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DESIGN OF A FLEXIBLE CAGE FOR BENTHIC ECOLOGICAL EXPERIMENTS IN HIGH ENERGY MARINE ENVIRONMENTS*

by

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ABSTRACT

Bernstein, B.B. and Welsford, R.W. 1983. Design of a flexible cage for benthic ecological experiments in high energy marine environments. Can. Tech. Rep. Fish. Aquat. Sci. 1221: 26 p.

We present the design of a flexible, extremely resilient caging system for benthic experiments with large invertebrates (e.g. sea urchins, lobsters, crabs). Cages are constructed of monofilament stretched over a circular frame, and anchored to a grid of chains. This system was deployed at 7 m depth, and successfully survived winter storms with wind velocities in excess of 65 km per hour, and swells of 7 m.

RÉSUMÉ

Bernstein, B.B. and Welsford, R.W. 1983. Design of a flexible cage for benthic ecological experiments in high energy marine environments. Can. Tech. Rep. Fish. Aquat. Sci. 1221: 26 p.

Cet article présente les plans d'un système de cages flexibles et très résistantes servant aux expériences benthiques faites avec les invertébrés de forte taille tels que les oursins, les homards et les crabes. Les cages sont faites d'un monofilament qu'on étire sur un cadre circulaire; elles sont assujetties à des chaînes formant un quadrillage. Le système a été utilisé à sept mètres de profondeur et s'est avéré très solide, résistant à des tempêtes d'hiver avec des vents de plus de 65 km/h et une houle de sept mètres.

1. INTRODUCTION

Much scientific evidence indicates that subtidal kelp beds in Nova Scotia have undergone a radical change of state during the last decade (Breen and Mann 1976, Bernstein et al. 1981, Mann 1977, Mann and Breen 1972). Widespread destructive grazing by aggregations of sea urchins has transformed these areas into barrens devoid of macroalgae. As part of a continuing research effort on this subtidal ecosystem, the Richard W. Welsford Research Group Limited performed controlled, manipulative field experiments to elucidate the ecological mechanisims controlling the formation of sea urchin aggregations (Bernstein et al. 1983). This behaviour is a critical point in the transition of this ecosystem to the barrens state, since without the formation of aggregations, destructive grazing does not occur.

These experiments required that we develop a caging technique that would enable us to manipulate sea urchins and their predators, but would interfere as little as possible with their natural behavior. The design had to meet the following criteria. It had to enclose a large enough area of natural substrate to enable the urchins to display the behavioural responses we were interested in. Since the experimental design required 36 cages, we wanted them to be relatively easy to construct and/or install underwater. Cages had to be sturdy enough to survive winter storms at an exposed site in the shallow subtidal. Finally, as mentioned above, we desired minimal interference with the behaviour of the experimental animals (sea urchins, lobsters, crabs).

Cages are a widely used experimental tool in marine biology research. They have been used successfully in both the inter-tidal and sub-tidal. Existing caging techniques were of little help to us, however, for several reasons. Most experimental manipulations involve small organisms, and the cages are correspondingly small. Thus, while solutions exist to the problem of designing small cages that will survive intense wave shock, corresponding solutions for large cages do not exist. In addition, the conditions in Nova Scotia's rocky sub-tidal environment render most commonly used cage attachment techniques useless (see 3. OTHER METHODS OF ATTACHMENT). We thus present our solution to this problem in the hope that it will enable other researchers to more easily perform manipulative experiments in rocky sub-tidal habitats.

In the first section below, we describe our cage design in detail, along with a discussion of its strengths and weaknesses. We then summarize our experience with other methods of cage attachment, such as rock anchors and underwater epoxy. We include suggestions about situations in which these other methods would be applicable. Finally, we include prices and sources of supply for all cage components and tools discussed.

2. CAGE DESIGN FOR ROCKY SUB-TIDAL

Each cage contains several components: attachments, structure, wall, connection between the wall and the substrate, and support to keep the cage erect. These must not only complement each other, they must, separately and in total, satisfy the criteria outlined above. Figure 1 shows the successful system we developed. It is flexible, and as transparent as possible to water movement. The lack of rigid structure permits the cages to bend in the surge, and allows the strain to be distributed over a resilient network of attachment points.

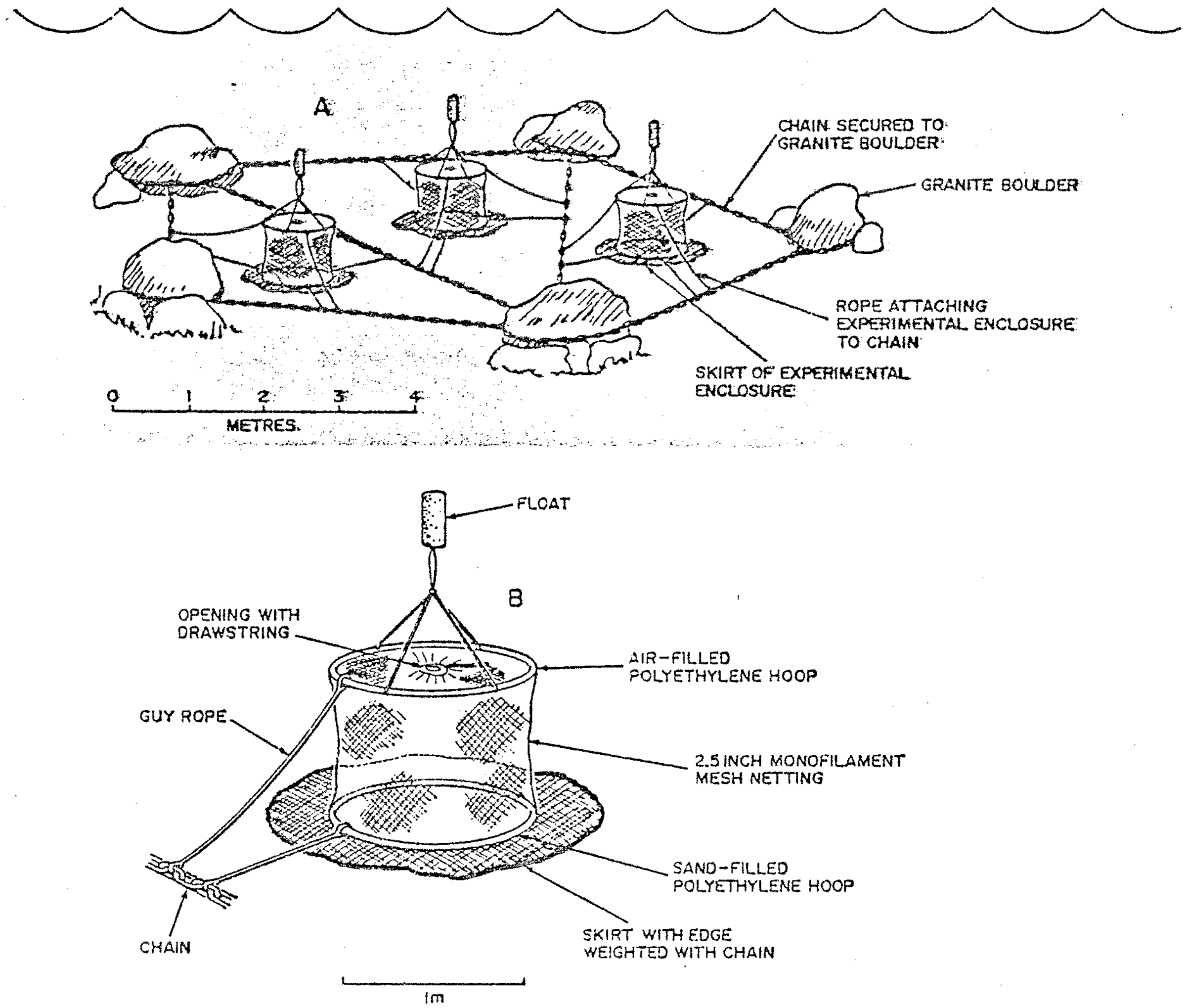

Figure 1. Schematic of the caging system, and detail of an individual cage.

This design was extremely successful. The cages were installed at 7 m depth at an exposed site near Cape Sable Island in southwest Nova Scotia. Extended gales with wind velocities greater than 65 km per hour, and swells up to 7 m, are common in the winter. Cage survival rates were 75% to 100% after three-day storms, and half the cages survived a protracted eight-day storm. The cages were thus quite resilient, but required frequent maintenance. In the following sections, we describe the design in detail and discuss alternate materials and methods.

2.1 Cage Anchors

We used a grid of chains to anchor cages to the bottom (Fig. 1). We wrapped separate lengths of 3/16 inch chain around the bases of several large boulders (1-1.5 m diameter) and fastened them tight with shackles. We then extended additional lengths of chain between the rocks, attaching them firmly with shackles at either end. We subsequently found U-bolts and eye bolts to be as effective as shackles and much cheaper. The fact that the shackles or U-bolts can fit through any of the links means that the chain need not be measured precisely before deployment. Water movement induces vibrations in the chain which tend to rapidly undo bolts and shackles. Lock washers, or two nuts, should therefore be used. During winter, when cold temperature reduces dexterity and efficiency, quick-acting snap shackles could be used, but these are very expensive. We found that water movement and the tension from the cages lifted the interconnecting lengths of chain off the bottom, in some cases damaging the cages. This was a severe problem only when the lengths of chain were longer than about 3 m, and was easily solved by placing rocks at a few points along the chains.

This method is very effective in high energy zones with large boulders available. It permits rapid and secure deployment of the anchoring system, even during periods of strong wave surge. We do not recommend using ropes instead of chains. Unlike chain, rope chafes quickly, and stretches and loosens under tension. In addition, it is difficult to tie tight, secure knots underwater, especially with polypropylene rope.

2.2 Frame

The frame determines the shape and size of the cage, and these in turn depend on the size of the experimental animals and the type of experiment performed. We wished to minimize as much as possible the additional structure provided by the cage. Our cages were therefore round, with no corners.

Structural steel reinforcing bars can be shaped and welded to whatever dimensions are required. We found that a less expensive and easier-to-work-with alternative was ½ inch stiff polyurethane tubing, available at any hardware store. To make circular hoops we cut off the desired length and glued a connecting joint between the two ends. We were able to make the hoops buoyant by gluing the joint carefully to make an airtight seal. We could also make them negatively buoyant by filling them with sand.

Our frame utilized two hoops, the bottom one filled with sand, and the top one filled with air. The frame served only as a support to the netting, since the buoy kept the cage erect and the guy ropes anchored it to the chain grid (see Fig. 1 and 2.3. WALLS).

Other shapes can also be built using a stiffer variety of tubing. The tubing, various type of joints (T, 45°, 90°, etc.) and glue are all available at any hardware store. Using these materials in combination can provide a cage of practically any geometric design. Some options are square, round, oval, hexagonal, and rectangular. Of these, the square, round and rectangular are the easiest to attach netting to and are therefore easier to build.

2.3 Walls

To cover the cage to prevent escape of experimental animals and to ensure water flow, some form of open net must be used. Mesh size should be small enough to prevent escape or entry of experimental animals, but large enough to reduce the effects of fouling, which is inevitable especially in shallow habitats. Surface area presented by a small mesh also creates drag which may put undue forces on the cage.

There are many different types of materials available for netting. Fishing supply stores can provide monofilament nylon netting in all sizes as well as cotton and tarred cotton. The tarred cotton may leach chemical substances and may not be suitable for some applications. Heavy duty plastic netting (Vexar), commonly used in aquaculture, is also available in various mesh sizes. This plastic is very stiff and can become a structural part of the cage. It is, however, difficult to work with underwater, and the thick mesh creates an inordinate amount of drag. In addition, thick mesh of any kind caused unacceptable bias by providing a surface for the urchins to climb upon.

Vinyl-coated wire can also be used for cage walls. Like Vexar, however, it is stiff, is difficult to fit to the uneven substrate around the edges of the cage, and creates high drag. It is best suited for smaller cages on flat substrates.

We used clear monofilament nylon netting with 2 1/4 inch mesh size. This material was flexible, fairly transparent to wave surge, and was difficult for urchins to climb on.

2.4 Net Attachment

Nets must be securely attached to supports, hoops or each other, with no gaps or holes which would allow passage of animals. Some of the methods we tested were: sewing with nylon monofilament, sewing with twine, twist ties, and electrical cable clamps. The most effective were electrical cable clamps which are available at any electrical supply store. A great number of them are required to attach the nets to the supports of hoops, however, and they cannot be used to fasten nets together. To fasten the nets together and to the hoops, we instead used a braided twine (No. 8). This twine is less likely to slip a knot than other types of twine or nylon monofilament. A net mender's needle is used to secure the twine to the net and hoops. It is important to lock every stitch in place with a knot of some sort to prevent unraveling if a section breaks or chafes. Sewing should be continuous throughout each mesh to provide a solid running seal. Books may be obtained from libraries on the art of sewing nets, or the service of a local fisherman may be solicited.

Nets were attached to the hoops with the mesh pulled taut so the net would compress vertically and not horizontallly. This prevents bunching and flexing along the cage wall which could interfere with animal behaviour. The net was attached to the hoop at the bottom, but was gathered over the top hoop to allow a drawstring arrangement for easy access to the cage (Fig. 1). Skirts were made by attaching six short triangular sections of netting together with the apex of each triangle touching the hoop and the base spread out below it. This allowed us to spread the skirt out along the bottom to achieve a continuous seal. All the nets were sewn together and to each other with No. 8 braided twine. A chain (3/16") was also sewn along the edge of the skirt for additional weight and a better seal. When the cages were deployed, the bottom hoop was placed as close to the bottom as possible and the skirts were spread out. The chain was arranged to follow the contours of the bottom and then rocks were piled upon the skirt.

2.5 Guy Lines

We used rope guy lines to secure the cages, and to offset the forces produced by waves and currents. We attached four lengths of 1/4 inch polypropylene rope to both the top and the bottom hoops. Polypropylene will stretch slightly under a load, rather than breaking, making it ideal for this application. By fastening the eight ropes tightly, forces from any direction can readily be absorbed.

Guy lines should be long enough to ensure that an attachment point can readily be found when the cages are placed on the bottom. When deploying the cages, we tied eye bolts at the end of each rope, and selected a spot along the chain grid which provided the required tension. We then bolted the rope to the chain. Care must be taken to singe the ends of polypropylene rope to prevent unraveling, and to splice the free end from a knot back through the rope. This can be done by simply twisting the strands of the rope open several inches from the knot and inserting the free end through it. If this precaution is not followed, the knot is certain to come untied. Nylon rope is much more likely to hold a knot, but the extra cost does not justify the saving of a few seconds in knot tying.

2.6. Buoy

We used a small buoy to provide the upward force necessary to keep the sides of the cage taut without interfering with the cage's overall flexibility. The buoy was attached with a snap swivel that allowed easy connection underwater and prevented kinking of the rope as the buoy turned.

The size of the buoy is important. The proper size depends on water depth and the degree of water movement. A too large buoy will exert too much upward force and allow wave action to work the skirt free. Too small a buoy will allow wave and current action to constantly flex and collapse the cage. This may abrade the cage walls, but, more importantly, will interfere with the animals inside the cage.

2.7 Construction, Deployment and Maintenance

This section outlines the sequence of steps to be followed in constructing, deploying, and maintaining the cage system

Construction: Cages

1. Cut polyurethane tubing into proper lengths, fill with sand (if desired), and glue ends together to form hoops.
2. Measure and cut monofilament.
3. Sew nets to hoops with No. 8 braided twine. Sew edges of nets together.

4) Measure and cut triangular pieces of net for skirts.
5) Sew triangular pieces together along edges, and sew skirts to bottom hoops with No. 8 braided twine.
6) Sew 3/16 inch chain around bottom of skirts.
7) Fasten rope crosspieces across top hoop.
8) Tie four guy ropes to each hoop.
9) Tie eyebolts to end of each guy rope.
10) Stack cages carefully.
11) Fasten snap swivels to buoys.

Construction: Chain Grid

1) Select area with suitable boulders.
2) Shackle chains around boulders spaced at 3 - 7 m intervals.
3) Fasten interconnecting chains with U-bolts or eye bolts.

Deployment:

1) Position cages.
2) Attach lower set of guy ropes to chain grid.
3) Attach upper set of guy ropes to chain grid.
4) Spread skirts and weight down with rocks.
5) Attach buoys to top of cages.

Maintenance:

1) Check all attachment points for loose knots or nuts.
2) Check ropes for tension, chafing.
3) Check skirts to ensure bottom of cage is sealed.
4) Clean nets of fish, drift algae, or other debris.

3. OTHER METHODS OF ATTACHMENT

We investigated several other methods of anchoring large cages. These were generally of two types. The first used underwater cement or epoxy to attach shackles or U-bolts to the bottom. These were then utilized as attachment points for guy ropes to support the cage. The second type used holes drilled in the rock in which to seat a rigid cage frame. The upright parts of the frame were fixed in the holes with either rock anchors, underwater cement, or epoxy. Neither method was workable at our study site. Underwater cement and epoxy will not set up well in water less than about 10°C, while winter temperatures at our site were 0-1°C. Drilling holes did not work because the granite substrate was so hard even diamond drilling bits wore out quickly. It would have required an unreasonable amount of time and money to drill the holes required for 36 cages. We review these methods, however, because they could prove useful in less demanding environments.

3.1 Cementing Anchors

We attempted to cement U-bolts into cracks and depressions in the bottom as anchors for the flexible cages. This method has the advantage of utilizing many separate attachment points, so that, even if one fails, the others will be unaffected. Theoretically, any type of pre-mixed concrete can be used underwater. It should be mixed on the surface according to instructions, then carried underwater in sealed containers such as small plastic bags. Quick setting varieties are also available; these can set in as little as four minutes. In practice, concrete proved extremely difficult to work with. It dispersed rapidly into the water, reducing the visibility almost to zero. The low water temperature (0-2°C) with which we were faced kept even the quick setting variety from setting up, and even relatively moderate water motion dispersed the soft concrete before it hardened.

We experienced similar problems with marine epoxies. These consist of two or three different components. They include expoy resin and a curing agent or catalyst, while some add an extra aggregate for bulk and bonding. We tested both types and found that the aggregate absorbed some of the heat released during the resin-catalyst reaction and retarded curing in cold water. Manufacturer's specification claimed twenty-four hours were required for curing at 5°C. We found, however, that we had to wait seven days for either type of epoxy to harden at 0-2°C. Even then, the bond with the substrate was not strong and the epoxy could be peeled off. Waiting this long for the epoxy to cure is not practical because, over this length of time, the weight of the U-bolts will cause them to sag, and the pressure of water movement will work them loose.

At warmer temperatures, epoxy is extremely useful. It cures quickly, is very hard, and adheres well to rocks, especially if they have been cleaned with a wire brush. When mixing epoxy in air temperatures below about 15°C, we recommend keeping the components in a warm water bath (e.g. an ice chest full of hot water). This keeps the components syrupy and makes mixing easier. We found that mixing by hand was ineffective, and we utilized a pneumatic drill, operated from a S.C.U.B.A. tank, with an electric mixer blade substituted for the drill bit. We carried the epoxy underwater in small plastic cups, and packed it around U-bolts that had been hammered into cracks in the substrate.

3.2. Drilling

Another method of permanently attaching cages to the bottom is drilling into the rock and attaching supports for a cage frame. These supports must be strong enough to withstand all forces exerted by waves and currents. Local conditions will dictate the size of these supports and therefore the size holes to be drilled.

We explored several different methods of drilling into rock. There are basically three procedures that can be used underwater. These are pneumatic drilling, hydraulic drilling and hand drilling using a "star drill".

3.2.1. Pneumatic Drills

There are no air operated hand tools designed specifically for underwater use, however, with proper care and minor modifications, any air operated drill can be submerged. Air drills usually employ compressed air to spin rotary vaned gearing which in turn operates the gearing which rotates the drill bit. Rotary gearing is the only gearing available in this type of tool. As long as the air is flowing through the drill, water connot enter. If the flow of air to the drill is cut off while submerged, water will flood the interior chambers of the drill. Once air flow is resumed, the water will be forced out, but extra care must be taken to protect against interior corrosion. After every period of salt water immersion, the drill should be partially stripped down and soaked in lightweight solvent such as alcohol, kerosene, penetrating oil, diesel fuel, or gasoline. The drill should remain soaking unless it is being used underwater. Field stripping whould include removal of the air hose, oil plug, and chuck assembly, as well as anything else that will allow the replacement of salt water with the solvent. Care must be taken when using these solvents around diving gear as they are particularly effective in dissolving rubber products. This same care applies to the rubber air hose which supplies compressed air.

When choosing a drill for underwater use, special attention must be given to the air pressure required for operation, to the R.P.M. and the chuck size. Most air drills require about 90 p.s.i. (620 kPa) to operate on the surface. Compressor output should match that required by the drill and should be adjustable to compensate for depth.

For example when working at a depth of 30 feet and using surface supplied air, the compressor must produce 180 p.s.i. (1240 kPa) as the pressure is reduced by 50% at this depth. A S.C.U.B.A. tank, and the first stage of a regulator, may be used as an air supply that will produce a constant pressure regardless of depth. A dive shop can adjust the pressure output of a first stage from its normal 140 p.s.i. to the input required by the drill used. Fittings can be obtained at hardware stores to attach air hoses. The volume of air required by the drill and the duration of drilling will effect the size and number of S.C.U.B.A. tanks required. We found that an 80 $ft.^3$ S.C.U.B.A. tank filled to 3200 p.s.i. provided four to five minutes of uninterrupted drilling at 25 feet. Substrate, diameter and depth of hole, and size of drill will all affect performance.

To keep the drill operating constantly and keep water out, a worm gear hose clamp or thick rubber band can be attached to the trigger. A steel clamp is preferable as it will survive the solvent bath following drill use. To reduce air bubbles interfering with visibility, a section of hosing can be attached to the air exhaust of the drill to redirect air away from the diver. A section of radiator tubing from a car part supplier attached to the handle of the drill with a steel hose clamp will work effectively.

The rubber air hose should have a bursting strength of at least 800 pounds working pressure. The hose is available at hardware and auto supply stores, and can be obtained in 25 and 50 foot lengths. The lengths can easily be joined with fittings to permit adapting the length required for a particular project. A surface supplied air system requires sufficient scope to allow for wind and current movements, but must not have an excessive amount which may entangle a diver.

There are a variety of drill bits available. The best for drilling into rock are carbide bits designed for rock and masonry, and diamond drill bits designed for rock.

Depending on the hardness of the rock, a carbide drill bit may only drill from one-quarter of an inch to five or six 2-inch deep holes. In granite, for example, we used four high quality carbide bits to drill a single 1 1/4 inch deep hole. A diamond bit, while more expensive, drilled four 1/4 inch by 1 1/4 inch deep holes in granite before wearing out. Carbide bits are available in sizes from 1/16 inch to ½ inch, while diamond bits are available from 1/4 inch to six inch diameter. To ensure maximum success, it is necessary to keep the drill bit diameter as small as possible, as smaller holes are drilled faster.

3.2.2. Hydraulic Drills

Hydraulic drills use a fluid pumped under pressure to operate the gears which rotate the drill bit. These drills are manufactured to be used underwater and have the conventional rotary action chuck, as in the air drill, along with a percussion or 'hammer drill' chuck. The hammer drill is more effective in drilling in rock as it delivers approximately 3500 impact blows per minute while turning at 1000 r.p.m. This allows for both a chipping and grinding action which wears rock away quickly. These units are used with a carbide bit and drill the same size holes as do air drills.

The cost of the hydraulic drill is many times that of an air drill and requires a costly hydraulic pump. We did not use a hydraulic drill but we were told (Sharpe, Fisheries and Oceans, Halifax, pers. comm.) that they are effective even in granite.

The expense, and the length of time required for each hole (at least 30 min.) made this method unsuitable for our purposes. We would recommend hydraulic drilling in situations without severe cost or time constraints, or where only a few holes must be drilled.

3.2.3. Hand Drills

Hand drilling into rock using a Star drill is a method employed by the construction industry and surveyors where holes have to be drilled in rock without a conventional power source. The drill consists of a very hard steel cylinder, the diameter of the hole size required with a flat striking end and a star-shaped drilling end. The drill is placed on the rock and hit with a heavy hammer. After every blow the drill is twisted to a new position. This effectively chips a hole in the rock. Needless to say, due to the density of water it is difficult to strike a heavy blow underwater. This method does work underwater, however, and would be an inexpensive, albeit time consuming, method for drilling holes.

3.2.4. Rock Anchors

There are two methods of attaching cage supports in holes drilled in the substrate. One is to drill the hole slightly larger than the diameter of the support and glue it in using underwater cement or epoxy. This method has the advantage of being quick and utilizing the minimum of equipment. Disadvantages include the length of time it takes for cement to harden, during which time the support must be braced in position, and the extra effort expended in drilling a larger diameter hole.

Another method is to use a rock anchor to which a support is attached. A rock anchor consists of a screw or nail which is ensheathed with a thin aluminum or white metal coat. As the anchor is screwed or driven into the hole the aluminum or white metal crumples or spreads open to firmly grip the sides of the hole. A threaded section of screw or nail is left protruding from the hole and a support can be threaded to it by means of a coupler. Rock anchors and couplers are readily available in a variety of shapes and sizes. They are quick and easy to use, but may be difficult to screw in underwater. While the rock anchor itself provides a very solid attachment to the rock, the joint via the coupler between the rock anchor and the support may be weaker than the two components. If available, underwater cement or epoxy may be used to strengthen the joint.

Eyebolts may also be attached to rock anchors. These may be used for guy wire supports. Rock anchors are available with eyebolts built in, but these are too small to insert 1/4 inch rope, and wire or thinner rope would have to be used.

4. COSTS

Table 1 shows costs and sources for all materials and equipment described above. Costs should be considered only approximate, since they are indicative only of prices in Halifax, Nova Scotia, during early 1982. The one exception is the marine epoxy. The range of prices represents sources in Southern California, Toronto, Ontario; Halifax, Nova Scotia; and Pennsylvania. Table 2 itemizes the costs per cage, for the flexible, round design. These costs could be reduced by purchasing the chain, rope and netting in bulk.

Table 1. Sources and prices of equipment and supplies for underwater cage construction.

ITEM	PRICE	UNIT	SOURCE
Pneumatic drill	$ 325.00	ea.	*1,2
Air hose	80.00	25 ft.	1,2
Carbide bit (3/16")	4.89	ea.	1,2
Diamond drill bit (3/16")	62.50	ea.	1,2
Rock anchors	.10	ea.	1,2
1/4" Threaded rod	.60	1 ft.	1,2
Shackles	1.00 to		
	10.00	ea.	3,4
U-bolts	.29	ea.	1,2
Eye bolts	.29	ea.	1,2
U/W Concrete	15.00	10 lbs.	1,2
Marine epoxy	50.00 to		
	200.00	1 gal.	4,5,6
3/16" Chain	.90	1 ft.	1,2,3,4
1/2" Poly tubing	5.49	100 ft.	1
1/4" Polypropylene rope	.02	1 ft.	1,3,4
# 8 Braided twine	7.62	1200 ft.	3,4
Vexar	3.00	1' x 6'	7
2 1/4" Monofilment net	31.32	40 mesh x 50 yds.	3
Vinyl-coated wire mesh	n/a		8
# 2 Lobster buoy	3.15	ea.	3
Swivel	1.40	ea.	3,4

(Table 1 cont'd)

*KEY:

1: Hardware/Building Supply Store

2: Construction Supply Store

3: Fishing Supply Store

4: Boating Supply Store

5: Sika Corporation, 1280 Wall St. W., Lyndhurst, NJ

6: Koppers Inc., Andrew Brown Division, Pittsburg, Pennsylvania, 15219, USA

7: DuPont Canada Inc., P.O. Box 2200, Streetsville, Postal Station, Mississauga, Ontario L5M 2H3, Canada

8: Coatings Engineering Corporation, 33 Union Avenue, Sudbury, Massachusette, 01776, USA

Table 2: Cost of materials for one round, flexible cage.

ITEM	AMOUNT	PRICE
1/2" Poly tubing	23 ft.	$ 1.28
2 1/4" Monofilament net	40 mesh x 4 yds.	2.51
Cable clamps	30	.99
3/16" Chain	11 ft.	9.90
# 8 Braided Twine	25 ft.	.16
1/4" Polypropylene rope	56 ft.	1.12
Eye bolts	8	2.32
Swivel	1	1.40
Buoy	1	3.15
	TOTAL:	$22.38

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