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NATURAL ENVIRONMENT RESEARCH COUNCIL
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Design study for a re-usable seismic source for use on the sea-bed

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DESIGN STUDY FOR A RE-USEABLE SEISMIC SOURCE
FOR USE ON THE SEA-BED

Following recent experience using free fall projectiles as seismic sources generating seismic waves by their impact on the sea-bed, it was decided that a re-useable source using the same impact principle should be developed (see R.B. Whitmarsh internal note 24.3.1980). It was envisaged that this device would be used off Discovery attached to the coring warp. This warp has 25t breaking load and the weight of 6000 m of it outboard in sea-water is 8t. The speed restriction for hauling in and paying out this warp on the double drum capstan winch is 1.5 m/s. This places certain restrictions on the weight of the device and the size of impact that can be delivered. The most successful of the drop weight experiments indicated that a blunt nosed 1t weight estimated to fall at 4.5 m/s delivered a sufficient impact to produce good seismographic records. Thus the momentum that is required is 4500 kgm/s. If a simple weight is attached to the cable and may only fall at 1.5 m/s, the mass required to give the same momentum is 3t (3000 kg). Note that the momentum that the device delivers to the sea-bed is the relavent quantity in any impact not the amount of energy. Energy can be dissipated in a large variety of ways in an impact as heat or sound energy that is not transferred to the sediments, but momentum is a conserved quantity in an impact, so all of the momentum of the device is delivered directly to the sea-bed. An important but difficult calculation, in the sense of being confident that it is correct, will be the estimate of the pull-out force which will give the maximum load on the warp, but some maximum bounds may be estimated. Perhaps of greatest importance however will be the handling of this device on the ship and over the side into and out of the sea. Such a device, if indeed it weighs 3t could be extremely dangerous if adequate handling procedures or facilities are not available.

Three possible solutions have been considered

(i) a 3t cast iron weight

(ii) a spring released impact device, similar in concept to a centre punch

(iii) a lighter weight having water entrapped in it giving an effective mass when moving through the water of 3t.

(i) A 3t weight

The volume of cast iron required to give a mass of 3t is $0.417 m^3$ (density of cast iron $7200 kg/m^3$). To give the maximum impact with little penetration, a weight with a flat bottom seems desirable. Reducing the penetration depth will reduce friction forces in the pull out and apparently gives a better seismic trace than a high velocity streamlined drop weight. A flat bottom will give larger suction forces in the pull out but this could be relieved by putting holes top to bottom through the weight. Thus a suitable geometry for the 3t weight might be that shown in fig. 1.

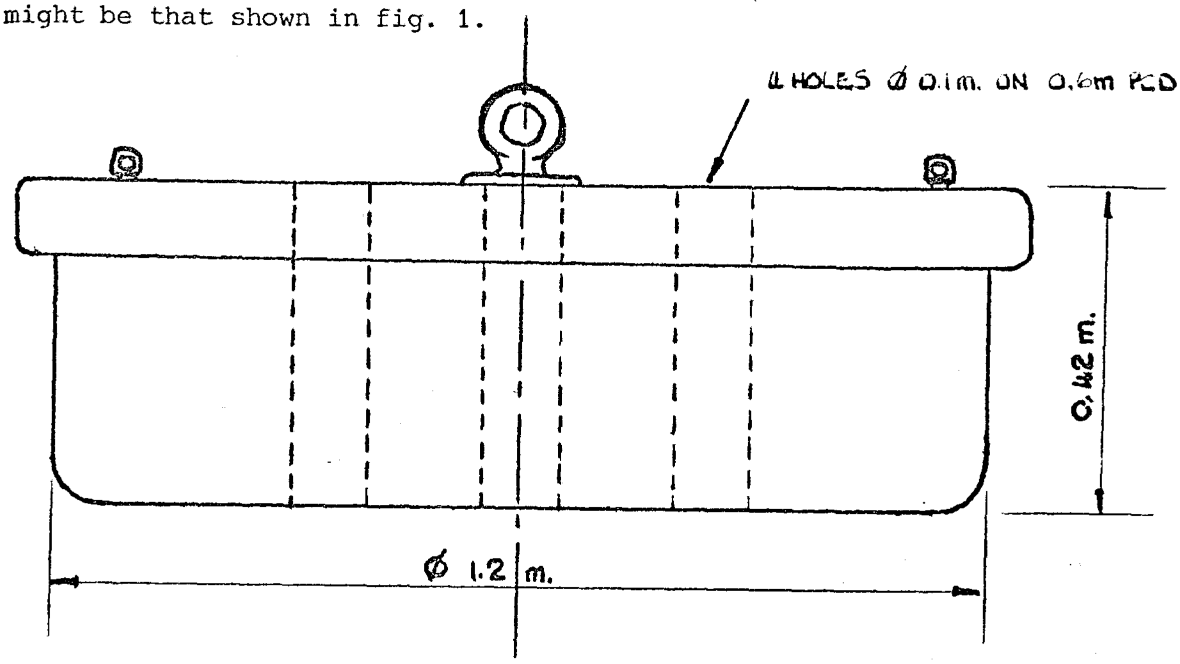

Fig. 1 3t cast iron weight

The construction of such a weight is obviously quite simple but the major difficulty comes in its handling. A suitable strong point would have to be found on the ship for its stowage, not too far distant from the crane davit on the starboard quarter of the rear deck area. Special arrangements would have to be made for moving the weight from this point to the davit, possibly using the crane and several restraining lines. The most vulnerable part of the operation would be deployment and recovery. Unfortunately, a crane having a rigid arm capable of reaching down the 5 m from deck level to the sea surface and thus restraining the swinging motion of the weight, is not currently available. A 3t weight could do serious damage to the stern plates of the ship if unrestrained during these potentially hazardous phases of the operation.

(ii) A spring released impact device

The principle of such a device would be the same as that used in a spring released centre punch. A spring is compressed storing potential energy which is released giving kinetic energy to a mass which impacts on the surface. In order to work repeatedly on the bottom, the simplest method of compressing the spring would be to use a weight. The system is diagrammatically shown in fig. 2.

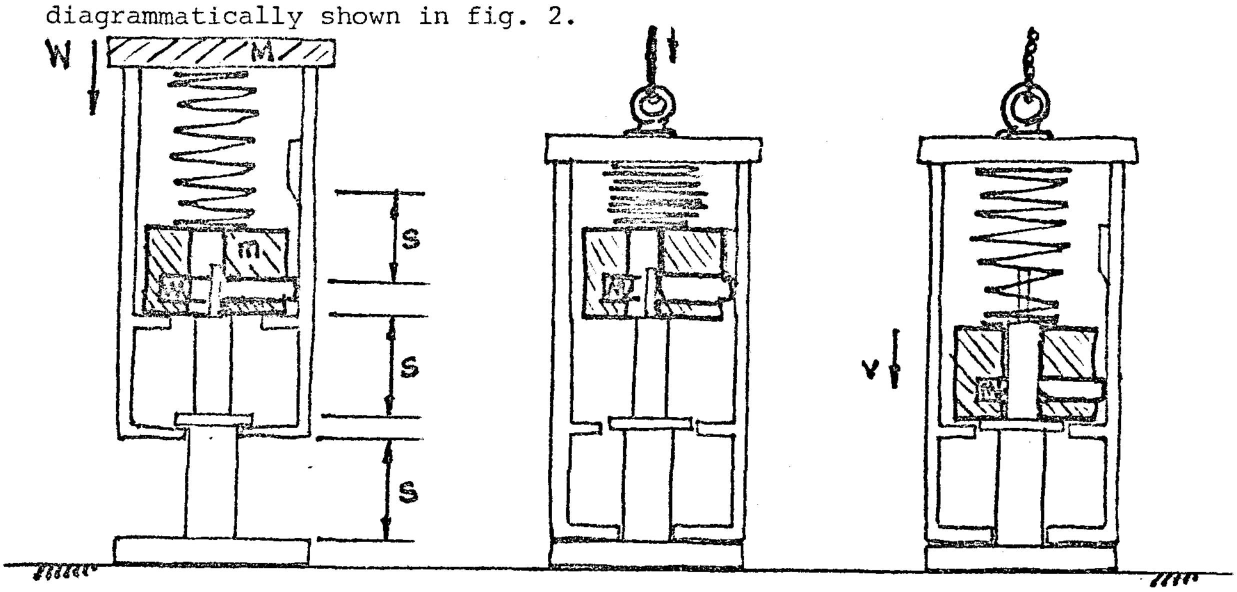

Fig. 2 Diagram of spring released impact device

If the weight W compresses the spring over a distance s to the release point, then the stored energy is $\frac{Ws}{2}$. If all of this energy with the potential energy released in the drop is converted to kinetic energy then

$$\tfrac{1}{2}mv^2 = \frac{Ws}{2} + ws$$

where w = weight in water of the small mass m, giving the velocity v at impact

$$v = \left(\frac{Ws}{m} + \frac{2ws}{m}\right)^{\frac{1}{2}}$$

thus the momentum at impact is $mv = \sqrt{ms}\ (W + 2w)^{\frac{1}{2}}$

The required impulse is I = 4500 kgm/s

so $$I = \sqrt{ms}\ (W + 2w)^{\frac{1}{2}}$$

Let s = 1 m say and assuming the masses to be very much denser than water so that buoyancy forces can be neglected for the moment and $W \simeq Mg$, $w \simeq mg$, then with s = 1 we find

$$m^2 + \frac{Mm}{2} - \frac{I^2}{2g} = 0$$

If I = 4500 kgm/s and g = 9.81 m/s² then solving for a range of values of M the corresponding values of m are:

M(kg)	m(kg)	total(t)
500	900	1.4
1000	800	1.8
1500	710	2.21
2000	630	2.63

For the lighter values of M it is the potential energy of m that provides the impact velocity and not the energy stored in the spring. As M decreases so the device becomes more a controlled free fall of the mass m. In the extreme case of M = 0, or very small compared with m, m ≈ 1t and the velocity is $\sqrt{2gs}$ neglecting drag or 4.4 m/s if s = 1m. This is the case where there is no spring at all, such a device might look like that shown in fig. 3. Ingenious as this may appear, it is clear that it will be a very large device, at least 4 m long and 1 m or more in diameter. It would involve some clever engineering to ensure the release would be reliable and the drag of the free fall mass and the damping effect of the water inside the casing would have to be minimised if the weight were to be able to deliver its full momentum. It has the advantages of only weighing perhaps 1.5t in air and would be less damaging to the cable than the 3t weight which would suddenly unload the cable at impact at full payout speed. This device could be more gently placed on the bottom and the casing slowly lowered to trigger the impact.

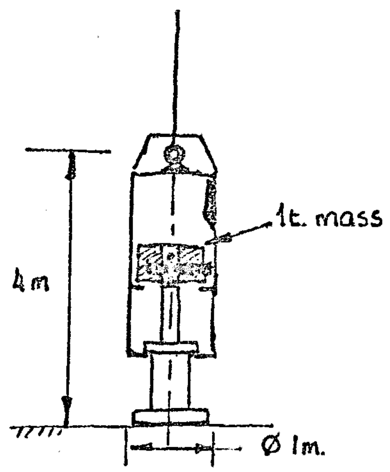

Fig. 3 Free fall mass system

(iii) <u>The water trapping weight</u>

The principle involved here is that if you can get the weight to trap a large volume of water inside it when descending, then it will have a high effective mass when it collides with the bottom. To make the bottom weight significantly lighter than the 3t of example (i) then the volume trapped will have to be quite large, 1 to 2m³ say, if the weight is to fall at 1.5 m/s, as dictated by the winch. The advantage of such a construction is that it will weigh less than 3t in air and thus reduce handling difficulties. However the advantage gained in reducing the weight is paid for in increased bulk. An important feature of such a construction must be the ability to dump water quickly as it comes out of the water in recovery so that the weight of water does not have to be lifted by the crane. The reduced weight will also bring down the tension in the wire through all phases of operation. Having considered several shapes and designs, the final device might look like that shown in fig. 4-5. This has an overall weight of 1.5t in air and would trap 1.45 m³ of water giving an overall mass of approximately 3t. The bottom weight could be of steel and concrete construction and assuming the upper steel container to weigh 200 kg, this would have to have a mass of 1.3t. Since it stands 2 m high, it may be handled over the side by the crane davit, although some additional method of constraint during deployment, recovery and deck handling is still necessary. The water is trapped during descent by the closing of a conical valve. This valve could be made of a buoyant material so that the valve was always closed when submerged or else it could rely on differential pressure to close it during descent. When falling on the wire at 1.5 m/s, the internal pressure will build up to near stagnation pressure, water being forced into the container through the holes on the bottom face which will be at stagnation pressure. At 1.5 m/s stagnation pressure is 1.15 kPa (kN/m^2), in the wake behind the valve the pressure will be lower than ambient and this differential should be sufficient to close a valve fabricated from 3 mm thick steel. The valve travel need not be large, just sufficient to allow air to rush in and discharge the trapped water as the container comes through the water surface on recovery. It is estimated that the drag on such an object travelling at 1.5 m/s might be 160 kg and the free fall velocity if detached from the wire might be 4 to 5 m/s depending on its weight in water which may be only 1t if the base is constructed using concrete. A 5 cm gap has been left at the bottom of the container for rapid draining during recovery. Some of the impact forces of the weight on the side of the ship may be absorbed using rubber fenders, but some quite substantial structure will have to be built into the water container to take such loads should they occur. The base will require reinforcing if made of concrete and the provision of some inbuilt structure to transmit the weight of the concrete to the central pole. Steel sheathing may also be necessary to prevent the concrete from cracking and breaking up on impact with the sea bed.

Penetration depth and pull-out forces

Schmid (1969) gives a variety of formulae for the penetration of objects into the sea bed, all of which depend upon the bearing capacity of the sediment. Obviously this will vary very considerably but the worst case will probably be for soft clays. According to Lee (1974) red clay has an undrained cohesive shear strength of 7 kPa. The bearing strength for deep-sea cohesive soils as given by Valent (1974) is

$$P_o = 5.7\ kc$$

where c is the cohesive shear strength of the sediment and k is a shape factor for the object penetrating the soil, k = 1.3 for a circular footing. This gives a bearing capacity of P_o = 52 kPa.

For constant area penetration, i.e. a cylinder penetrating the surface end on, as in the case of the 3t weight, the penetration depth x_{max} is given by

$$x_{max} = \frac{vm^2}{2\pi R^2 P_o}$$

where v = velocity at impact, m = mass of the body, R = radius of cylinder. For the 3t weight (i) this gives x_{max} = 6 cm and if applied to the 1.5t weight (iii) x_{max} = 5 cm. If the weight (iii) is approximated to that of a sphere of 1 m radius then if $x_{max} < R/4$ the penetration of a sphere is given by

$$x_{max} = v\left(\frac{m}{2\pi RP}\right)^{\frac{1}{2}}$$

which gives x_{max} = 14 cm. From this point of view to minimise penetration it is obviously better to have a flat bottom than a spherical or conical bottom i.e. it might be better to alter the shape of the weight in fig. 4 to a cylinder of 1.3 m diameter.

It is evident that the impact penetration depths will be small but it will be important to pull the weight off the bottom before it has time to settle under its static loading. The excess pressure built up in the sediments under the weight will help to push the weight out and reduce suction forces on the pull out if the weight can be lifted as soon as possible after impact, otherwise the excess pressure will be dispersed through the sediments laterally and the weight will gradually settle into the mud. If the weight is allowed to settle, then the full pull out suction force will have to be overcome, this suction pressure is usually taken to be equal to the soil bearing capacity. Thus if frictional resistance on the sides of the weight can be ignored, a good approximation if the penetration depth is small, then the pull-out force of the 3t weight is 6t plus its weight in water (≃3t). For the 1½t weight, the pull out is 7t plus its weight in water (≃1t). These forces may be alleviated by drilling holes through the weight to reduce the effect of the suction. In figs 1 and 4, four 10 cm diameter holes are shown. Suppose each hole reduces the suction over an area of 30 cm diameter, this would reduce the suction force by 1.5t. This indicates that 8 holes would reduce the suction force to perhaps only 1 or 2t but swift action on pulling out the weight before it settled may reduce pull out forces to zero.

From these calculations, it is clear that the maximum load expected at the weight hooking point is less than 10t. It is suggested that 10t proof chain be used immediately above the weight and a 10t weak link to prevent excessive loading of the coring warp.

Conclusions

The 3t weight (i) is obviously the simplest and therefore likely the cheapest device. However, its large weight in air is a major disadvantage and could constitute a major risk to personnel and equipment on the after deck during manoeuvring operations to and from the crane davit and during deployment and recovery. Possibly therefore its low cost benefit would be lost in the provision of special handling equipment to cope with these operations.

The controlled drop weight has the advantage of a lighter weight, 1.5 to 2t, and it may be less destructive in its treatment of the warp. However, it would most certainly be the most costly of the three considered to manufacture, requiring some heavy and yet precise engineering to release a 1t weight and take its impact on a stepped shaft. It has more moving parts and, its major disadvantage, it stands some 4m high. Also being a self-cocking and releasing mechanism, there is the danger that through mis-handling it could be released on deck punching a hole through the deck structure. Aesthetically pleasing though the centre-punch release mechanism may be, it is perhaps impractical for this use.

The most viable proposal appears to be the third option. A 1½t weight standing 2m high fabricated in steel and concrete weighing perhaps only 1t in water. The penetration and pull-out calculations suggest the following modifications, shown in blue on figs 4 and 5, a flat bottom and another 4 holes through the base. Perhaps also the lower fender should be wrapped instead around the concrete weight where the highest lateral momentum will be should the weight begin to pendulum.

Handling a 1½t weight, though proportionately easier than a 3t weight, is still a non-trivial problem. Special handling techniques using the crane-davit and central crane in conjunction with additional ropes around the ship anchoring points will have to be devised when the stowage position for the weight has been allocated. Possibly the central crane used at full extension as a boom over the stern linked by a strop to the weight could be used to prevent the weight hitting the stern plates of the ship during the deployment and recovery phases of the operation. It has to be accepted that the present ability to handle heavy and bulky equipment off and onto the ship is not ideal but may be just adequate given a competant crew.

The maximum loads expected to be imposed on the coring warp are 1.5t weight + 7t max. pull out (all holes blocked) + 8t warp @ 6000 m, total 16.5t. It is to be hoped that the pull out forces by careful operation can be significantly reduced for it is doubtful that the coring warp would stand very many repeated cycles at this maximum level of loading.

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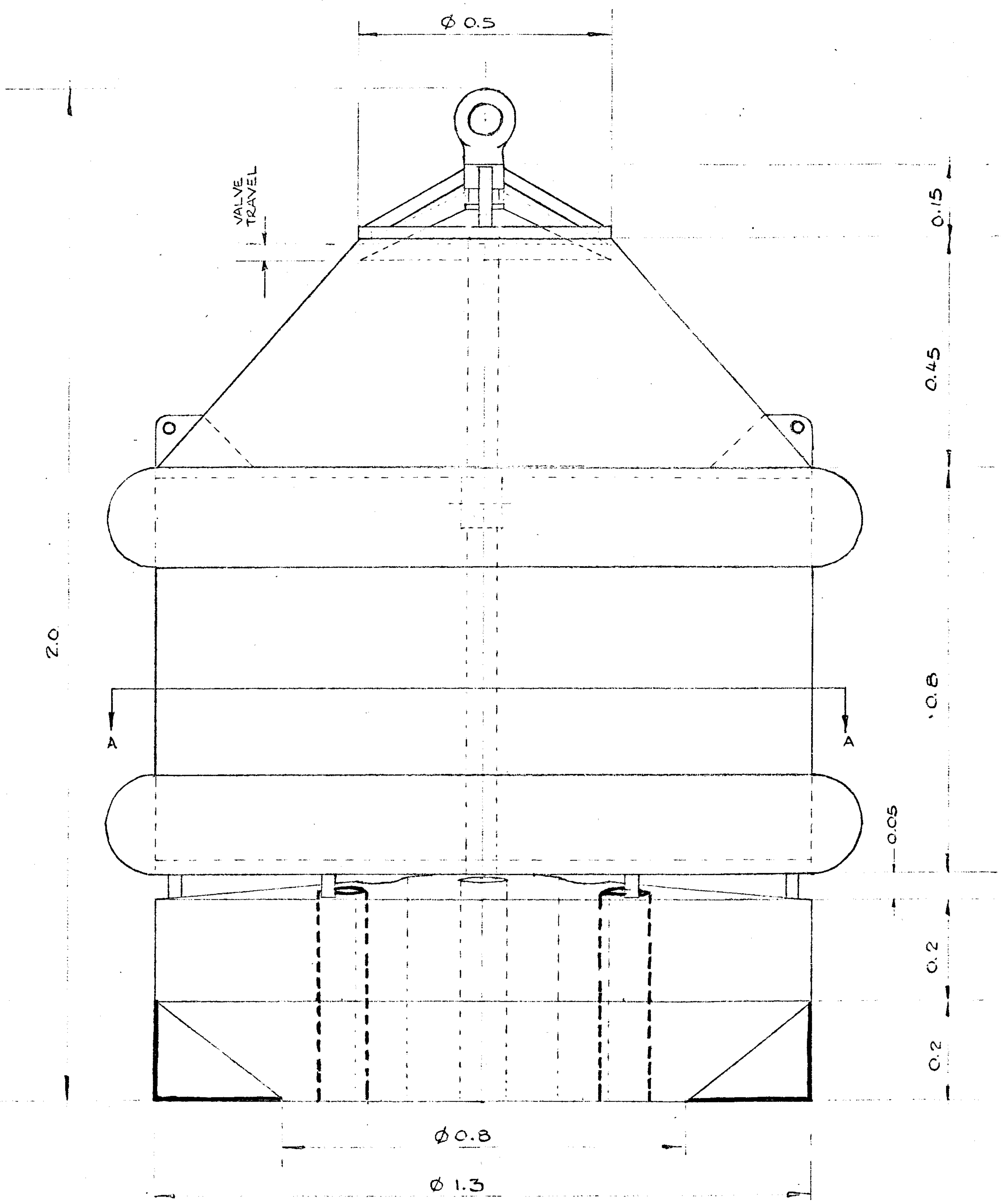


DIMENSIONS IN METRES

FIG. 4 WATER TRAPPING WEIGHT .... MODIFICATIONS SHOWN IN BLUE

BASE WEIGHT ≃ 1300 kg in air

AVERAGE DENSITY ≃ 2930 kg/m^3

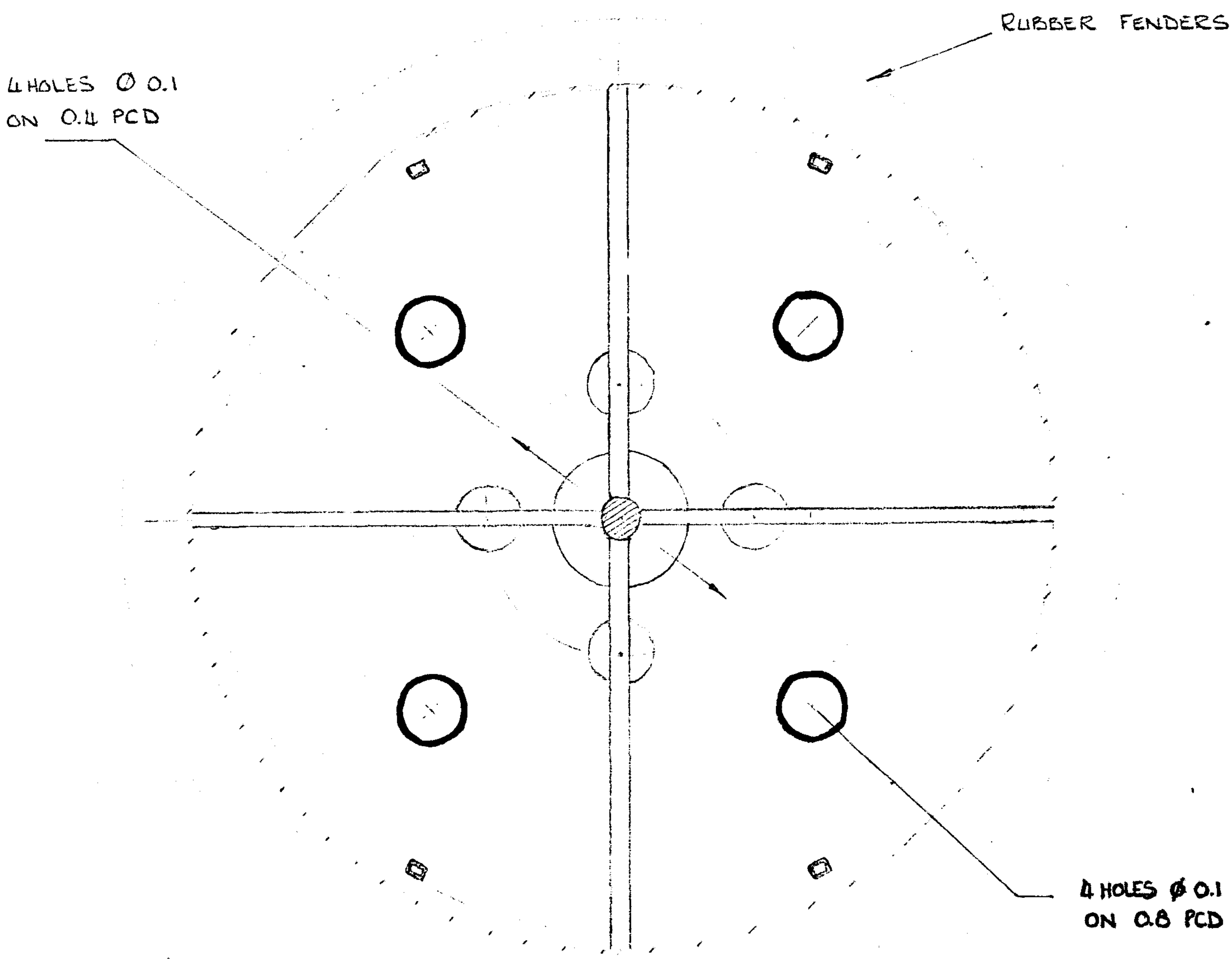
VOLUME ≃ 0.45 m^3

STRUCTURE WEIGHT ≃ 200 kg in air

($5m^2$ steel sheet + bracing)

TRAPPED WATER VOLUME ≃ 1.45 m^3

MASS ≃ 1490 kg



SECTION A-A

DIMENSIONS IN METRES

FIG. 5