 mm (5/8" diameter/2" circumference) nylon rope is recommended for this section of the mooring line. It will sink away from the surface and is very elastic. It will absorb the shock of the raft motion and reduce fatigue and wear on the components below. The rope should have 8-strand or l2-strand plaited construction, although 3 strand will suffice (see discussion Section IV.A). The rated break strength of 5300 kg (11 680 lb) will exceed the 5:1 safety factor (rule of thumb) for the maximum force expected from the raft in the SPC area. Under calm conditions, the lower loop of nylon must not be long enough to reach the bottom. (See the next section for synthetic rope length calculations.)

Item 9: A 20 mm (13/16" diameter/2—l/2" circumference) polypropylene rope section is specified to buoy the bottom chain. It should have the same construction (for splicing) and a comparable wet break strength to the nylon above. The size may be increased to provide more buoyancy if necessary. Similar to the nylon, the upper loop of polypropylene must not be long enough to reach the upper hardware or surface as this would result in abrasion, entanglement or boat damage.

Item 10: This synthetic rope thimble (2—1/2" circ.) is sized to fit the rope above and should have similar characteristics to the previous one (Item 7).

Item 11: The 19 mm (3/4") safety shackle is sized to fit the thimble above Item (10).

Item 12: The 16 mm (5/8") swivel specified at this point is optional, but recommended (particularly when using 3-strand rope) if the one above (Item 5) is of poor quality or there is a possibility that it may become fouled. This swivel must be suspended off the bottom so it is free to rotate.

Item 13: The 19 mm (3/4") safety shackle is sized for the chain below (Item 14). A 16 mm (5/8") shackle should be sufficient, but as the lower hardware cannot be inspected or replaced, the larger size is recommended.

Item 14: The bottom chain is subject to wear during heavy weather. The 30 m (100 ft.) of 19 mm (3/4") open-link chain was chosen for adequate strength after two years and for adequate weight on the bottom. It serves to anchor the raft in mild conditions and acts as a shock absorber in heavy seas. The polypropylene will be of sufficient size and length to provide enough buoyancy to support approximately 10 feet of hardware off the bottom. This is expected to clear any rocks on the bottom, and will protect the rope and connecting hardware from abrasion. More chain may be suspended, if necessary, by increasing the amount (length or diameter) of polypropylene above.

Item 15: The 19 mm (3/4") safety shackle is sized to fit the chain to the anchor.

Item 16: A 900 kg (2000 lb) concrete block will have approximately 450 kg (1000 1b) of holding power on the rocky bottom, and should be sufficient for most moorings. A single concrete block is preferred for reasons previously stated. The anchor attachment point should be at least 19 mm (3/4") in diameter for wear and corrosion protection.

3. Synthetic rope length calculation

Determining the lengths of rope to use is critical to the success of any deep water mooring. The recommended design will accommodate considerable depth variation, but this must be estimated for each location. Two factors, echosounder error (rarely less than plus or minus 2% of depth in the most accurate of instruments, and usually higher), and the slope and irregularity of the seabed profile, will contribute to this figure. To illustrate the steps to be followed, the calculations necessary to determine the respective length of nylon and propylene in the generic FAD mooring example are presented in detail in a worked example (Fig. 15). Keep in mind that the assumptions on raft designs, oceanograpic conditions, and echosounder quality are conservative and these will differ from country to country.

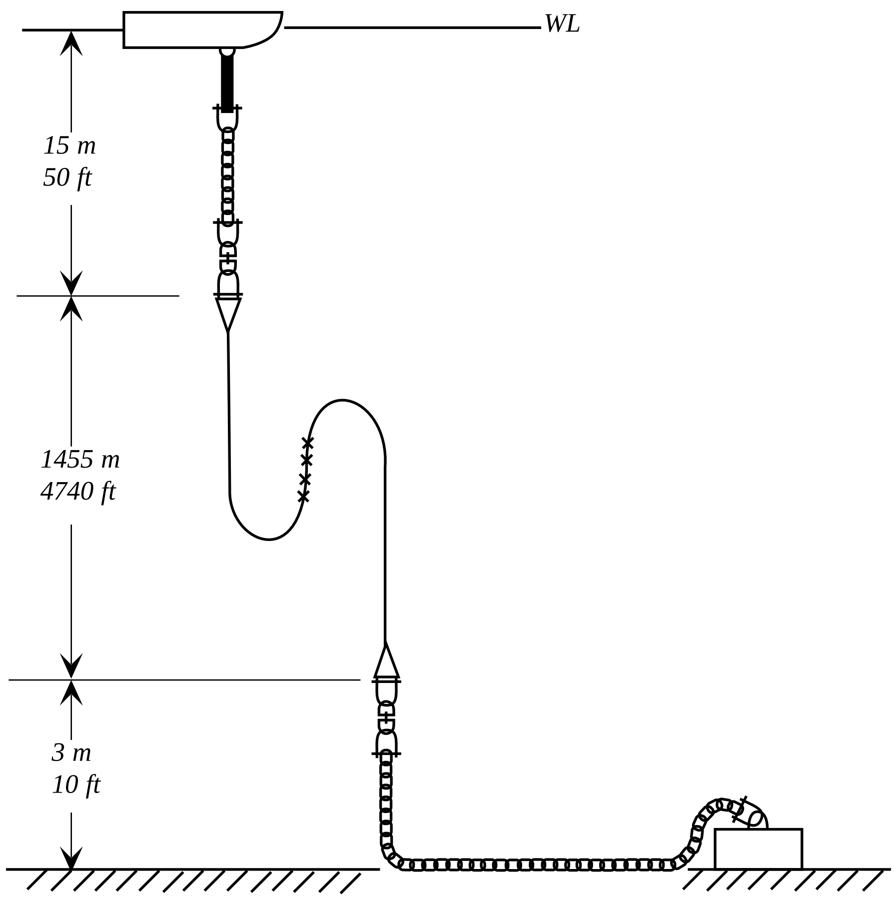


Figure 15: Recommended FAD mooring system—example designed for deployment in 1463 m (4800 ft).

WORKED EXAMPLE (Fig.15)

(i) Total length of synthetic line

For the example given, the water depth is estimated to be 800 fathoms or 1463 m (4800 ft) from chart and site surveys. Allowing for echosounder errors, and the steep outer reef slope situation commonly found inPacific Islands, the actual deployed depth may vary as much as ± 305 m (1000 ft).

The upper hardware falls to approximately 15 m (50 ft) below the surface while 3 m (10 ft) approximately of the bottom hardware and chain are designed to be suspended off the bottom. This delineates the depth to be covered by synthetic rope (*Rope*).

To facilitate discussion, the mooring rope is divided into the functional sections below.

Rope = Estimated depth – chain

= 1463 m – (15 + 3 m)
4800 ft – (50 + 10 ft)

= 1445 m (4750 ft)

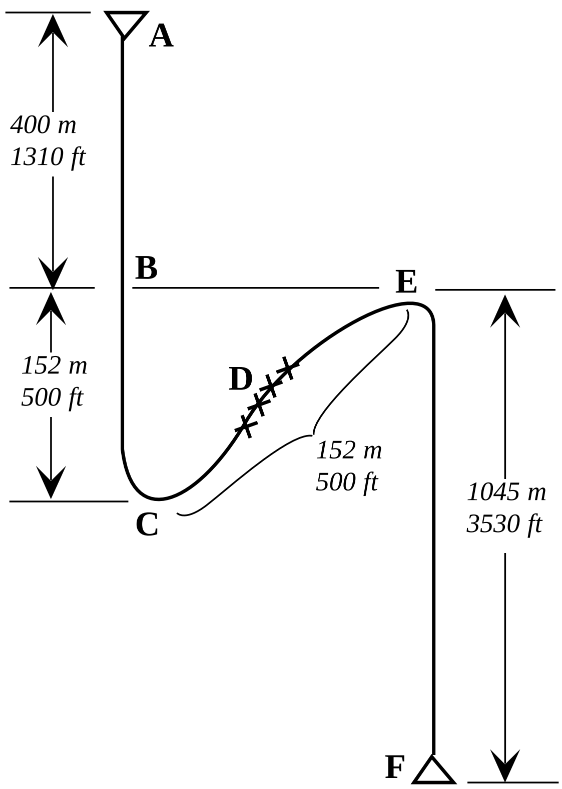


Figure 16: Rope sections.

(ii) *Polypropylene section* EF

The length of the polypropylene section is determined by the amount of buoyancy necessary to suspendthe required amount of bottom hardware. Weight of suspended hardware components in air is given from manufacturers' data:

Item	Weight in air
2.5" thimble (Newco)	... 0.4 kg (0.9 lb)
19mm (3/4") shackle	... 1.2 kg (2.6 lb)
16 mm (5/8") swivel	... 1.0 kg (2.3 lb)
19 mm (3/4") shackle	... 1.2 kg (2.6 lb)
2.4 m of 19 mm (3/4") chain	...17.8 kg (39.2 1b)
Total Wt (air) =	**21.6 kg (47.6 lb)**

The weight of hardware in seawater is approximately 87% of its weight in air. Therefore the actual weight to be suspended by the polypropylene is 18.8 kg (41.5 1b)

20 mm polypropylene (superfilm weighs 401 g/220 m coil (12.2 1b/100 ft) and has positive buoyancy in seawater equal to 9.9% of its dry weight (information supplied by Donaghys).

Therefore the length of polypropylene required to suspend this hardware weight (rope section *EF*) is 1045 m (3430 ft).

(ii) *Nylon section* AB

The polypropylene section *EF* covers 1045 m (3430 ft) of the original 1445 m (4740 ft) of depth for synthetic rope (*Rope*). This leaves 400 m (1310 ft) to be covered by the nylon (Section *AB*).

Total Wt (air) = 21.6 kg (47.6 1b)
Suspended hardware

Hardware Wt (sea) = 87% Wt (air)

Wt (sea) = 0.87 x 21.6 kg
Suspended hardware 0.87 x 47.6 1b

18.8 kg (41.5 1b)

Polypro
Wt (sea) = 9.9 % Wt (air)

Buoyancy = 40 x 0.099 kg/m
Factor 12,2 x 0.099 1b/ft

= 0.018 kg/m (0.0121 lb/ft)

EF = HARDWARE ÷ BUOYANCY FACTORE Wt (sea)

= 18.8 ÷ 0,018 m
41.5 ÷ 0.0121 ft

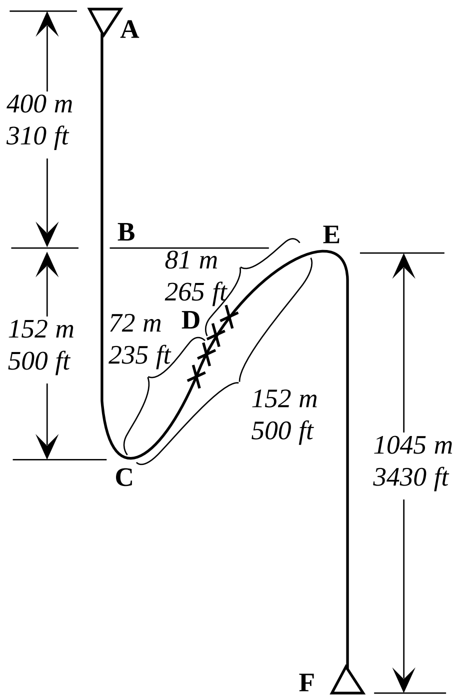
= 1045 m (3430 ft)

AB = *Rope – EF*
= 1445 m – 1045 m
4740 ft – 3430 ft

= 400 m (1310 ft)

*(iv) Composite length of nylon and polypropylene in catenary loop (*BCDE*)*

The catenary loop incorporates all the slack mooring line in the system, with the characteristic shape formed as a result of the balance between the sinking (nylon) and buoyant (polypropylene) rope components, and its exact shape will be determined by the relative proportions of these two components, and the forces exerted on the line by current and the aggregator (raft and appendages). The amount of slack line and therefore the size of the loop will vary in response to errors in depth estimation (provided this is within the range specified earlier).



All that remains is to calculate the proportions of nylon and polypropylene required to form the catenary section (in this example 305m (1000 ft) long. This section is best envisaged as a rope suspended from two points, thus forming a parabola. One end is suspended from the raft by being attached to the 400 m (1310 ft) nylon rope section (*AB*) which hangs directly from the raft. The other end will be suspended by buoyant polypropylene, which will give the loop its characteristic inflected shape. The weight of a rope hanging between two points is distributed equally between them. Therefore, half of the weight of the 305 m (1000 ft) catenary loop, or 152 m (500 ft) will rest on the raft (*BC*), and the other half will need to be a nylon/propylene composite which achieves neutral buoyancy. In other words, the polypropylene section (*DE*) supports the nylon (*CD*).

16 mm nylon weighs 36.5 kg/200 m (11.1 lb/l00 ft), of which 12.3% is retained in seawater (information supplied by Donaghys), giving a weight of 0.0204 kg/m (0.0137 lb/ft).

Nylon
Wt (sea) = 12.3% Wt (air)
Wt (sea) = 0.123 x 36.5 kg/m
0.123 x 11.1 lb/ft
= 0.0204 kg/m
(0.0137 lb/ft)

As already discussed, polypropylene provides 0.018 kg/m (0.0121 lb/ft) buoyancy, a smaller force and hence polypropylene must comprise a larger proportion of the composite length (*CDE*) to achieve neutral buoyancy. Therefore, a neutrally buoyant balance of 81 m (265 ft) of polypropylene (*DE*) supporting 72 m (235 ft) of nylon (*CD*) is required.

Ratio (Polypro/Nylon)

$$= \frac{\text{Wt (sea) Nylon}}{\text{Wt (sea) Nylon + Wt (sea)Polypro}}$$

$$= \frac{0.0204 \text{ kg/m}}{0.0204 + 0.018 \text{ kg/m}} \qquad \frac{0.0137 \text{ lb/ft}}{0.0137 + 0.01211\text{b/ft}}$$

$$= 0.53$$

Length Polypro *DE* in section *CDE*

= Ratio (Polypro/Nylon) x *CDE*

= 0.53 x 152 m

0.53 x 500 ft

= 81 m (265 ft)

Length Nylon *CD* = *CDE* – *DE* in section *CDE*

= 152 – 81 m

500 – 265 ft

= 72 m (235 ft)

(v) Summary = Specified rope lengths

TOTAL LENGTH – NYLON

ABCD = *AB* + *BC* + *CD*

= 400 + 152 + 72 m

1310 + 500 + 235 ft

= 624 m (2045 ft)

TOTAL LENGTH – POLYPRO

DEF = *DE* + *EF*

= 81 + 1045m

265 + 3430 ft

= 1126m(3695ft)

OVERALL LENGTH SYNTHETIC ROPE

ABCDEF = *ABCD* + *DEF*

= 624 + 1126 m

1045 + 3695 ft

= 1750 m (5740 ft)

The overall nylon length of 624 m (2045 ft) and overall polypropylene length of 1125m (3695 ft) checks with the original calculated depth to be covered by synthetic rope (*Rope*) of 1445 m (4740 ft), plus an additional 305 m (1000 ft) depth variation factor in catenary loop, giving a total synthetic line length of 1750 m (5740 ft). The design as specified in the example above is presented in Figure 17.

For most deployment at depths greater than 1200 m, the depth variation factor used above (305 m or 1000 ft) would allow a reasonable safety margin. The length of 20 mm polypropylene necessary to support the same 3 m (10 ft) of hardware off the bottom remains unchanged. Therefore, only the length of the nylon (section *AB*) should change with increasing depth, thus varying the scope. The notion that scope is the determining factor or mooring length is misleading. Scope was developed for using lightweight anchors in shallow water; it is not directly applicable to deepwater moorings.

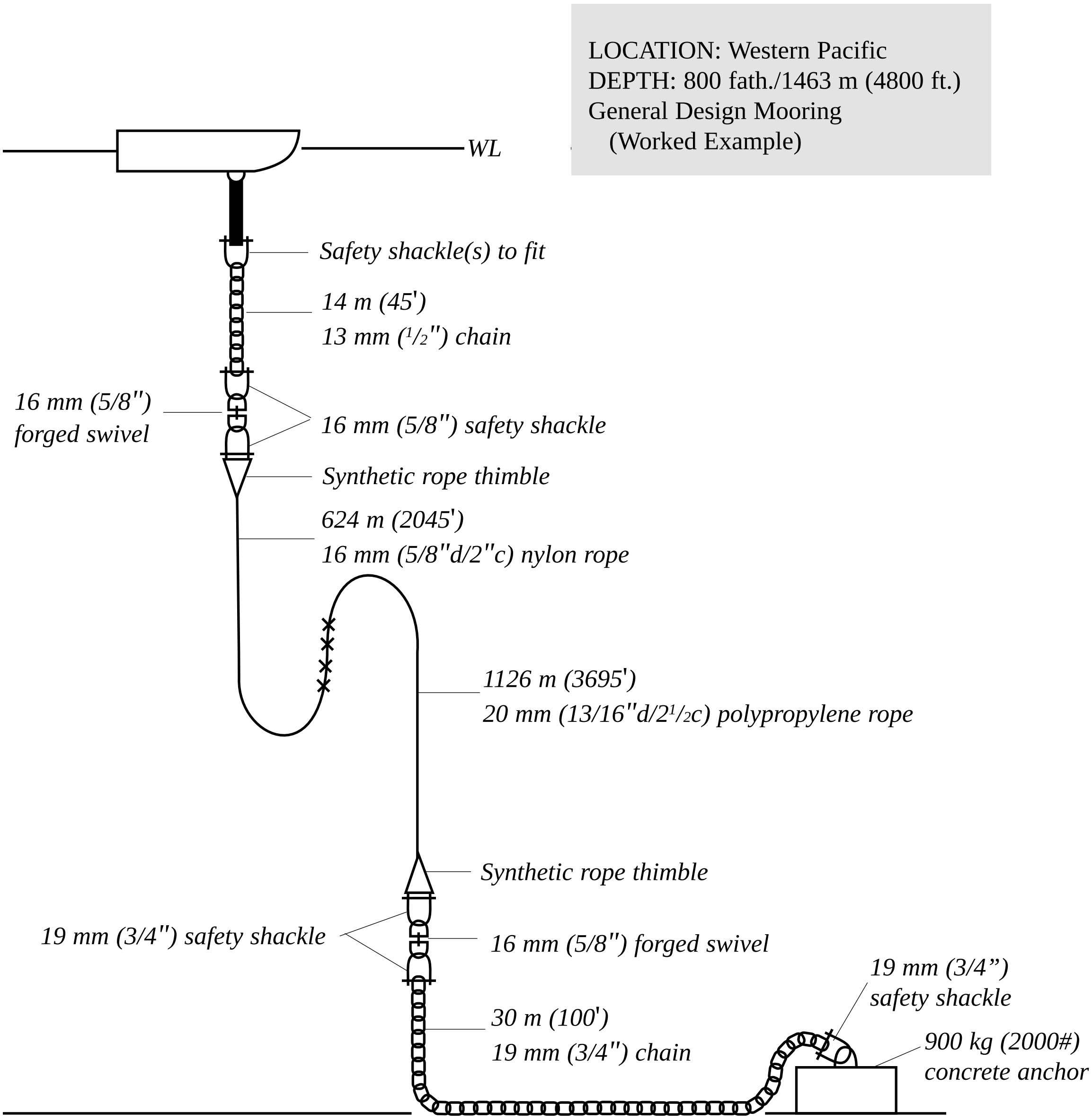


Figure 17: Recommended FAD mooring design.

D. Modifications to generic design

The recommended generic mooring design as detailed in the above section (Fig. 17) should be adequate for most Pacific Island areas. The following presentation contains useful suggestions to enable the design to be customized to meet specific site requirements or the needs of individual countries.

(i) Site deeper than worked example

Add 1 foot of nylon per foot of depth.

(ii) Site shallower than worked example

Subtract 1 foot of nylon per foot of depth until the thimble to upper loop distance (*AB* in the worked example) is equal to the depth variation estimate. Then increase the polypropylene diameter or reduce size of bottom chain to 16 mm (5/8"), if environment is mild and buoy is small, and recalculate the required length of rope. Specific examples of mooring designs for hypothetical locations and conditions in moderate depths (400 fath/732 m) are presented in Figure 18 (light FAD mooring) and Figure 19 (heavy FAD mooring). Shallow-water moorings are mentioned briefly in Section V.E.

(iii) Reduce cost

Use more polypropylene and less nylon (see shallow-water limitation). This will support more of chain off the bottom. Costs can be substantially reduced by purchasing supplies in large quantities with a longer lead time, and bidding suppliers against each other to encourage competitive pricing.

(iv) Reduce maintenance

Increase upper chain size along with connecting hardware. Ensure quality hardware is used. Strengthen any anticipated weak points.

(v) Severe weather/current

Streamline the buoy and its appendages. Uniformly strengthen all components as necessary.

(vi) Boat mooring

FADs are deployed for use in artisanal fisheries, it is highly likely that small boats will tie up to the raft, particularly at night; this must be allowed for in the design. Expect more wear on the upper components and shorter expected life. Uniformly strengthen all components if multiple rafting is expected. Unless rafting up is prohibited, allow for tying up to the raft to reduce structural damage to the buoy:

– Provide cleats on raft stern

– Ensure FAD appendages will not foul vessel propellers

– Allow short lines with floats to stream from buoy on the surface. These should have break strength much less than mooring line.

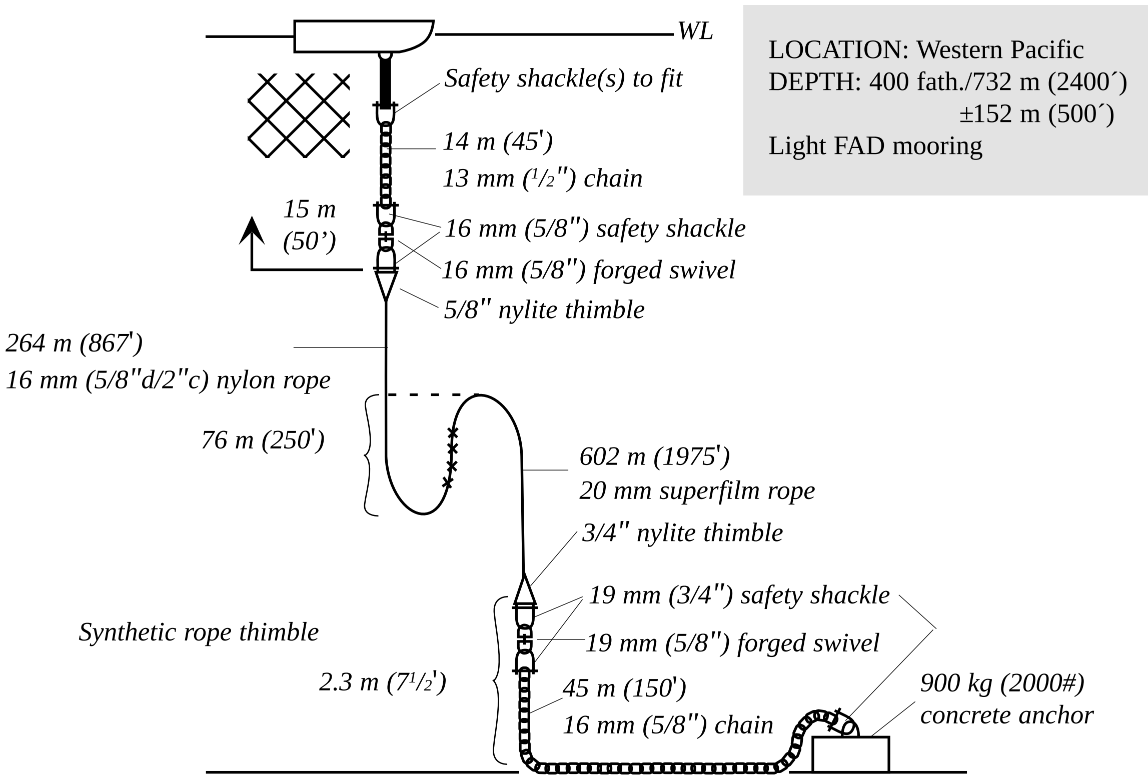


Figure 18: Specific example of a lightweight FAD mooring for deployment in 400 fathoms (732 m) depth

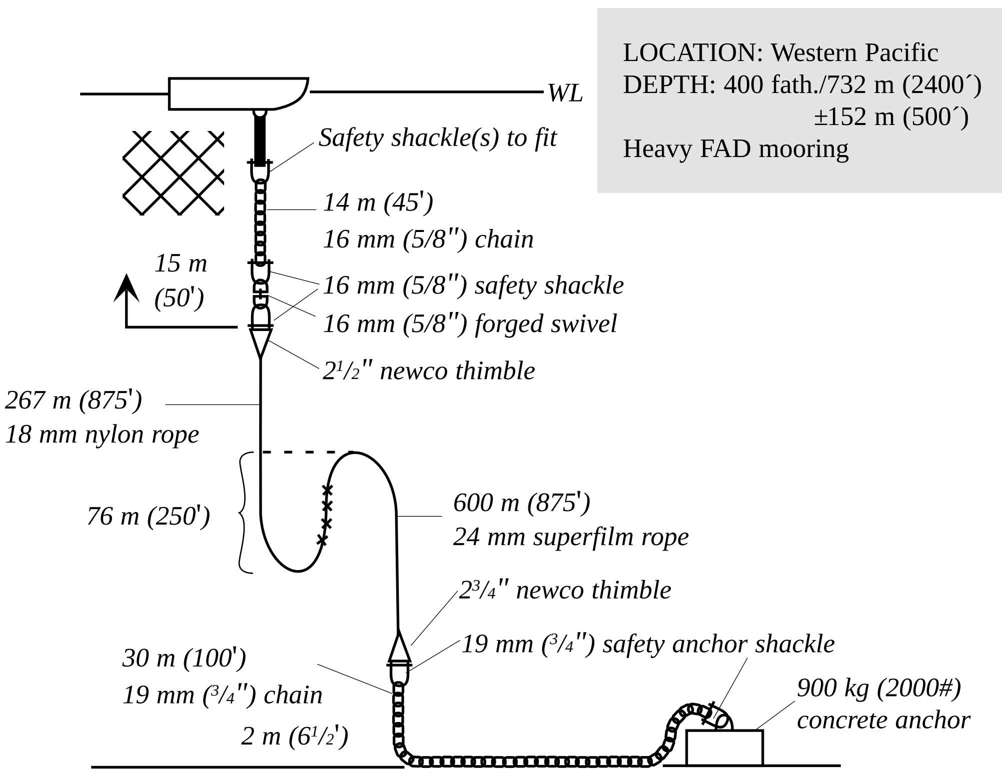


Figure 19: Specific example of a heavyweight FAD mooring for deployment in 400 fathoms(732 m) depth

(vii) *Rope fairing*

Fairing is easily applied to rope at the factory during fabrication. It was originally developed to reduce vibration (strumming) of the rope in moderate to strong currents, which caused greater drag and fatigue failure on oceanographic moorings and instrumentation. In addition to reducing the drag on FAD moorings it may serve to enhance or replace buoy appendages when used in the upper nylon portion of the mooring. Paradoxically, while attracting fish, it may reduce shark-attack by reducing the strumming. These latter attributes have yet to be tried and proven.

(viii) *Rope coatings*

Many manufacturers offer rope coatings which reduce abrasion and colour the rope while allowing normal splicing. The Hawaiian FAD moorings use a dark colour coating on the nylon rope reportedly to reduce fishbite on the otherwise bright virgin nylon.

E. Shallow-water moorings (Fig. 20)

(i) *All-chain moorings (Fig. 20a)*

To moor a buoy in very shallow water, an all-chain mooring should be used. The chain should be at least 5/8" as wear will be significant. The chain catenary and length will act as a shock absorber. A 3:1 to 5: scope is recommended depending upon chain size and local conditions.

(ii) *Semi-taut moorings (Fig. 20b)*

If the water gets too deep for the buoy to support the weight of the chain, nylon can be added. It will act as a shock absorber, thus reducing the bottom chain length (and scope). This nylon must be well below the surface as in the inverse catenary mooring. However, the buoy must support enough chain off the bottom to cover the depth variation expected for the location and fathometer. Expect 5% to 10% nylon stretch under calm conditions. If the weight of bottom chain is too great in deeper water, an inverse catenary mooring must be used. A specific example of a lightweight semi-taut mooring for a hypothetical location in 200 fath./366 m (1200 ft) is presented in Figure 21.

(iii) *Auxiliary float moorings (Fig. 20c)*

Buoyant floats can be used to support semi-taut and inverse catenary moorings. The location and quality of the auxiliary floats is critical to the success of the mooring. Inquire with NDBC for assistance with these moorings.

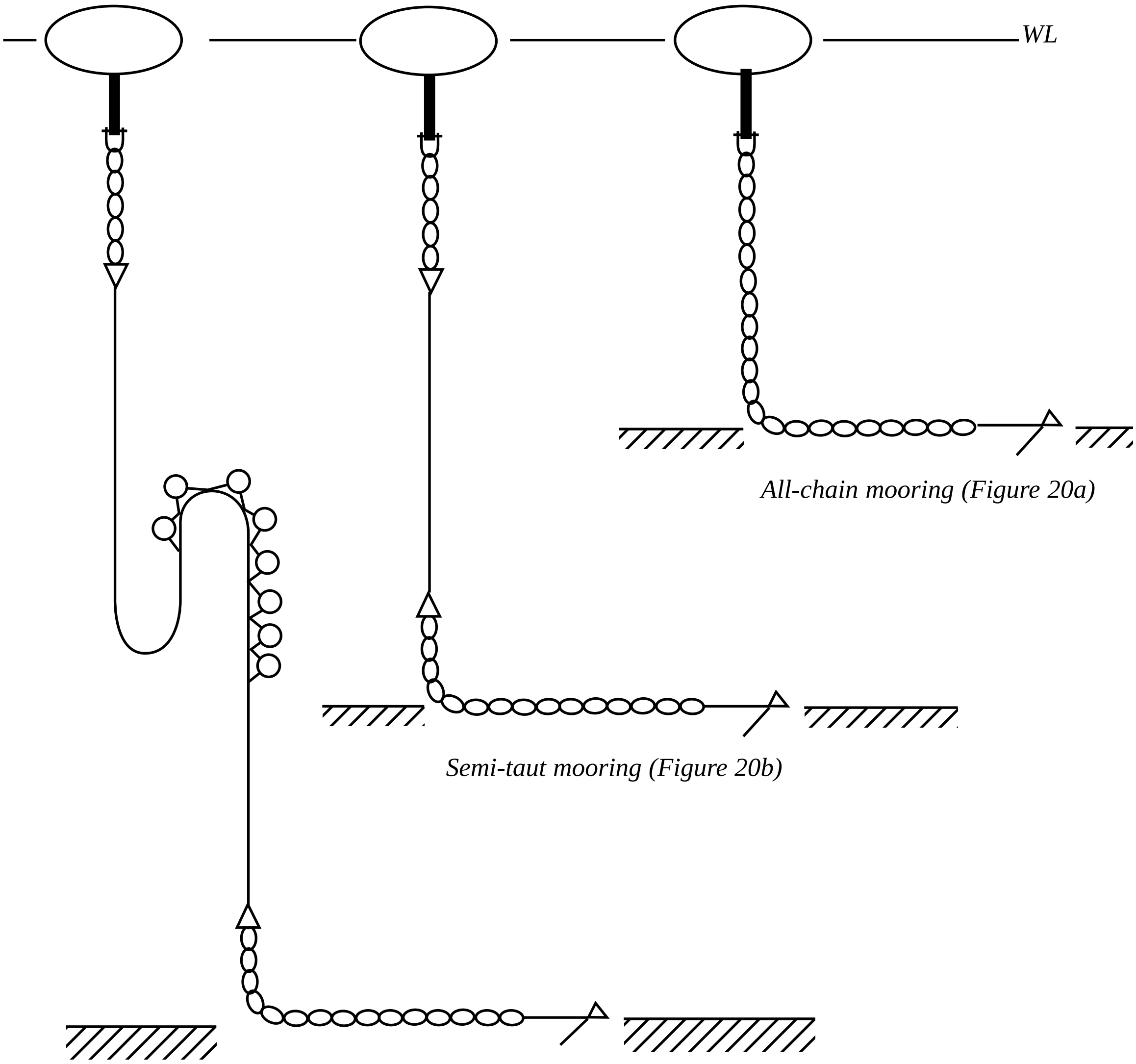


Figure 20: Shallow-water moorings.

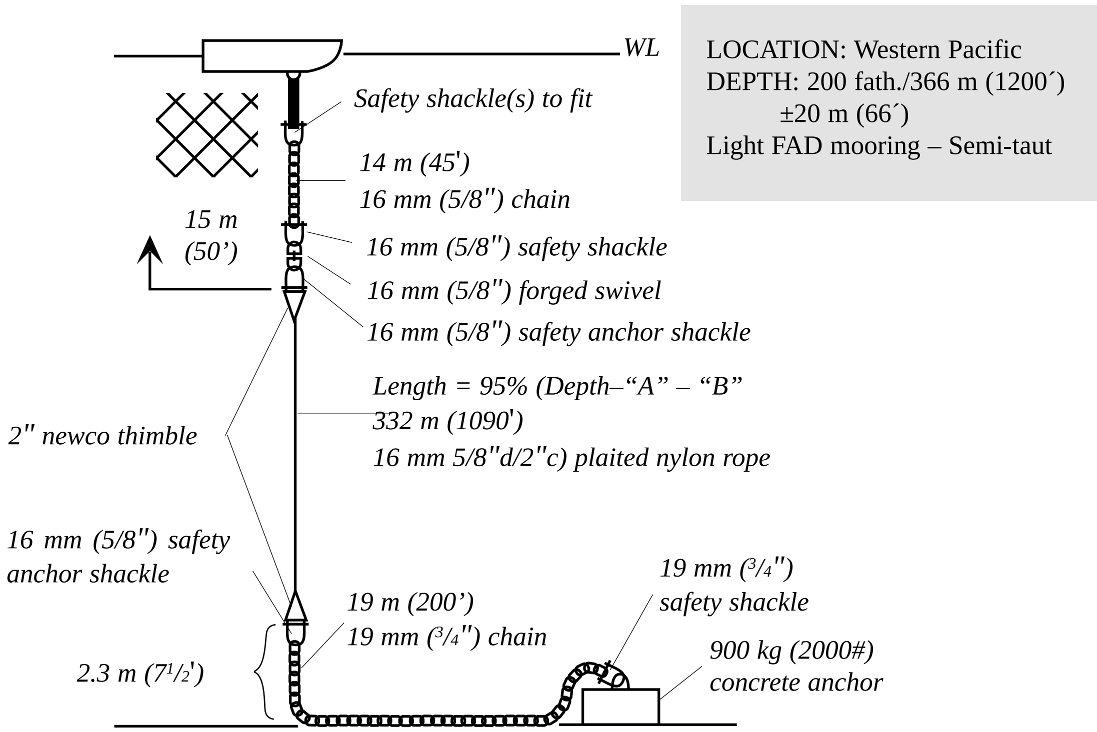


Figure 21: Specific example of a lightweight semi-taut FAD mooring design for deployment in 200 fathoms (366 m) depth.

F. Computer modeling

The recommended FAD mooring design has been checked with a frequency domain computer programme to determine its probable environmental limits in the SPC area. The programme is regularly used for modeling NDBC moorings and has proven to be very reliable. The results of the inverse catenary mooring described in the worked example (Fig. 17) show good performance up to 60 knots of wind and a 3-knot surface current. Above this, the anchor may drag, depending upon specific buoy hull shape and size of appendages. Buoy wind resistance does not seem to affect the mooring greatly. Wave height also has a minimal effect on the mooring, although, large breaking waves will probably capsize the raft.

The semi-taut example (Fig. 21) was modeled in depths of water up to 400 fathoms (732 m). It shows good safety factors and anchor-holding power to this point for a generic buoy sized and shaped to model the "average" FAD. In water deeper than this, or where winds and surface currents exceed 60 knots and 3 knots respectively, an inverse catenary mooring is recommended.

Remember that time and experience are the best judges for the overall success of a design. The computer estimates are a tool to be used to model specific systems under ideal conditions. Variable human factors, such as quality of workmanship and vandalism, and environmental factors, such as fishbite and rough bottom conditions, must also be considered when developing a realistic FAD mooring system.

G. Maintenance

The recommended FAD mooring design should last for two years without maintenance. At this point, the buoy should be recovered and refurbished. Recovery of the mooring will provide very valuable information on where to cut costs further or where to strengthen weak points and extend the expected life of future moorings. Close inspection of failed or recovered moorings is very important, and in addition to determining the primary failure modes, secondary sources for problems should be investigated.

If possible, regular scheduled maintenance should be performed on the buoy and mooring every six to twelve months. Inspection of the upper mooring and replacement of parts where necessary will extend the average FAD mooring life by an additional year. The feedback gained on problems with the original mooring line design will be very cost effective. With reliability and confidence established, more effective buoy designs can be tried. At this point, variables such as fishbite and manbite will become easier to deal with.

H. Deployment considerations

The two most common methods of mooring FADs in deep water are the “Anchor Last” and “Anchor First” methods. The following is a brief discussion and critique of the methods as used.

(i) Anchor last method

Typically, a buoy will be set adrift in the water attached only by its mooring line to the deployment vessel. The mooring line is paid out from the vessel as it moves ahead to prevent tangles. The line has been pre-cut to the particular site depth and allowances have been made for depth variations. When all the line is in the water, the buoy is towed toward the drop point, where the anchor is released. A rule of thumb used to allow for anchor drift during deployment: release the anchor at a distance equal to one-third (1/3) of the depth past (usually upcurrent) the target anchoring site. The anchor and buoy configuration will vary this 1/3 depth rule of thumb and is best determined by experience.

(ii) Anchor first method

In this method the anchor is released and the line is paid out under control until the anchor embeds. Another 5—10 per cent depth (usually the latter) is added to the line and the raft and top hardware attached. Strain is sometimes taken on the mooring line before release of the buoy to allow any twists to spin out of the rope (if using 3-strand construction). This method is useful where the bottom depth is in question, but can be dangerous.

The anchor last method is the most widely used in the oceanographic community. The critical aspect of this mooring is the requirement either to estimate the depth accurately or to provide adequate allowance for depth variation in the design. This method is safer and can be accomplished in rougher weather than the anchor first method. The total amount of rope used is usually less, while the raft and other components can be attached in the optimum locations much more easily. Site selection is critical to the survivability of the mooring. A relatively flat area free from ledges, pinnacles, and deep crevasses is recommended while a slight depression is ideal for containing the anchor. The maximum recommended slope is extremely variable depending upon the bottom sediment and topography. However, anchoring a FAD on a pinnacle or upcurrent from a large slope is not advisable.

V. DISCUSSION

FAD design improvement will be an ongoing process in each country and this study is but one step along the way. As the average mooring life is extended, other failure sources will become increasingly important. There is a progressive but variable deterioration of all components of the FAD system with time, the rate being determined by environmental and usage factors, quality of materials used, etc. Only experience will determine where such problems lie and what remedial action is required.

Very few countries maintain detailed records of all FAD deployments, and this lack of information has hampered their efforts to overcome failure problems. It is important that all FAD moorings be fully documented. As well as the more obvious details relating to design and component selection, site location, life history, etc., inspection and maintenance details should also be recorded. Every effort should be made to recover failed moorings and critically examine remaining components. This will provide valuable feedback on both the cause of the present failures as well as other problem areas which would lead to future failures—the next “weak link”.

Anchoring of a FAD requires the use of an accurate echo sounder to determine deployment depth. Too many deployments have been made relying on an inadequate instrument which is operating at the limit of its designed depth range, or no echosounder at all in some cases. At a cost approaching US$4000, an adequate echosounder does not cost much more than a single FAD unit, and should be regarded as an essential component of any FAD programme.

The FAD mooring line design recommended in this report should eliminate or accommodate many of the identified major causes of premature FAD loss in this region, and within design objectives should double or treble the life expectancy of such moorings, provided that due control and supervision are maintained on fabrication and deployment procedures.

REFERENCES

Anon (1983). *Hawaiian fish aggregating buoys*. Status report. Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawaii. January 1983, 13 pp.

Berteaux, H.O. (1976). *Buoy engineering*. John Wiley and Sons, New York.

Meyers, J.J.; Holm, C.H.; Allister, R.F. (1969). *Handbook of ocean and underwater engineering*. McGraw-Hill Book Company, New York.

Philipp, A.L. (1983). *Country statement—Western Samoa*. Working Paper 8. Fifteenth Regional Technical Meeting on Fisheries. 9 pp.

Preston, G. (1982). *The Fijian experience in the utilisation of fish aggregation devices*. Working Paper 25. Fourteenth Regional Technical Meeting on Fisheries. 61 pp.

Prindle, B. (1981). *Factors correlated with incidence of fishbite on deep-sea mooring lines*. Woods Hole Oceanographic Institution, WHOI-81-57, Woods Hole, Massachusetts 02543.

Prindle, B.; Walden, R.G. (1976). *Deep-sea lines fishbite manual*. National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Office, Bay St Louis, Mississippi 39520.

APPENDIX l

SUMMARIES OF COUNTRY EXPERIENCES WITH FAD DEVELOPMENT PROGRAMMES IN COUNTRIES VISITED DURING THIS STUDY

A. AMERICAN SAMOA

In October 1979, the Office of Marine Resources in co-operation with NMFS in Hawaii deployed 10 FADs in American Samoa; all of the original NMFS design, they were deployed primarily to assist sports and recreational fishermen, and locations were chosen with this in mind, (most within 5 miles of land, and in depths from 100 to 2500 m). The average life of this design was 9 months. A replacement programme was initiated in May 1981, with a further 10 buoys being deployed. The high loss rate with this second generation of devices (8 within 3 months of deployment) indicated serious problems remained with the design and basic components. Plans to deploy semi-taut, stainless steel wire rope to chain moorings were modified after discussions with SPC consultant.

Comments on the current FAD design (Fig. 1)

I. Mooring line:

The second generation FAD incorporated a number of changes to earlier designs:

- a single stainless steel ball-bearing swivel used at junction between rope and topchain;
- bronze thimbles and galvanised shackles used to join rope coils and to link rope to chain components;
- counterweight eliminated:
- longer anchor chain (50 ft cf. 25 ft) with two concrete blocks or concrete filled oil drums (2 x 600 lb) cf. a single block of 2500 lb.

II. Aggregator:

Raft: two designs trialled, a fibreglass spar buoy and a toroid or doughnut raft. The latter, while expensive, has proved far superior, and will be used for future deployments.

Appendage: car tyres encased in a tube of purse seine webbing—presently experimenting with two types, a floating or surface streaming appendage vs. a weighted or sinking version.

III. Deployment

FADs were deployed both from Marine Resources vessel and from commercial tuna purse seiners, the latter proving less reliable. Deployment by “buoy first” method. Sites for deployment selected after consultation with local fishermen. Echosounder transects used to locate drap point.

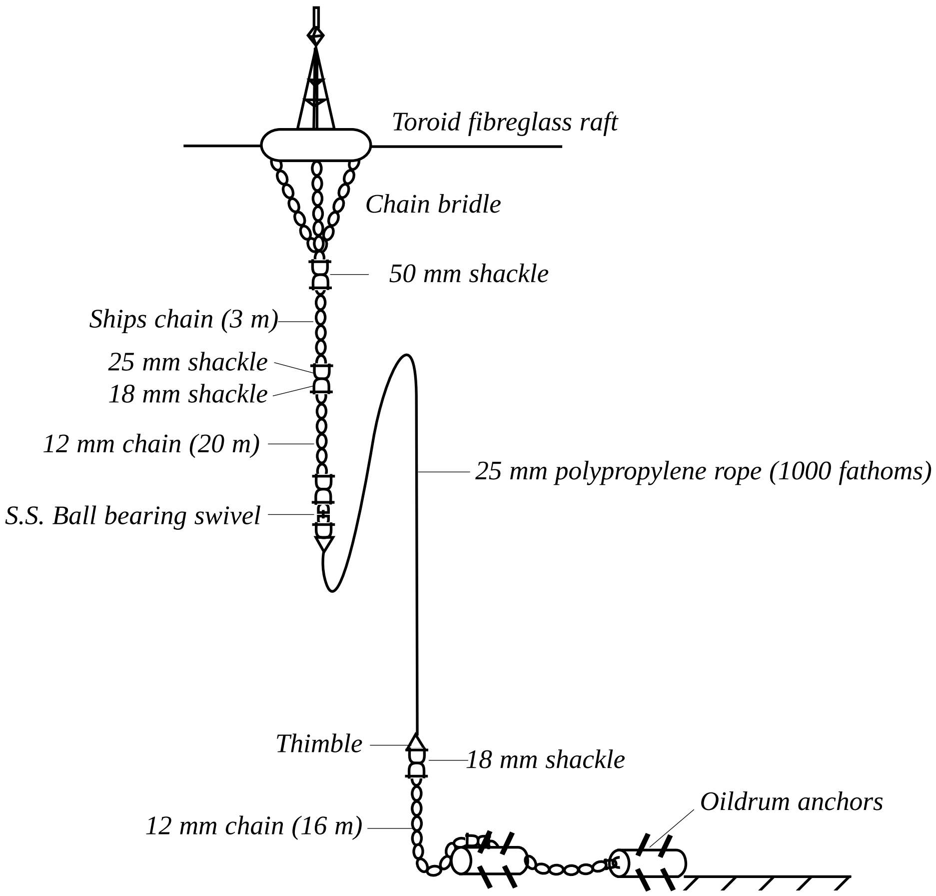


Figure 1: Latest FAD design—American Samoa.

Summary of results

No. deployed	22	Depth 1000—2700 m
No. lost	20	Av. life span 3—12 months
No. recovered	10	Cost/unit US$5000
No. planned	4	

Known or probable causes of failure

–		
Hardware failure	1	Shackle
Unsuitable site	2	Shallow exposed sites
Boat propeller	1	
Raft Breakup	2	
General line failure	2	
Poor deployment	1	Rope badly tangled—FAD drifted

B. COOK ISLANDS

The first two FADs were deployed by Fisheries Division in 1980, one off Rarotonga, and another off Penhryn. Encouraged by the substantial improvement in the catches by local fishermen, a further four FADs were anchored off the coastline of Rarotonga in 1981—82, in depths of 600—800 fathoms and up to 2 miles off the steeply shelving coastline. While initial losses were high, this early failure rate has been drastically reduced by the implementation of a regular maintenance programme. Further deployments are planned for late 1983 with additional FADs (3) around Rarotonga and a FAD programme for the Outer Islands.

Current FAD design (Fig. 2)

I. Mooring line

The early FADs were based on the original NMFS design, and later substantially modified with FAO assistance. The present design has been further modified in the light of experience, both local and that reported from other countries, and incorporates a number of changes:

1. Use of ball-bearing swivel as primary swivel;

2. Use of safety shackles (bolt and pin type) throughout eye splices whipped onto wire rope thimbles;

3. Replacement of stainless steel ring in bridle of catamaran raft with forged galvanised iron ring;

4. Factory-prepared continuous lengths of 20 mm polypropylene 3-strand rope used to reduce the number of splices;

5. Scope of line reduced from 1.4:1 to 1.1:1 to reduce watch circle and make raft easier for fishermen to locate;

6. Anchor: reduced number of concrete clump anchors from 3 x 800 lb to 2 x 1400 lb for ease of handling.

II. Aggregator

Raft: the aluminium catamaran raft from Boat craft in Western Samoa has proven itself in the Cook Islands as elsewhere. However, the high landed cost (US$1400) is prohibitive and the Marine Resources Department is looking at a number of replacement designs, the simplest and cheapest of which is fabricated from a plastic foam-filled 200 litres plastic drum, encased in a polypropylene rope harness, with a PVC mast to hold a light. The light unit used is a simple 4-cell plastic net light.

Appendage: 4 x 20 m lengths of polypropylene rope threaded with plastic strapping material and weighted with chain. This has proved to be light, durable and effective, with low drag charac-teristics. Different colour strapping tried but results inconclusive.

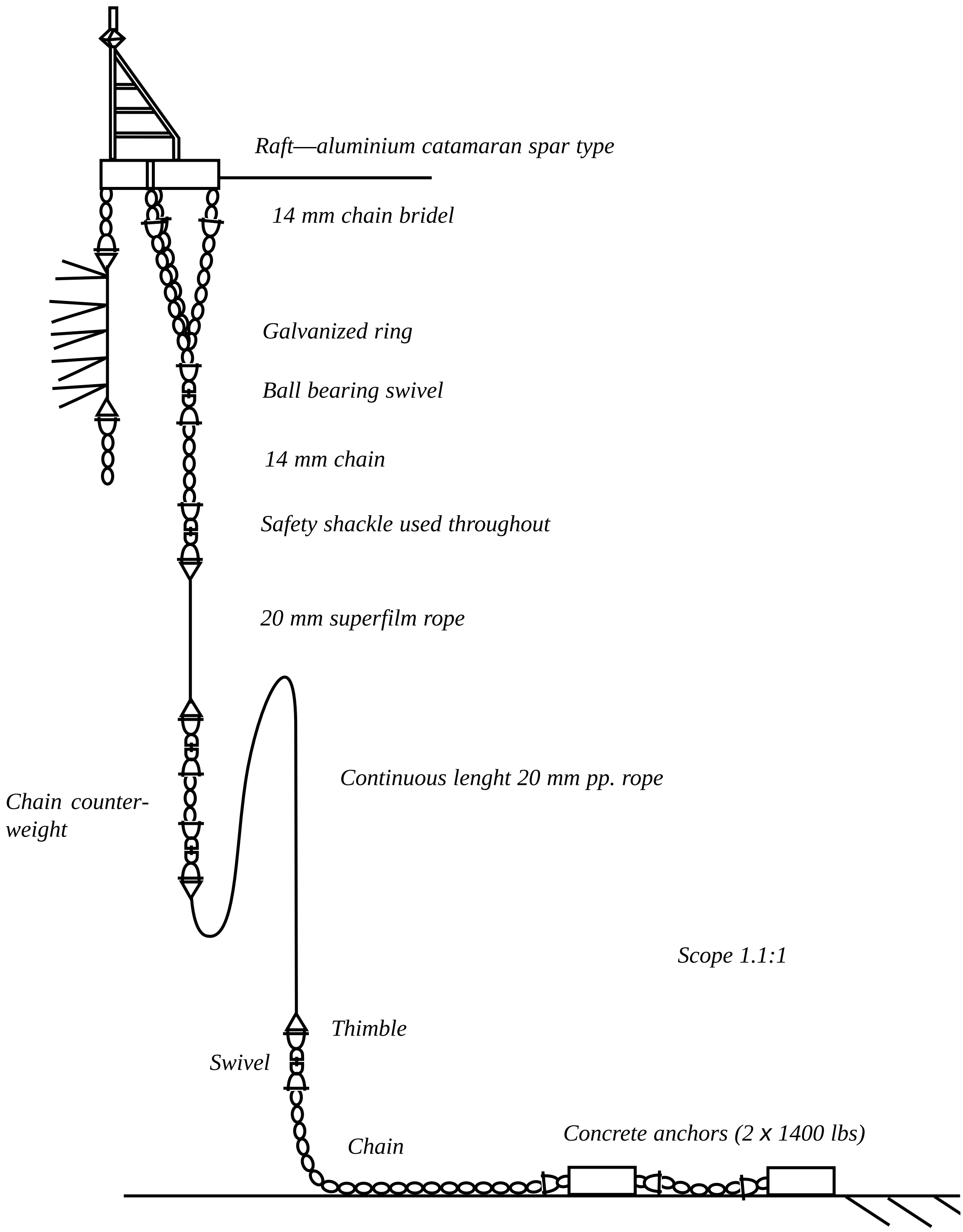


Figure 2: Latest FAD design—Cook Islands.

III. Deployment

Use buoy first method—from government vessel. Echosounder used to select suitable site.

IV. Maintenance

Following the loss of a second generation FAD after 9 months and evidence of severe corrosion as the major cause, a regular maintenance programme was initiated, with all accessible elements (raft, chain and hardware components, top section of the rope) visually inspected and refurbished where necessary every four months, and a more vigorous inspection before the onset of the cyclone season. This regular maintenance has enabled at least two potential breakaways to be identified and the faults remedied, greatly extending the average effective life of the devices.

Summary of results

No. deployed	6	Depths 600—800 fathoms
No. lost	4	Av. life span 16+ months
No. recovered	2	Cost/unit US$2500—3000
No. planned	12+	

Known or probable causes of failure

Hardware failure	1	Shackle failure—caused by accelerated corrosion between SS ring and steel shackle
Raft failure	1	3 drum design—sank after developing leak
General mooring failure	2 2	Both lost during calm weather—suspected hardware failure

C. FIJI

There have been more FADs deployed in Fiji than anywhere else in the region, with over 200 anchored over the 21-month period, June 1981 to March 1983, most within 10 miles of the reef edge. The majority (more than 170) were deployed by commercial fishing interests to service the industrial tuna fishing fleet, both purse seine and pole and line, while a smaller number (8) were deployed by the Fisheries Division for use by artisanal fishermen. Preston (1982) documents the Fijian experience with FADs in considerable detail, and provides a critique of the designs in use at that time, together with many useful suggestions for changes in design, fabrication and deployment practices. The attrition rates for all four designs in current or recent use have been high, further compounded by cyclone activity which caused the almost total loss of existing FADs both in 1982 and 1983.

Current FAD designs

Existing designs are discussed in detail by Preston (1982) and treatment here will be limited.

I. FADs deployed for purse seine fleet (Fig. 3)

This design was developed and deployed as a low-cost limited effective life unit for use in what has been to date at least a seasonal purse seine fishery. It features a bamboo raft styled after the original Philippine payao, with an intermediate styrofoam float to facilitate disconnection of the raft during purse seining operations. The loss rate has been severe with a high proportion lost within 3 months of deployment. Scope 1.25: 1.

Summary of results

No. deployed	150+	Depths 1600 m approx.
No. lost	150+	Av. effective life 7—9 months
No. planned	100	Cost/unit US$700

Very little detailed information is available on causes of failure as the FADs were considered expendable and little effort was directed towards the retrieval of breakaway rafts. Most losses reportedly occur in the second third, and fourth month after deployment; the lack of a top chain pennant and line chafe on the intermediate weight is suggested as the most likely design faults contributing to such early losses (Preston 1982).

II. FADs deployed for pole and line fleet (Fig. 4)

Two designs were employed, but only the more successful IKA design is discussed here. Scope large 1.5:1.

Figure 3: FAD designs deployed for industrial tuna fishing fleets in Fiji—purse seiner

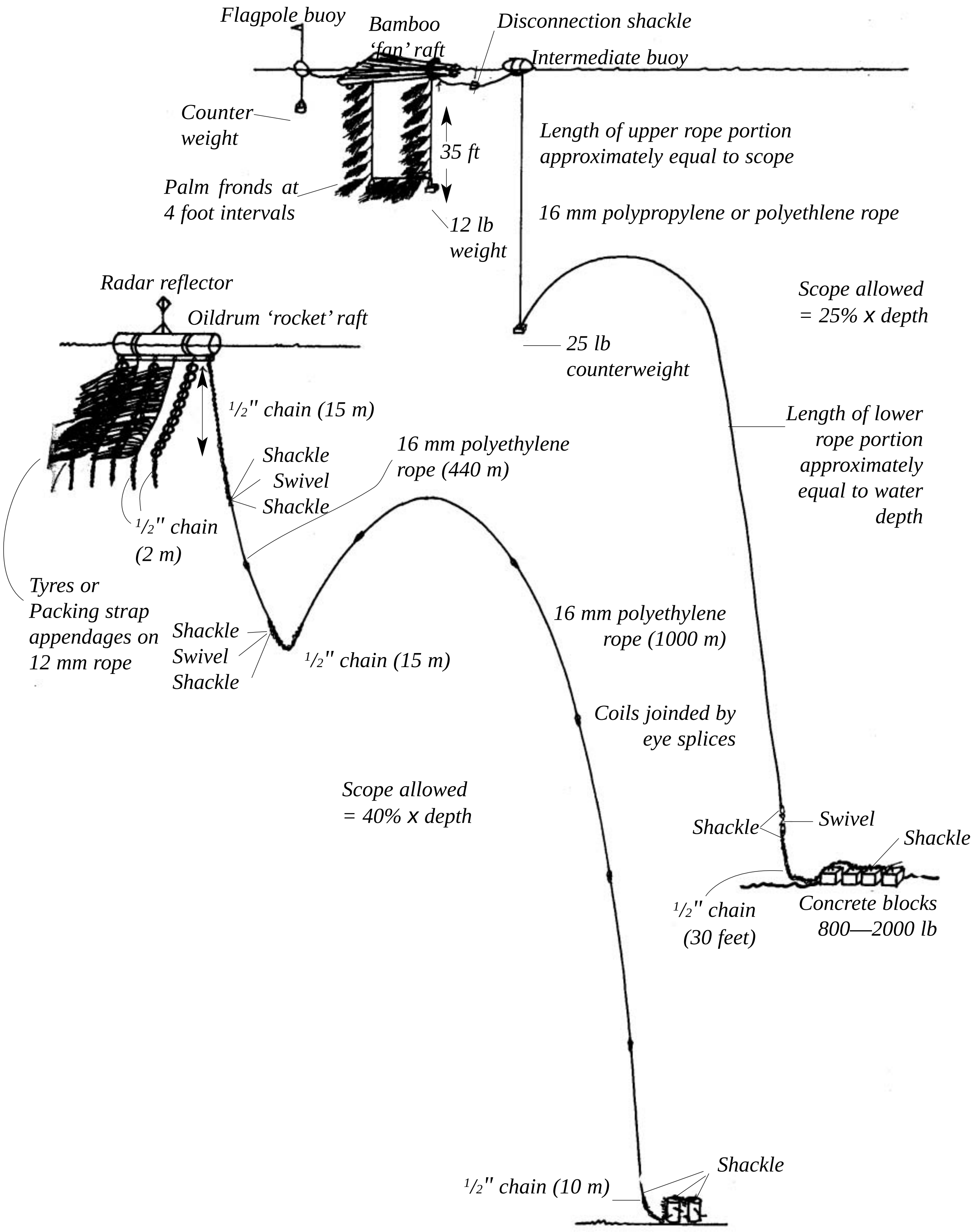


Figure 4: FAD designs deployed for industrial tuna fishing fleets in Fiji—pole-and-line

Summary of results

No. deployed 20+	Depths 1600 m
No. lost 17+	Av. life expectancy 9—12 months
No. planned 75	Av. cost/unit US$1400

Loss rates have been high, with most lasting less than 9 months. Comparatively few breakaway FADs have been recovered "intact" with most washed over the reef or vandalised before retrieval. Of the seven rafts recovered in reasonable or untempered condition, most had 100 to 200 m of trailing rope attached. One case of fish bite has been confirmed by laboratory analysis. During cyclone Oscar (February 1983) 17 out of 20 remaining FADs were lost.

The use of polyethylene rope in the mooring line would be one of the major contributing factors ta premature lasses with this design. Polyethylene is not suitable for use in marine mooring applications as it has comparatively poor energy-absorbing characteristics and performs badly under repeated loading situations.

III. FADs for use in artisanal fisheries (Fig. 5)

A slack buoyant line/chain counterweight design similar to that used in other countries. Features include a long top pennant (50 m), an oversize counterweight (20 m of 12 mm chain), chain swivels used at bath ends of the top chain and anchor pennant, and at the point of insertion of the chain counterweight. A multiple clump anchor system is used comprising either concrete-filled ail drums (2 and up to 4) or small concrete blocks (8 to 10, each weighing 200 lb).

IV. Aggregator

Raft: a number of raft designs have been tried—NMFS 3 ail drum type aluminium catamaran (Western Samoan design), and more recently the tyre buoy.

Appendage: chain-weighted lengths of polypropylene rope threaded with plastic strapping material.

V. Deployment techniques

FAD sites were selected using marine charts, and confirmed by echo-sounder before deployment. Most of the echosounders used were not effective beyond 1600 m and this limited planned deployments at greater depths. The majority of FADs were deployed "anchor first", with the necessary slack rope added to the mooring line after the anchor had bedded. The line was tensioned, the required scope measured out, and the raft and top components attached. One company preferred to prefabricate the mooring line and aggregator for the specific depth range anticipated at the selected site with sufficient scope added to the mooring line (usually greater than 1.5: 1) to allow for considerable depth error.

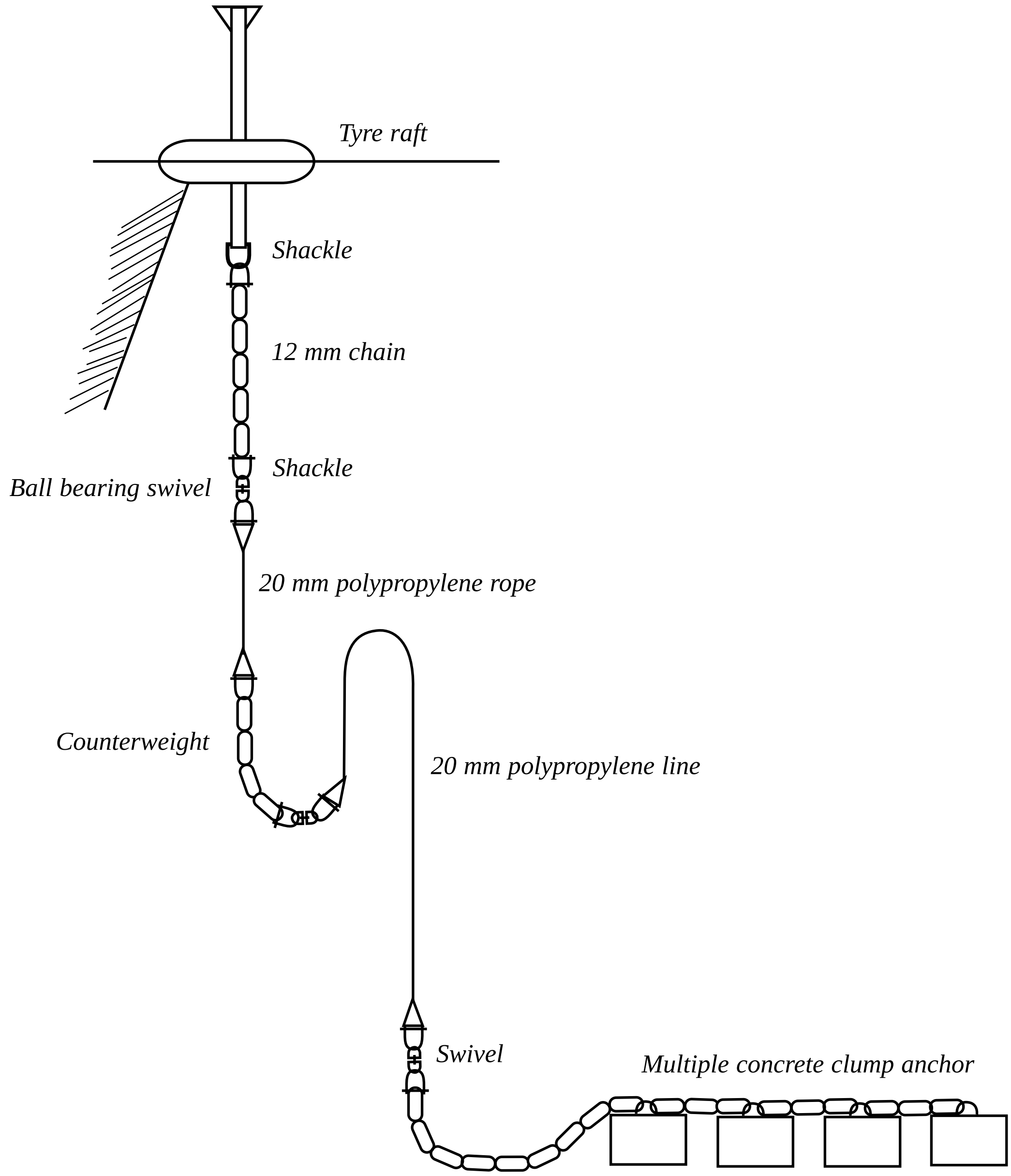


Figure 5: FAD design deployed for use by artisanal fishermen—Fiji.

Summary of results

No. deployed	8	Depths1000—1600 m
No. lost	4	Av. effective life 9—12 months ?
No. planned	20	Cost/Unit US$2300

No details available on causes of failure with this design

D. FRENCH POLYNESIA (Fig. 6)

The programme was initiated by E.V.A.A.M. (previously Service de la Pêche) in June 1981 with the deployment of an experimental FAD off Tahiti. The prototype raft, a steel, foam-filled rectangular pontoon, proved unsuitable and was replaced in later designs by a steel, disc-shaped raft. Ten second generation FADs have since been deployed for use by local fishing fleets. Loss rate has been high, accentuated by recent cyclone activity, with three of five remaining FADs lost during cyclone "Veena".

Current FAD designs

1. Mooring line

Mainline formed of coils of 22 mm polypropylene shackled together with all eyesplices protected by galvanised wire rope thimbles. Swivels are inserted at both ends of top chain and anchor pennant, with the primary or larger swivel linking the top chain to the rope. A second "safety" chain links discus raft to the primary swivel. A counterweight is attached at 600 m (after third coil). Scope large 1.7:1 to 2.0:1. Anchor: concrete block weighing 1300 kg. Weight decreased for shallow moorings.

II. Aggregator

Raft: use a steel, disc-shaped buoy fabricated locally from tank end caps, and filled with a 30-kg ballast pipe. An expensive solar-powered flashing light system is mounted on a welded panel, with the light 2.5 m above sea level. A number of fibreglass raft designs are now under consideration.

Appendage: use a sheet of braided nylon netting.

III. Deployment

FADs deployed using "buoy first" method with sites identified from marine charts and surveyed by echosounder before deployment—1000 m the preferred depth.

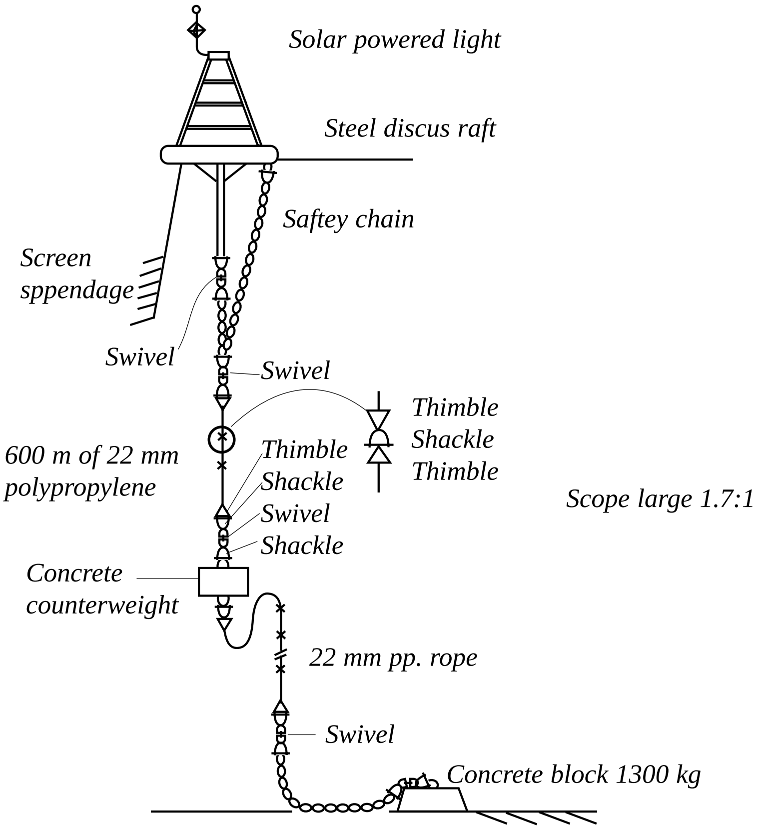


Figure 6: Latest FAD design—French Polynesia.

Summary of results

No. deployed 11 No. lost 8 No. recovered 5 No. planned 17	Depths 830–1270 m Av. Life 7 months Cost/unit US$5500

Known or probable causes of failure

Hardware failure 3	Counterweight (1) Iran connection ring (2)
Typhoon 3	2 recovered buoys indicated hardware failure, swivel (1) iron ring (1)
Poor site l	Slipped into deep water
Vandalism l	

E. HAWAII

A recently published report by the Division of Aquatic Resources, Department of Land and Natural Resources, entitled Hawaiian fish aggregation buoys provides an excellent summary of the history, as well as progress and problems associated with the development of our FAD design suitable for Hawaiian conditions and requirements. A figure from this report depicts the three designs used by the State of Hawaii, with the most recent, a single sphere raft design deployed with a reverse catenary nylon polypropylene composite mooring line. This mooring system is very similar to that recomment in this report and merely requires "fine tuning" to satisfy design objectives fully (See Fig. 7).

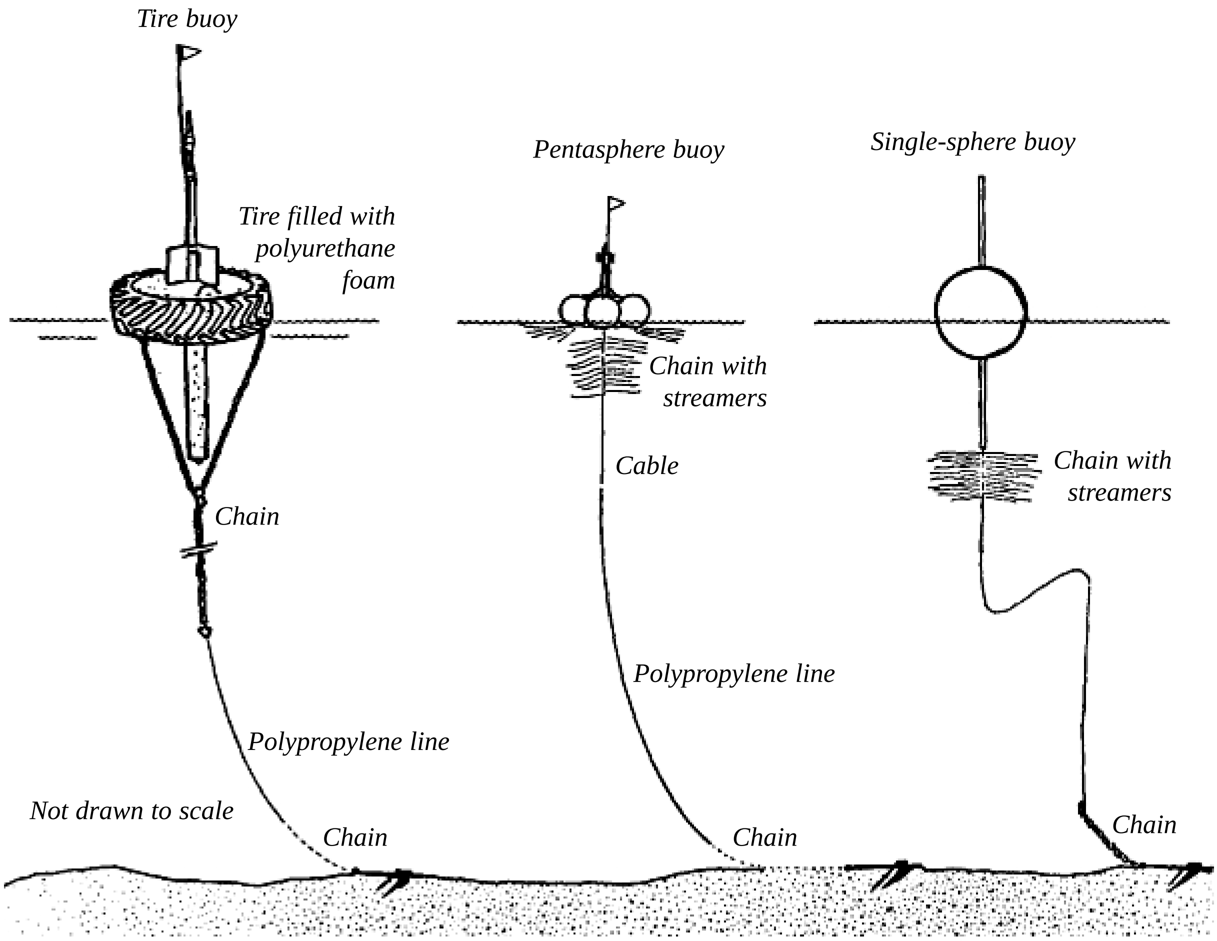


Figure 7: FAD designs used in State of Hawaii

F. VANUATU

Two FADs were deployed off Efate in June/July 1982 in comparatively shallow water (500—700 m), and 3 to 7 miles from land respectively. A third device was anchored in 780 m in March 1983. There have been no failures to date. The devices have proven productive, and further deployments are planned to assist village fishermen in other islands of the group.

Current FAD designs (Fig.8)

1. Mooring line

FAD design similar to that used in Cook Islands: 20 mm "superfilm" mainline, chain counter-weight, ball-bearing swivel, 14 mm chain top and anchor pennants. Anchor: use multiple surplus steel clumps.

II. Aggregator

Raft: two designs used—a plywood, foam-filled catamaran (2.5 m x 1.9 m), with three part chain bridle, for first two deployments, and a rectangular, foam-filled plywood raft with single attachment point for the latest FAD.

Appendage: a "christmas tree" drape of longline rope woven into large mesh cargo type netting threaded with lengths of plastic strapping material and weighted with chain.

III. Deployment

"Buoy first" method. Echosounder used to select drop zone.

Summary of results

No. deployed	3	Depths 500—700 m
No. lost	0	Av. life expectancy 9+ months
No. planned	N/A	Cost/unit US$3500

The deployment area features complex, comparatively strong currents which contribute to turbulent sea conditions in rough weather. The only serious problems encountered to date have been the loss of the appendage (2 occasions) and intermittant tangling of the appendage with the mooring top chain.

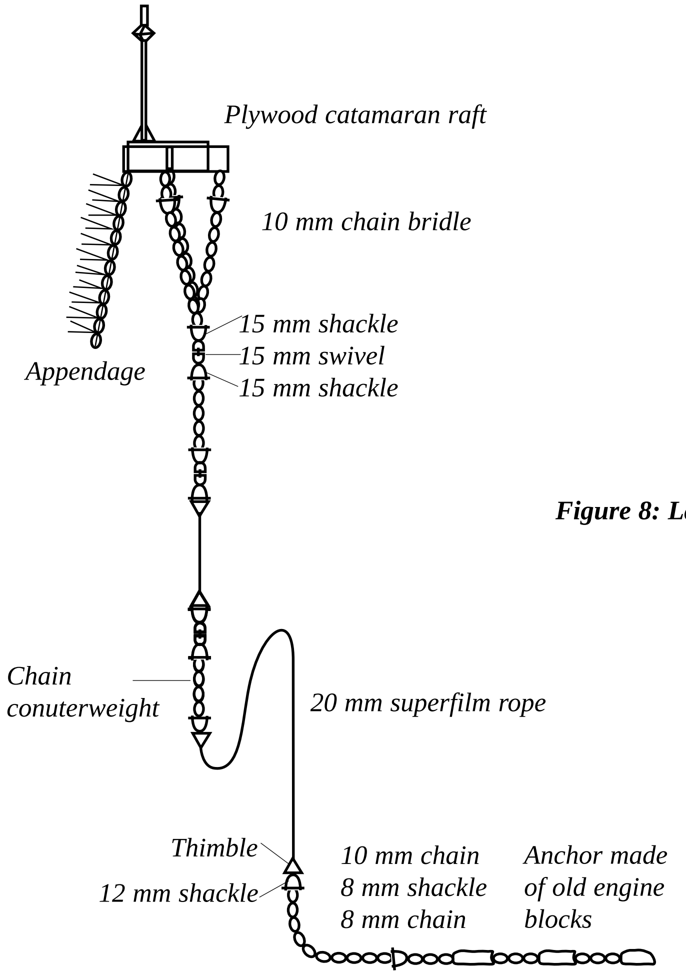


Figure 8: Latest FAD design—Vanuatu

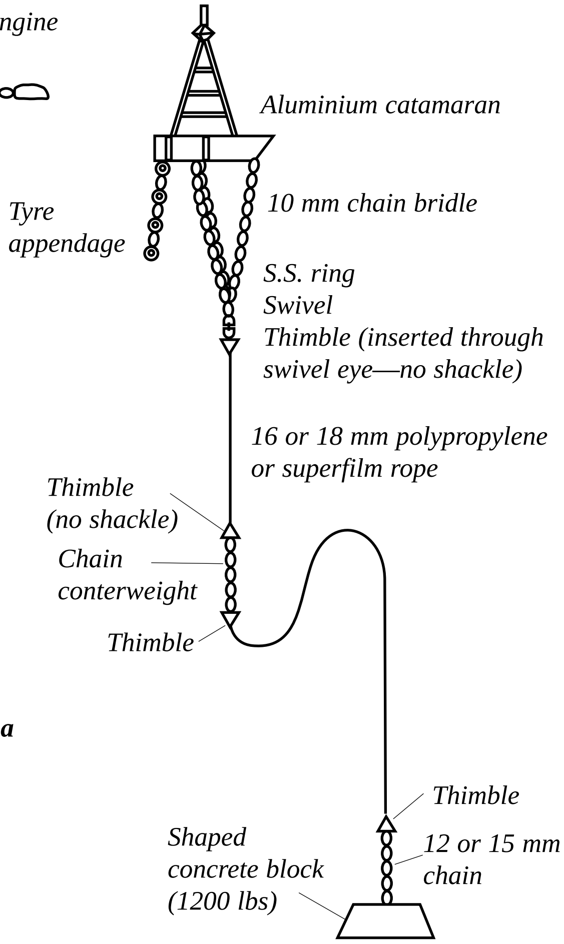


Figure9: Latest FAD design—Western Samoa

G. WESTERN SAMOA

Initiated in September 1979, the Western Samoan FAD programme lias been one of the more successful in the region, resulting in a dramatic increase in fish landings from local fishermen. A total of 37 FADs have been deployed, 15 of which are still in place. Two comprehensive experience papers by Philipp (1981, 1983) document design development and general experience with the deployment and utilisation of FADs in Western Samoa.

Comments on the current FAD designs (Fig. 9)

1. Mooring line

The original NMFS design used for first generation devices (1979) has been continuously modified and simplified to improve performance and to reduce the number of potential weak points. The present design includes a number of notable features:

1) No shackles—welded stainless steel ring links raft bridle and swivel, while rope is connected by opening the wire rope thimble, passing it through an outsize chain link or swivel eye, and splicing the rope in place.

2) No top chain pennant.

3) Bottom chain used primarily for chafe protection and held vertical in water column by buoyancy of rope.

4) *Anchor*: a single, reinforced concrete block is used, with the bottom chain (18.3 m (60 ft) of 12 mm chain) embedded in the block. The weight of the block was reduced from 1800 to1200 lb in recent deployments with satisfactory results.

II. Aggregator

Raft: a number of raft designs have been trialled, the most successful of which has been the aluminium catamaran design, which has proven stable and durable, with an excellent, readily visible dayshape, its only drawback being that it is relatively expensive to build.

Appendage: a number of different types have been used including half-tyres wired to a loop of chain, and weighted lengths of rope woven with strips of plastic strapping materials (dan band). The half-tyres are considered superior and will be used on all future moorings.

III. Deployment

Depths 1600—3000 m. Echosounder transects are used to identify a suitable anchoring site, and the device is deployed–“anchor first”. For a full description see Philipp (1983).

Summary of results

No.	deployed	37	Depths 1600—3000 m
No.	lost	22	Av. Lifespan 14—15 months
No.	recovered	13	Cost/unit US$3000 (approx.)
No.	planned	(replacement only)	

Known or probable causes of failure

Hardware failure	6	Majority (5) suspected failure of wire rope pennant in 1st generation FADs
Vandalism	3	
Fishbite	1	Suspected but not confirmed by expert analysis
General mooring failure	11	Rafting up to FAD at night by small fishing boats overstressing mooring line
Whale	1	

FADs which are regularly used by the fishing fleet to tie up at night have a greatly reduced life expectancy (average12 months) compared to those deployed in less accessible areas (18—20 months) (A. Philipp personal communication).

A CRITIQUE OF THE MORE EFFECTIVE RAFT DESIGNS IN CURRENT USE IN THE CENTRAL AND WESTERN PACIFIC

General comments on some of the more commonly used raft designs, which have given satisfactory service, and which were examined during the present study, are presented together with suggested modifications which should improve their overall effectiveness.

1. CATAMARAN TYPE

General comments:

- Directional
- Low current drag if wind in same direction
- High wind drag due to dayshape
- Good reserve buoyancy
- On an equal weight basis, a catamaran is more stable than a boat/barge shaped hull
- Moderate cost.

(i) Western Samoan Aluminium Design (Fig. 1)

a well-proven design, also used successfully in Fiji, Niue, Cook Islands.

Suggested modifications:

– Weld aluminium padeyes to hull for mooring attachment

– Avoid dissimilar metal contacts below waterline

– Use only marine grade aluminium (US 5000 series) for pontoons and bracing

– Cheaper aluminium (US 6000 series) can be used for mast

– Compartmentise pontoons for reserve buoyancy.

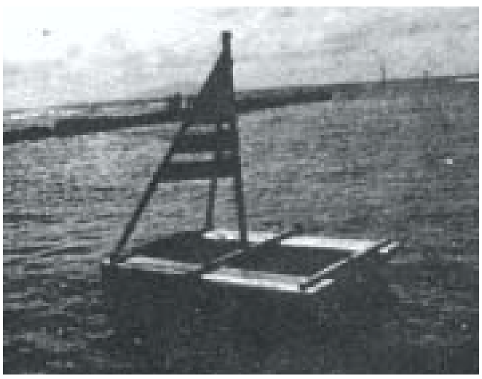


Figure 1: Aluminium catamaran design —Western Samoa

(ii) Vanuatu wooden catamaran design (Fig. 2)

foam-filled, fibreglass-sheathed plywood construction.

Suggested modifications:

– Pontoons should be longer and narrower for better stability and lower drag

– Provide better dayshape for increased visibility

– Securely anchor large padeyes for mooring attachment

– Provide more angular bow section to provide additional lift in strong currents.

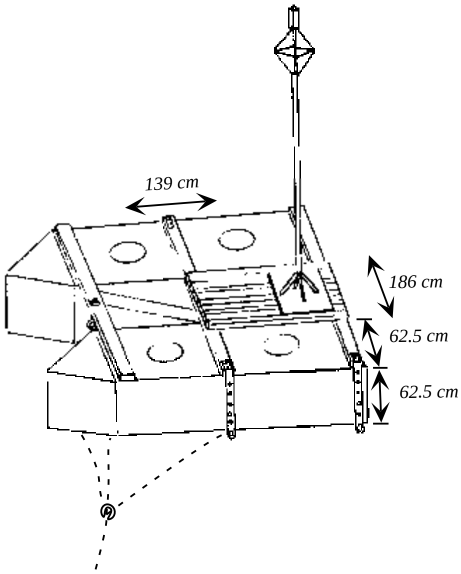


Figure 2: Wooden catamaran design—Vanuatu

2. HORIZONTAL SPAR TYPE

General comments:

- Directional
- Low current drag if bow is faired, low wind drag Good reserve buoyancy
- Low roll stability
- Low cost.

(i) Fiji (IKA) drum design (Figs. 3, 4)

three 200-litre oil drums, welded together end to end, foam-filled, and encased in a metal frame which provides attachment points for the mooring line and appendages.

Suggested modifications:

– Add mooring bar, pinned to rotate fore and aft only, to increase roll stability

– Prime steel drums to extend life

– Provide better dayshape

– Try plastic drums in an aluminium frame for cost/maintenance reduction.

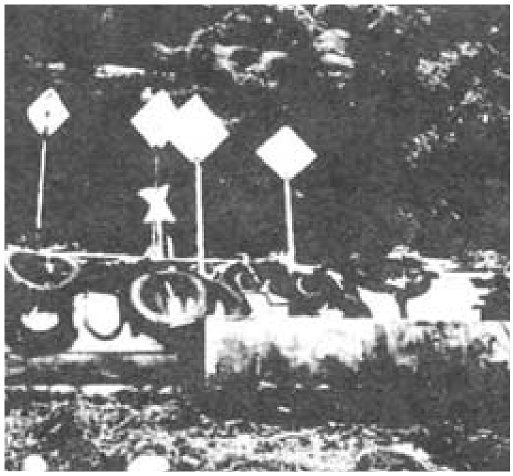


Figure 3: IKA oil drum raft

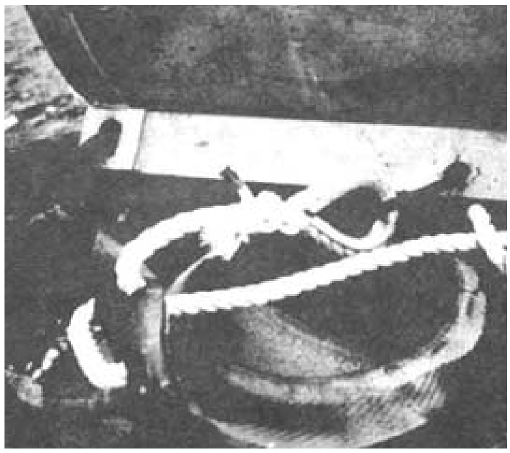


Figure 4: IKA oil drum raft—attachment points

3. TYRE BUOY

General comments:

- Non-directional (free to spin)
- High current drag/low wind drag
- Low reserve buoyancy
- Fair stability
- Low cost.

(i) Hawaiian Buoy (Fig. 5)

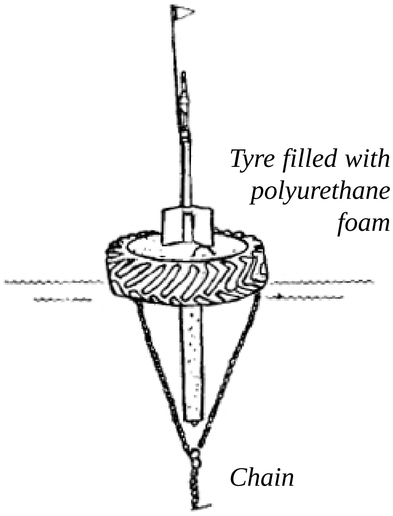


Figure 5: Early Hawaiian tyre buoy design.

Suggested modifications:

– Attach mooring to counterweight to increase stability; incorporate gusset to provide additional support of counterweight arm.

(ii) Fijian Buoy (Fig. 6)

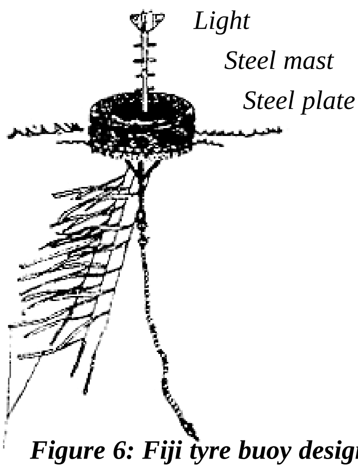


Figure 6: Fiji tyre buoy design

Suggested modifications:

– Provide larger dayshape.

4. TOROID OR DOUGHNUT BUOY

General comments:

- Non-directional (free to spin)
- High drag
- Moderate reserve buoyancy
- Good stability with rigid bridle
- Inexpensive to build.

(i) American Samoan Buoy (Fig. 7)

fibreglass construction with metal frame, chain bridle.

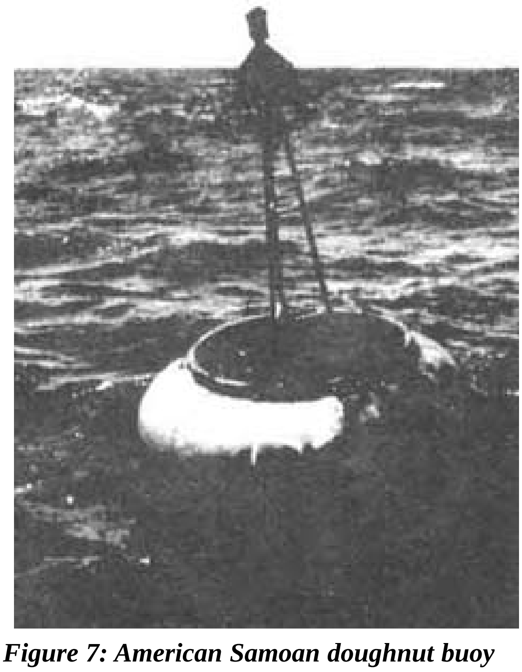


Figure 7: American Samoan doughnut buoy

Suggested modifications:

– Rigid bridle will increase stability.

5. ENCASED DRUM SPAR BUOY

General comments:

- Non-directional
- High current, moderate wind drag
- Low reserve buoyancy
- Fair stability
- Poor visibility
- Low cost.

(i) Cook Islands (Fig. 8)

200-litre plastic drum, foam filled, encased in woven rope “cargo net” with rope bridle.

Suggested modifications:

– Ensure cargo net is tight

– Strengthen mast mounting

– Investigate large or multiple drums.

Figure 8: Cook Islands prototype spar buoy

(ii) Western Samoa (Fig. 9)

styrofoam floats, fibreglass sheathed, encased in aluminium frame.

Suggested modifications:

– Weld padeye for single-point mooring attachment

– Provide puncture-resistant grating

– Provide short mast with radar reflector

– Seal square tubing for added buoyancy

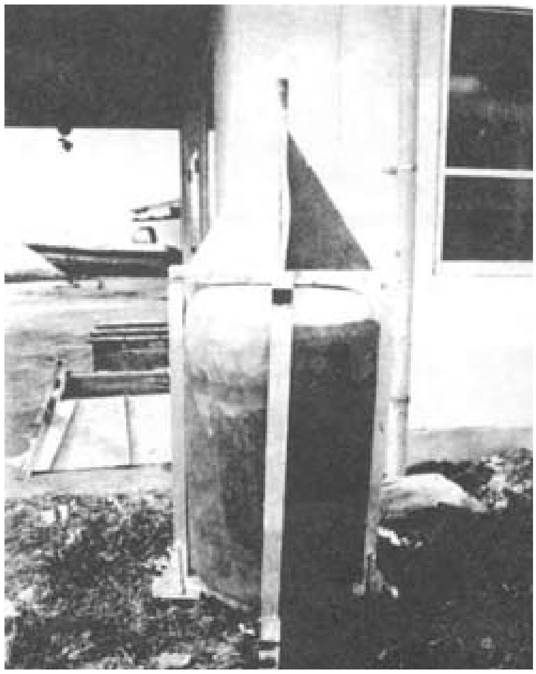


Figure 9: Western Samoan aluminium spar design

6. SPHERE

General comments:

- Non-directional
- Low drag
- Moderate reserve buoyancy
- Fair stability
- Low cost.

(i) Hawaii (Fig. 10)

constructed from large, 58 inch diameter, navy surplus steel buoys with welded counterweight and light mast.

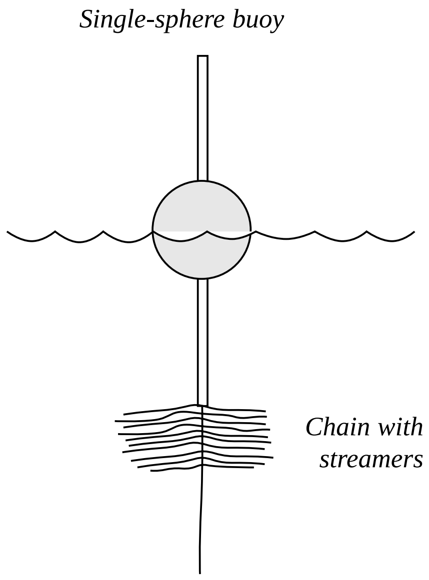


Figure 10: Hawaiian single sphere spar buoy

7. DISCUS BODY

General comments:

- Non-directional
- Moderate drag
- Good reserve buoyancy
- Good stability
- High cost.

(i) French Polynesian Buoy (Fig. 11)

welded steel construction with tripod arrangement for solar-powered light

Suggested modifications:

– Foam or compartmentalise buoy hull for survivability

– Decrease length of mooring arm, increase gusset size or go to tripod arrangement

– Prime metal and use anti-fouling paint scheme for longer hull life

– Investigate more reliable/less costly lights.

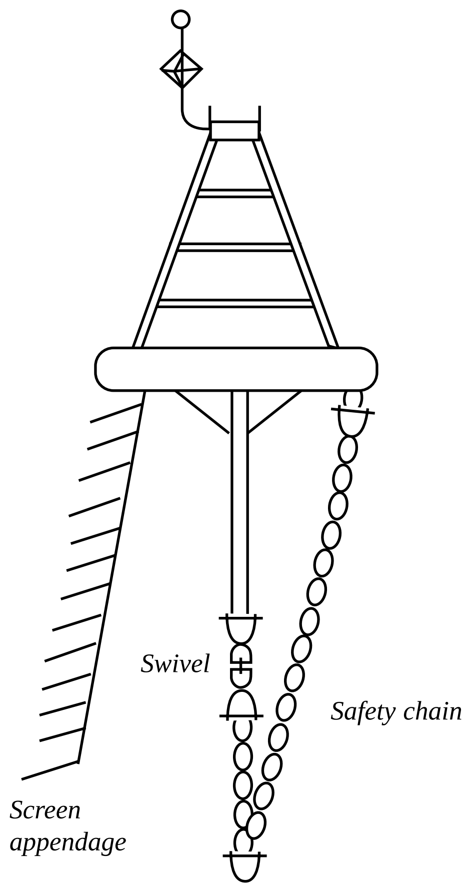


Figure 11: French Polynesian steel discus raft

APPENDIX III

ILLUSTRATED GUIDE TO RECOMMENDED SPLICING TECHNIQUES FOR ROPES USED IN MARINE MOORINGS

(1) 3-STRAND CONSTRUCTION

- eye splice
- end for end splice (short splice)

(2) 8-STRAND CONSTRUCTION

- eye splice
- end for end splice

(3) 12-STRAND CONSTRUCTION

- eye splice (tuck splice)
- end for end splice

Wall Rope Works
New Bedford Cordage
Yale Cordage

Splicing a-Strand rope

The length of a rope can limit its use -but by splicing two or more lengths of rope together to make one con-tinuous length, we can greatly increase its usefulness.

Most of us think of rope splicing as an activity on ships and in shipyards. Actually, rope splicing is a common every-day occurrence in ail trades from amateur sailors to professional riggers. The ability to make a good splice can serve us well in an unforeseen emergency.

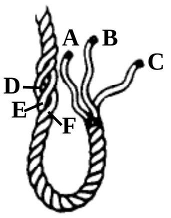
The most commonly used rope splices are illustrated below.

NOTE: Short splices in synthetic ropes should be given an additional full tuck (Allow 25% more length than with nat-ural fiber ropes). When unlaying the strands of synthetic ropes, tape each strand end to prevent untwisting. After the splice has been made, cut thru the tape ends and seal with heat (use flame, hot knife or iron). When unlaying the strands of Nylon or Polyester ropes of sizes 4" or larger, tape each strand every 6 inches to preserve the twist. This is done because the material is soft and tends to lose its formation

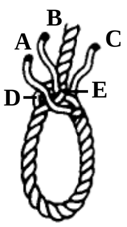
THE EYE SPLICE

The Eye Splice is also called the Side Splice because it is used to form an eye or loop in the end of a rope by splicing the end back into its own side. This splice is made like the Short Splice except that only one rope is used.

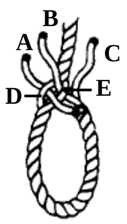
STEP 1—Start by seizing the working end of the rope. Unlay 3 strands (A, B & C) to the seizing and whip the end of each strand. Then twist the rope slightly to open up Strands D, E, and F of the stand-ing part of the rope.



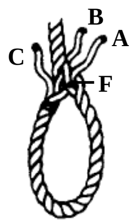
STEP 2—Make the first tuck. The mid-dle strand is always tucked first, so Strand B is tucked under Strand E, the middle strand of the standing part of the rope.



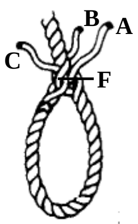
STEP 3—Make the second tuck. Left Strand A of the working end is tucked under Strand D, passing over Strand E.



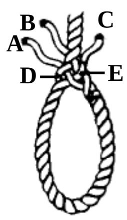
STEP 4—Make the third tuck. In order to make Strand F easy to get at, the rope should be turned over. Strand C now appears on the left side.



STEP 5—Strand C is then passed to the right of and tucked under Strand F This (completes the first round of tucks



STEP 6—Reverse the rope again for easier handling and begin the second round of A tucks. Strand B is passed D over Strand D and tucked under the next strand to the left. Continue with Strands A & C, tucking over one strand and then under one to the left. To complete the splice, tuck each strand once more.

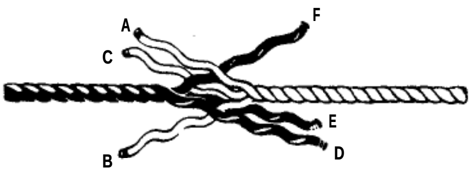


STEP 7—Remove the temporary seiz-ing and cut off the strand ends, leaving at least 1/2" on each end. Roll the splice back and forth under your foot to even up and smooth out the strands. The com-pleted Splice is shown in Figure 18.

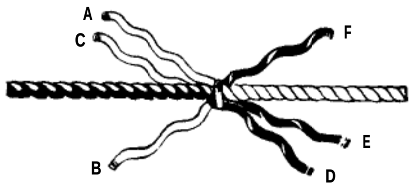
THE SHORT SPLICE

The Short Splice is used when it is not necessary for the spliced rope to pass through a pulley block, since the diameter of the rope will be almost doubled at the point of joining. This splice provides maximum strength since it is nearly as strong as the rope

STEP 1—Unlay the strands at one end of each rope for 6 to 8 turns. The ends of the strands should be whipped or taped to prevent their untwisting and brought together 50 that each strand on one rope alternates with a strand of the other rope

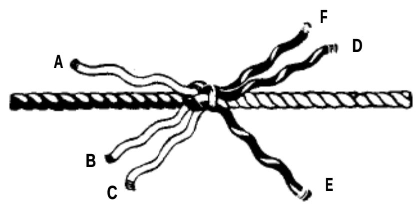


STEP 2—Bring the ends tightly together and apply a temporary seizing where they join



STEP 3—Take any one strand and begin tucking, the sequence being over one and under one Strand A is passed over the strand nearest it (Strand D) and then under the next strand (Strand E).

STEP 4—Rotate the splice away from you 1/3 of a turn and make the second tuck Strand B is passed over Strand E and then under Strand F.



STEP 5—Before making the third tuck, rotate the splice again 1/3 of a turn away from you. Strand C is then passed over Strand F and under the next one (Strand D).

STEP 6—This completes the first round of tucks in the left hand hall of the splice Each strand should now be tucked at least twice more, always over one and under one as before, making sure that each strand lies snug and with no kinks

STEP 7—To finish the splice, reverse the rope end for end 50 that Strands D, E, and F are now at the left instead of the right and repeat the tucking operation on their side of the rope. Each of the six strands will now have had at least three tucks A tapered splice is made by taking two or more tucks with each strand, cutting away some of the threads from each strand before each extra tuck.

STEP 8—When the tucking is finished, remove the center seizing and cut off the ends of ail strands, leaving at least 3/4" on each end. To give a smooth appearance, roll the splice back and forth, either under your loot or between two boards. The com-pleted splice should look something like Figure 6.

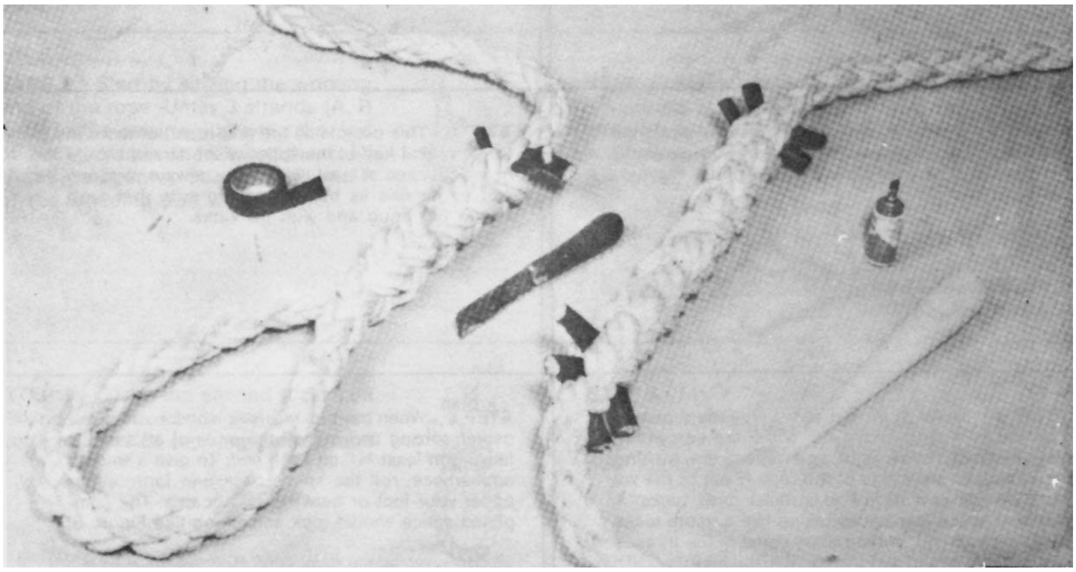
WaLL
Wall Industries, Inc.
P.O. Box 560, Elkin, NC 28621
(919) 835-6888

Bulletin: 8B–103

NEW SIMPLIFIED splicing instructions for eye splice & end-to-end splice

Super 8 - Strand

(the torque-free plaited rope)



Wall

Wall Rope Works
New Bedford Cordage
Yale Cordage

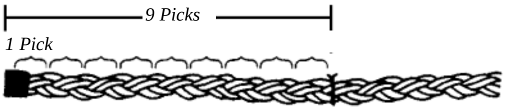
TOOLS OR ACCESSORIES

- Splicing Fid
- Plastic or Masking Tape
- Light Strong String
- Marking Pen or Colored Chalk
- Sharf knife

EYE SPLICE

1— STARTING

Lay rope out and count 9 picks or crowns from end of rope.



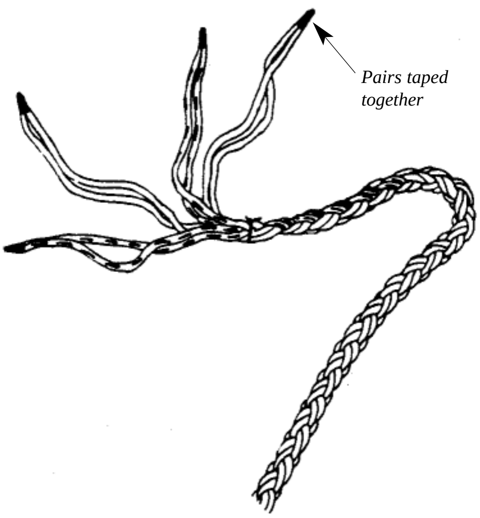
Tie string or tape securely at this point.

2 — MARKING

Holding the end of the rope, note the pair of strands going to the left. Mark these pairs. Mark the strands up to the string.

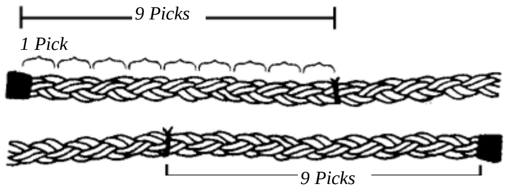
3 — SEPARATING & TAPING

Remove tape from end. Start unlaying strands in their respective pairs. Important to keep them together. After they are separated into pairs up to the string, untwist the pairs. Tape the ends of pairs together with a taper as shown.



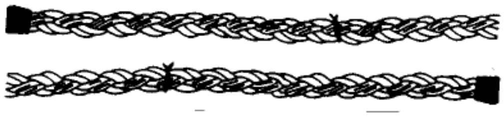
END-TO-END SPLICE

Lay ropes out and count 9 picks or crowns from end of bath ropes.



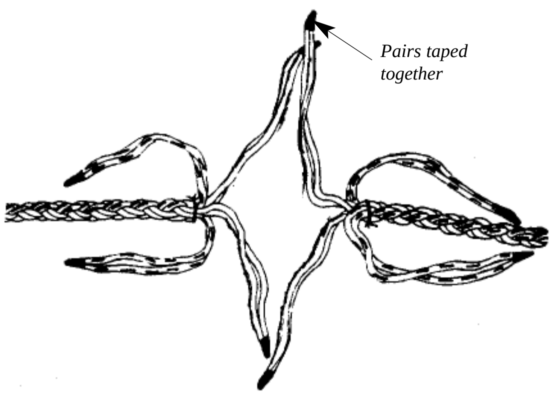
Tie string or tape securely at these points.

Same procedures as eyesplice except you will be doing it on two ropes, but you continue marking the strands for five (5) or more picks beyond the strings.



Same procedures as eyesplice except you will be doing it on bath ends.

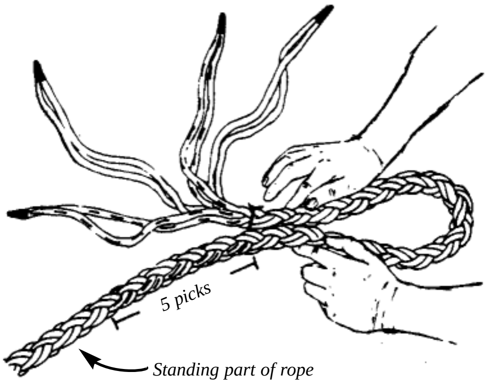
Layout ropes as shown.



End-to-End splice continued on back page.

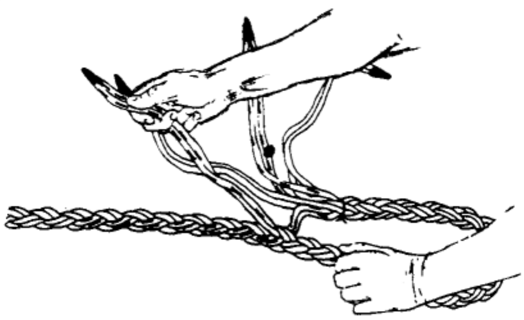
HERE'S WHERE THE PROCEDURE CHANGES FOR EYE SPLICE

4 –



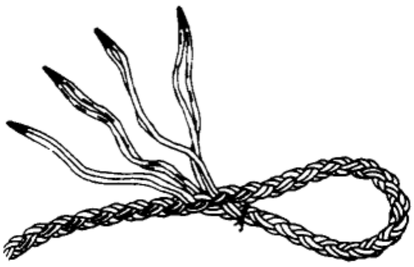
Determine how large an eye you want. Form eye as shown and mark the strands going to the left 5 or more picks on the standing part of the rope.

5 –



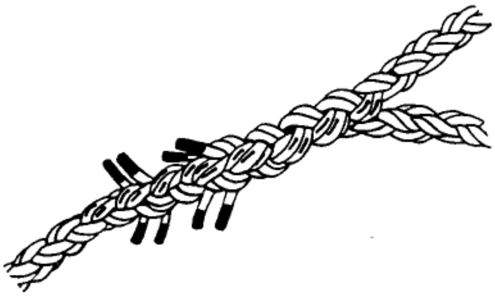
Take a marked pair and tuck them under an unmarked pair. Take the second pair of marked strands and tuck them under the next or successive unmarked pair.

6 –



Turn Splice Over. Tuck first unmarked pair under marked pair. Tuck second unmarked pair under successive marked pair. Pull all strands up snug. You have now completed one (1) full tuck. Turn Splice Over. Repeat steps. Be careful not to tuck twice under any pair.

7 –



Complete three (3) full tucks as in Steps 5 & 6. Next, the two (2) pairs of strands (one marked & one unmarked) protruding from the rope, closest to the eye, should each be tucked one (1) more time.

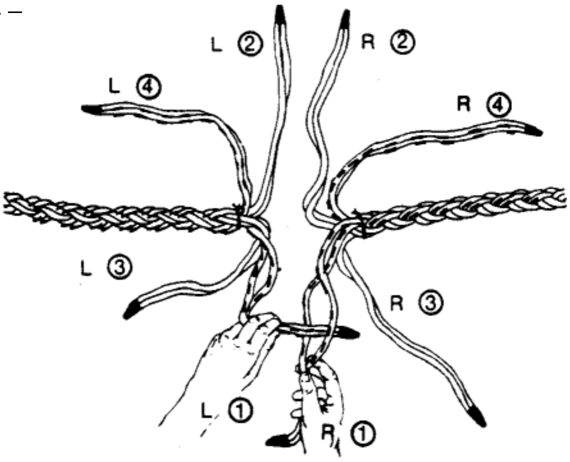
Cut one (1) strand from each pair two to three inches from the body of the rope.

Tuck all four (4) remaining strands two (2) more times and again cut off two to three inches from the body of the rope.

The splice is now complete.

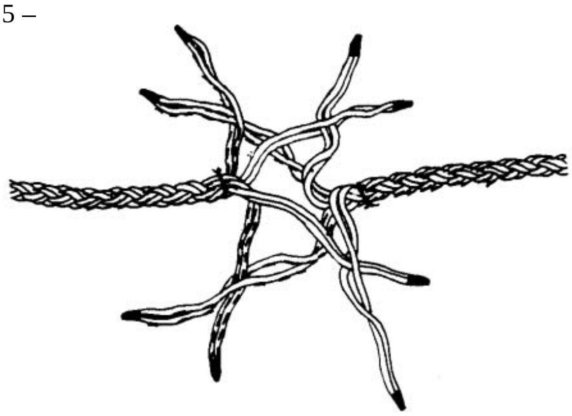
HERE'S WHERE THE PROCEDURE CHANGES FOR END-TO-END SPLICE

4 –



It is important that the next steps of the procedure be followed carefully.

5 –

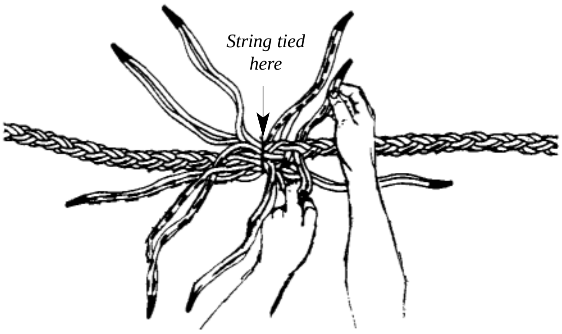


After the initial step has been completed, you should have something that looks like the above drawing.

Marry the ropes as shown in Step 6. This part is preferably a two-person job.

Cut the string that you previously tied at the splicing points of both ropes

6 –



Keep the ropes together snuggly. Tie a piece of string tightly around the splicing point as shown above.

Start your splice. A marked pair under an unmarked pair of strands. Now you can follow the same procedure as the eye splice. But we suggest that you complete one (1) full tuck in one direction and then do a full tuck on the other side of the marriage. Pull everything tight before proceeding.

7 – Complete splicing in both directions so that each side is finished off as per eye splice.

WALL ROPE WORKS NEW BEDFORD CORDAGE CO. *Divisions of Wall Industries, Inc.* P O. Box 560, Elkin, NC 28621 **(919) 835 – 6888**

3M–2/79

12-STRAND

Round Plait™ End-for-End Tuck Splice

Introduction:

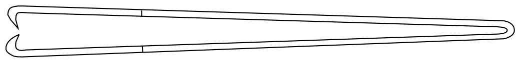
Samson Round Plait™ Polyester Rope is a new product re-quiring a splicing technique that is different from anything shown in any of our splicing manuals. This sheet illustrates a “tuck” splice that can be performed in the field on both new and used rope with a minimum of tools. Before you begin the splice you will need the following:

1. Tape: ordinary paper masking tape works well.
2. Wire fid: see chart for proper size fid.
3. Cutting tool: a knife or scissors to cut the strands.
4. Marking device: felt tip solvent marker works best.
5. Tape measure.

Note: Don’t pull the strands excessively tight and keep them twisted when making the tucks. This allows the tucked strands to elongate the same as the body of the rope, thereby preventing the tucked strands from being prema-turely overloaded.

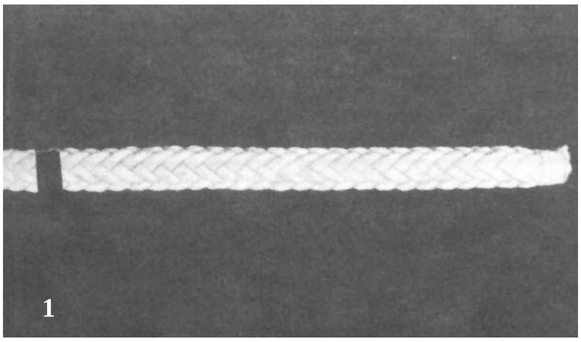
Fid Specifications:

A fid length is equal to 7 times the rope circumference. To complete the splice a Samson 2" Diameter Wire Fid may be used for most rope sizes. The dimensions of this lid are:



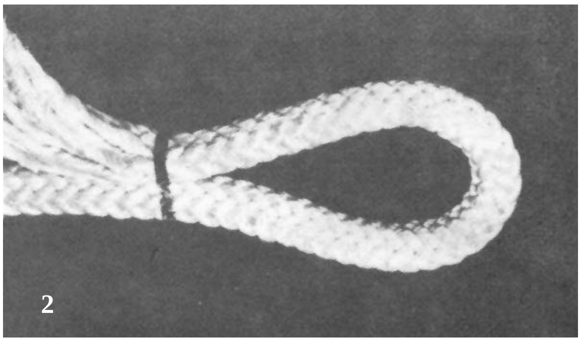
Fid length:	Wire Diameter:	Width:
21"(1/2 scale*)	1/4"	1 1/4"

See Red Book Splicing Manual for other fid lengths and dimensions, 1/2 scale is used to keep Wire fids to a practical length.



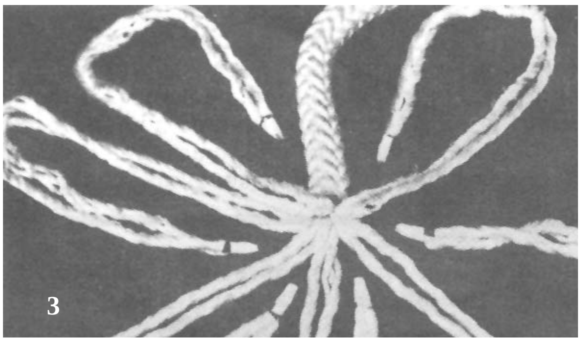
1

Lay-out and measure down from the end of the rope a length that is equal to 7 times the rope circumference. At this point put one loose wrap of tape around the rope.



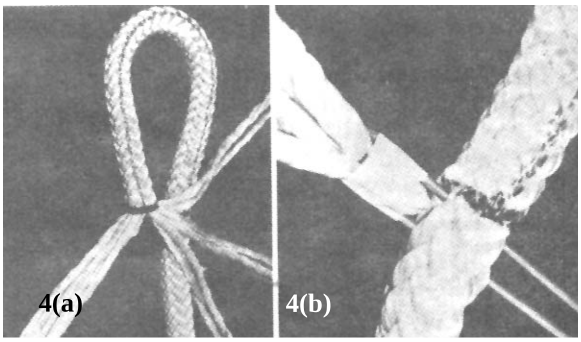
2

Tape each of the 12 strand ends at the end of the rope, Alter the ends are taped, unbraid the rope back to the tape wrapped around the rope Form the desired eye size using the tape wrapped around the rope as a reference mark. Mark the body 01 the rope at the point coinciding with the tape.



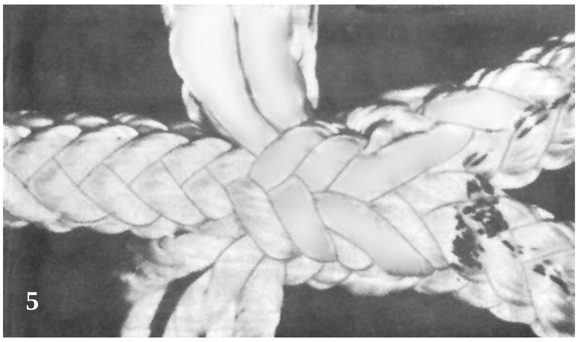
3

Combine the twelve individual strands into six pairs of two strands each. The strands that are paired up should be adja-cent to each other at the point where the unbraided rope meets the tape wrapped around the rope. Il done correctly there should be one “S” strand (rope has a clockwise twist) and one “Z” strand (rope is twisted counterclockwise) in each pair. Be-fore taping the two strands together twist each strand sepa-rately to maintain the twist of the fiber.

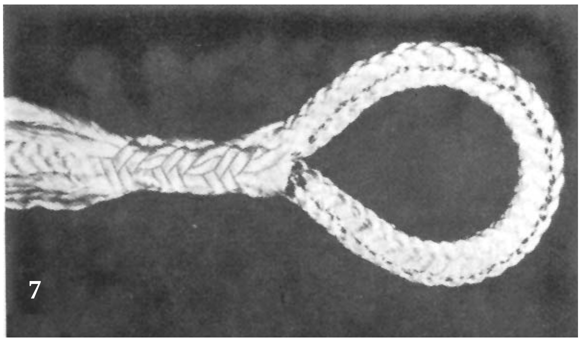


4(a) 4(b)

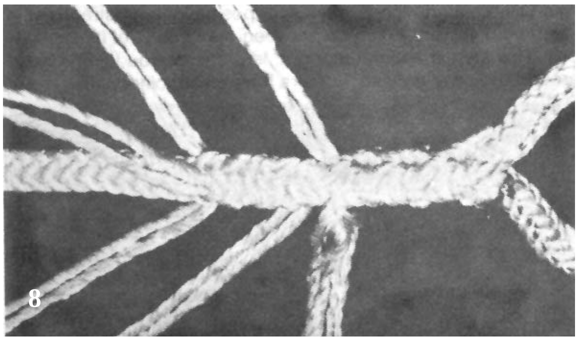
Lay-out the rope forming an eye making sure that there are no twists in the rope (4a). The black line that runs along the axis of the rope is there to illustrate how the pairs are sepa-rated for the splice. The three strand-pairs on one side of the line adja-cent to the standing part of the rope will be passed directly through the body 01 the rope Three of the strand pairs must be passed directly through the middle of the rope to the other side (4b)



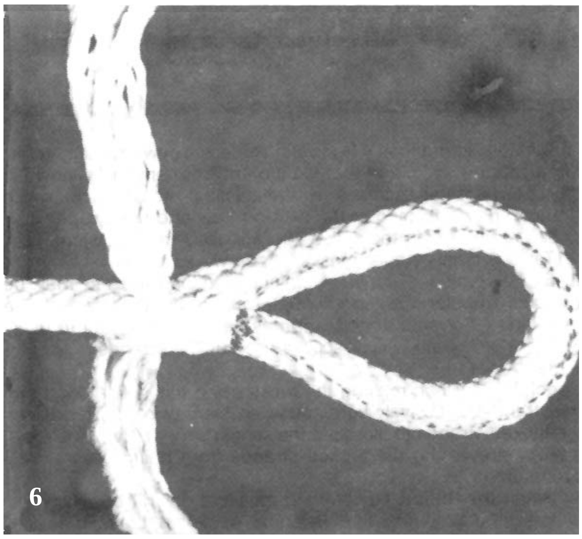
After the three pairs have been passed through the body of the rope you can start tucking the stand-pairs into the braid of the standing part. One complete tuck consists 01 passing a strand--pair under two individual strands in the braid and over one strand. Each strand-pair is always tucked under the same line of braid so that the tucks progress straight down the body of the rope.



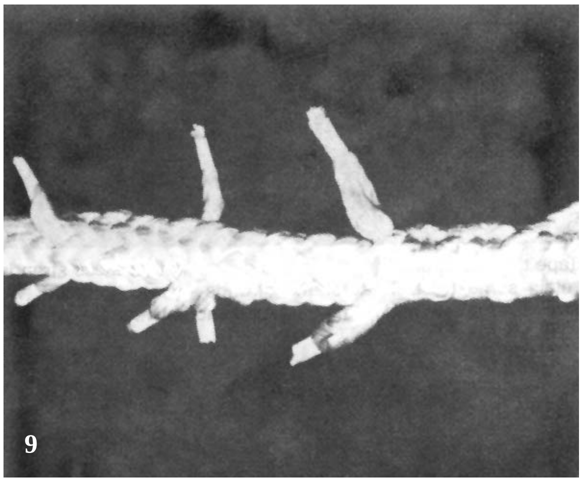
Do three complete tucks with ail six strand-pairs. Each strand pair is a1ways tucked under the same line of the braid so that the tucks progress straight down the body of the rope.



After completing the first three tucks drop every other strand pair and continue to do three more tucks with the remaining three pairs.



After one complete tuck has been made with each of the six strand pairs, pull on each pair to remove any slack from the strands and snug up the base of the eye. Note: When pulling on the strand pairs, do not attempt to pull them so tight that they become straight. It is desirable to leave the tucked strands with some twist in them so that they have the necessary elongation when the rope is placed under a load.



After completing the second set of three tucks untape the three strand pairs used to make these tucks. Drop one strand from each pair and do at least two more tucks with the remaining single strand of each pair. Once you have completed the last tucks, cut off the excess material and tape or whip the ends. Leave enough of an end protruding so that the end does not slip back into the rope when a load is placed on it.

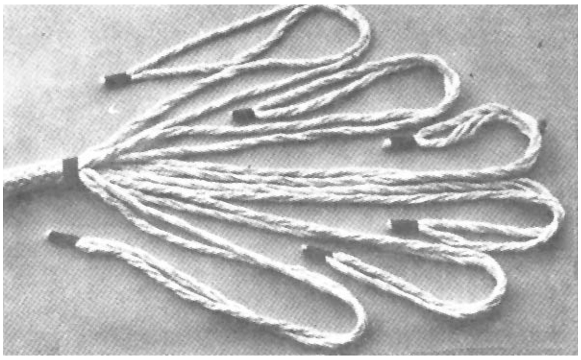
Samson Round Plait™ Polyester Rope is a new product requir-ing a splicing technique that is different from anything shown in any of our splicing manuals This sheet illustrates a "tuck" splice that can be performed, in the field on new and used rope.

Before you begin the splice you will need the following.

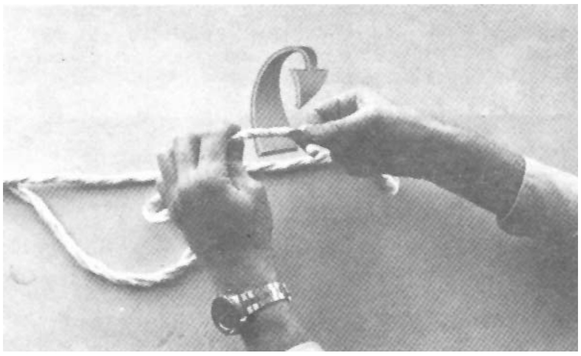
1. Tape ordinary paper masking tape works well.
2. Fid a Samson Tubular Aluminum Fid or Wire Fid may be used Tubular Fid size is determined by the size of the strands For smaller ropes it may be the easier tool to use.
3. Cutting tool a knife or scissors to cut the strands.
4. Tape measure.

Special Tip: When making the tucks using this splice don't pull the strands excessively tight and keep them twisted. This allows the tucked strands to elongate the same as the body of the rope, thereby preventing the tucked strands from being prematurely overloaded.

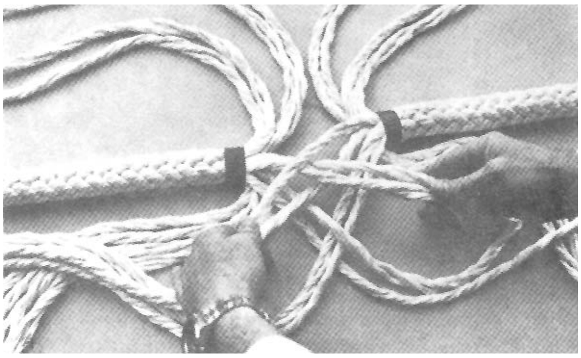
To Begin the Splice: Lay out and measure down from each end of the rope a length that is equal to seven times the rope circumference (21 times rope diameter). At this point put one loose wrap of tape around the rope (Point "A"). Tape each of the 12 strands at the end of the rope. After the ends are taped unbraid each rope back to Point "A".



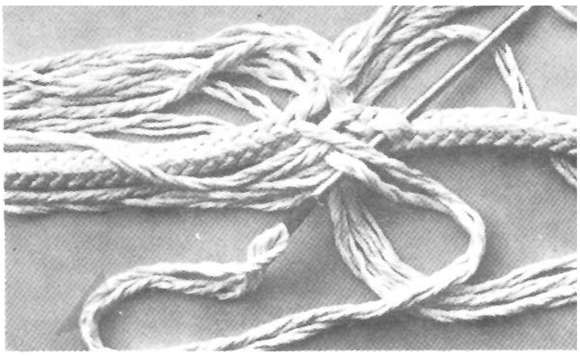
1. Combine the 12 individual strands into six pairs of two strands each. The strands that are paired up should be adjacent to each other at point "A". If done correctly there should be one "S" strand (clockwise twist), and one "Z" strand (counterclockwise twist) in each pair.



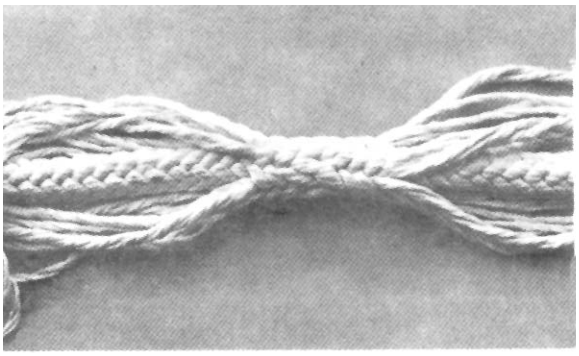
2. Tape the two strands together. It is desirable that these strands retain some twist To twist the strands merely hold the two strands as shown and rotate the taped end between the strands.



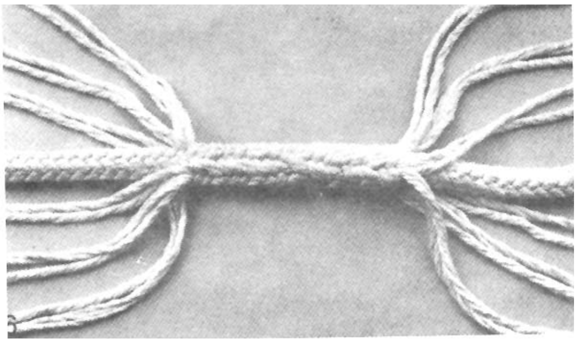
Join the two ropes together at point "A" and combine the pairs by starting at any one set of opposing set of strands and inserting one pair of strands between the strands of its opposite pair. This step is alternated, right, left, etc. as you join the pairs around the rope until all 12 pairs have been joined.



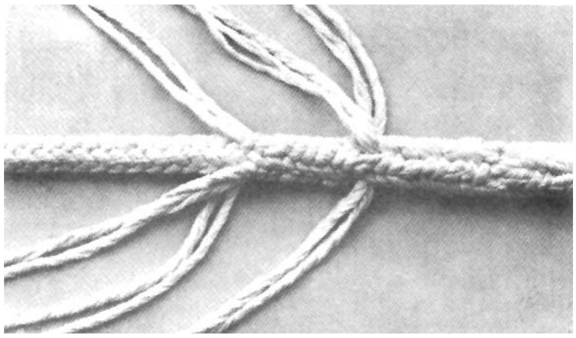
Now you can begin to tuck the pairs. One complete tuck con-sists of passing a strand pair over one strand and under two strands of the body of the rope. Pull the strands through and repeat on opposite pair, tucking straight down the body of the rope



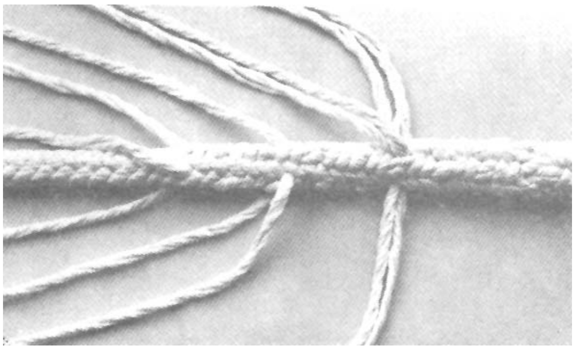
Do one complete set of tucks on all 12 strand pairs. Note: When pulling on the strand pairs, do not attempt to pull them so tight that they become straight. It is desirable to leave the tucked strands with some twist in them so that they have the necessary elongation when the rope is placed under a load.



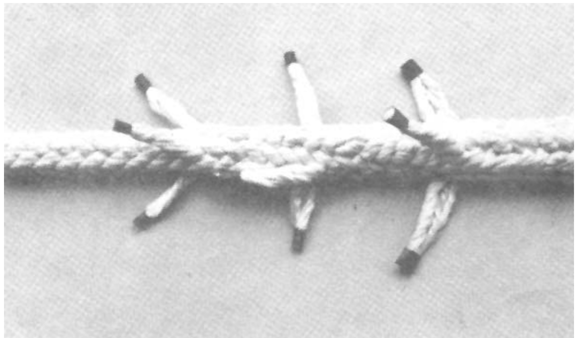
Do three complete tucks on each side of the splice with all six strand pairs. Each strand pair is always tucked under the same line of braid so that the tuck progresses straight down the body of the rope.



After completing the first three tucks drop every other strand pair and continue to do three more tucks with the remaining three pairs. This is done on each side of the splice.



Alter completing the second set of three tucks untape the three strand pairs used to make these tucks. Drop one strand from each pair and do at least two more tucks with the remaining single strand of each pair.



Once you have completed the last tucks, cut off the excess material and tape or whip the ends. Leave enough of an end protruding so that the end does not slip back into the rope when a load is placed on it.

SAMSON OCEAN SYSTEMS, INC.

99 High Street, Boston, Massachusetts 02110 • (617) 426–6550, TWX: (710) 321–0098