Dear Andrew,

Herewith as promised a copy of the short report on explosive charges for Operation 'Pluto'.

ISRB* was the technical division of the S.O.E.

Regards

Nathan 1/6/18

* Inter-Services Research Bureau

EXPLOSIVE CHARGES FOR OPERATION "PLUTO"

Special explosive charges were developed at Station IX in connection with Operation "Pluto", which involved the laying of oil pipe lines on the sea-bed for many miles. During the preliminary work on this operation, it was considered necessary to investigate a method of cutting pipe line free from the coiled drum after the required amount of pipe had been laid. Since this cutting might have to be done at a time when the ship was under fire from the enemy, it was essential that it should be carried out as quickly as possible. One method adopted was to haul the pipe away from the drum and cut it with a blow pipe, an operation which took several minutes to accomplish at the best.

I.S.R.B. were asked to investigate the possibility of cutting the pipe with an explosive charge. The problem was first mentioned without a specific request for assistance to Major Bailey, early in 1942. It was re-opened in November, 1943, by Professor F.H. Garner, and Lt. Cdr. Twysden of the Petroleum Warfare Department, at a meeting with Major Walker. Dr. Cox obtained further particulars of their requirements in a visit to Lt. Cdr. Twysden and Mr. A.C. Hartley, Scientific Advisor to P.W.D., in December, 1943. The whole problem was in charge of Captain Hutchings, D.S.O., R.N., Norfolk House, St. James's Square, London, S.W. 1.

The original requirements were stated to be as follows:

(a) Before the pipe is dropped in the water it must be plugged or capped to keep out sand, but not necessarily to make it watertight; the edges of the cut must therefore not be unduly ragged.

(b) Personnel involved can, if necessary, take cover but a cutting charge which did not give rise to dangerous fragments would be preferred. The pipe remaining on the drum must not be damaged. The use of a heavy steel or other screen around the charge to stop fragments is

undesirable because of the difficulty in man-handling such a shield over the gap.

(c) Owing to the necessity of subsequently putting a cap or stopper on the pipe, it is not thought that cutting the pipe below the water level is a good plan, although this would have the obvious advantage of doing away with trouble from flying fragments. An ideal solution would be a charge which cut the pipe under water and simultaneously closed it over. The pipe, a few feet below water, is at least 3 feet from any part of the ship.

(d) The total number of charges required for the whole operation will be only a few dozen.

The experimental work was commenced at Station IX by Mr. Meek and Mr. Barnsley during January, 1944. A detailed account of the work carried out on the explosive charges for Operation "Pluto" is given in Appendix A. A trial of the final design of charge was carried out at the Surrey Commercial Docks in March, 1944, and the results are described in Appendix B.

Subsequently, the Admiralty declared that it was considered impossible to attach anything to the pipes while on the drum, and consequently the use of the explosive charges was dropped.

P.W.D., however, were convinced that the correct answer had been supplied to the problem.

APPENDIX A. EXPLOSIVE CHARGES FOR OPERATION "PLUTO" 18. 4. 1944

REPORT ON WORK CARRIED OUT FOR OPERATION "PLUTO"

This operation involves the laying of oil pipe lines on the sea bed for many miles. The pipe is laid either from specially converted ships of the dredger type or directly from large drums towed by sea-going tugs. I.S.R.B. were asked to co-operate in preparing a method of cutting the pipe free from the carrier and possibly closing the pipe in order to prevent the ingress of sand, pebbles, etc.

(i) Pipe Cutting

The first requirement was to cut the pipe with a charge that could be fired on the deck of a ship without damage either to personnel or to any apparatus in the proximity. The pipe was $3\frac{1}{2}$" external diameter with $\frac{1}{4}$" walls.

At first sight this target seemed to be quite straight forward and, therefore, probably vulnerable to ordinary methods of attack; a plain charge of 4 oz. P.E. was placed around the pipe and fired. Rather surprisingly, the pipe was not severed, but merely necked (See Fig. 1), thus indicating a highly ductile steel, hence, in order to produce a cutting charge of small enough dimensions to satisfy the required condition, it was considered that probably a small hollow charge would be required.

Several experiments were carried out with this in view (see Figs. 2, 3, 4 and 5). Fig. 5 illustrates the result obtained from a 90° spun former, as shown in Fig. 6. In order to produce a charge suitable for service conditions, this former was assembled with the plywood walls. The P.E. was packed between these walls and backed with shellacked muslin, the two sections being held together by a length of webbing. This webbing also served for fixing purposes. The charge was initiated by a Nobel 1 cm. primer (Figs. 7 and 8). Such charges are robust enough to handle, but will not produce fragments of any penetrating power; the Nobel has a copper sheath, but this appears to be shattered into tiny pieces which do not penetrate more than 1/16" into $\frac{1}{4}$" millboard placed 10" from the charge. The effect of this charge on the pipe is seen in Fig. 9.

(ii) Closure of the Pipe

The original experiment with a plain charge for cutting purposes indicated the possibility of using a similar, but larger, charge as a means of sealing the pipe. However, it was obvious from preliminary experiments that an ordinary plain charge could not be guaranteed to close the pipe even when separated from the pipe by a layer of some inert material, the charge being liable to rupture the walls of the pipe (As in Fig. 10).

The method eventually utilised was to project a heavy steel plate so that it came in violent contact with the pipe. As a result, the pipe was indented and sealed sufficiently to prevent ingress of unwanted material.

The result of the first experiment using this method is illustrated in Fig. 11, a scab produced by a $1\frac{1}{2}$ lb. P.E. charge on a 5/8" mild steel plate was projected onto one side of the pipe. The scab was broken up and evidently had not sufficient momentum.

Further experiments were carried out on this scab-producing charge, but eventually it was deemed necessary to utilise an "assisted" cavity charge for the purpose.

This charge is illustrated in Fig. 12, consisting of a plastic charge with a small strip cavity at each end, the cavity cutting effect weakening the steel slab sufficiently for the main charge to project the centre piece as a whole. This charge functioned satisfactorily. Fig. 13 shows the result of firing two of these charges in air on to opposite sides of the pipe and a reasonably good seal evidently results.

Underwater Effects

It was decided by P.W.D. that the explosive operations should be carried out underwater. It was necessary to alter the design of the cutting charge for this purpose in order to make the whole charge waterproof. The sealing charge also was made into a waterproof charge.

Cutting Charge (Fig. 14)

The cutting charge was adapted for underwater work by replacing the plywood and paper components by tinplate of thin gauge. The The 6 oz. P.E. was pressed on the copper former as before and covered with shellacked muslin. The two halves were hinged together at one end of the semi-circle. The charge was primed by means of a waterproof Type 6 Burster, held in a clip which performed the double purpose of locating the primer in the primer space and also locking the two parts of the charge together. The burster itself, which normally is initiated by a percussion-type fuze, was adapted for electrical firing by means of a watertight gland screwing into the top of the burster, this gland holding a No. 33 electric detonator.

Crushing Charge (Fig. 15)

This was contained in two waterproof boxes, the two halves being hinged so that the whole could encompass the pipe. Inside the boxes was a $\frac{3}{4}$" steel plate, upon which the assisted cavity charge, 10 oz. of P.E., was placed. The charge was waterproofed by a layer of plasticine followed by a layer of paraffin wax. They were initiated by No. 6 C.E. pellets, with single Cordtex tails.

A preliminary set of experiments were carried out at the Frythe, the charges being fired underwater in small tanks. The results indicated that the water shock waves were producing somewhat peculiar results. The cutting charge still cut the pipe but also necked the charge considerably, almost completing the closure of the pipe, while the crushing charge caused the pipe to become corrugated and cracking was also observed.

It was proposed on the basis of these experiments to carry out a comprehensive trial to investigate:

(a) The possibility of using the cutting charge as a closing charge, as well.

(b) Most effective way of using the cutting charge and crushing charge as a pair with particular reference to the prevention of corrugation and cracking.

(c) Effect of the explosive shock on the P.W.D. securing clips.

These trials were carried out at the Surrey Commercial Docks on Wednesday, 23rd March, 1944. A report on the trials is attached to this report (Appendix B).

APPENDIX B. EXPLOSIVE CHARGES FOR OPERATION "PLUTO" 28.3.45.

REPORT OF TRIALS ON PIPE-CUTTING BY MEANS OF EXPLOSIVES

Present:
Mr. Meek)
Mr. Barnsley) I.S.R.B.

Mr. Ganley)
Mr. Veness) P.W.D.

Mr. Hammick)
Mr. Price) P.W.D. (part-time)

A trial was carried out at the Surrey Commercial Docks on Wednesday, 23rd March, 1944.

GENERAL

The charges were fired on lengths of pipes supplied by P.W.D' which were suspended in a horizontal position below the surface of the water. The ends of the pipes were plugged so that they were not filled with water. The charges were placed on the pipe which was then dropped into the water and held in position by means of various ropes. The explosive charges were initiated electrically by means of a firing cable and an Exploder Mark VII.

Care had to be taken during launching and manoeuvring of the pipe and charge into position that they did not come in collision with the dock side or any other solid object which might damage the charge. The depth of the dock was about 18 ft., and the depth at which the charges were fired varied from 5 to 10 ft.

CHARGES

For cutting charges a special ring cavity charge was used although modifications to this charge were made on the spot in order to obtain further experimental evidence.

The charge was in two semi-circular parts hinged together and the explosive was shaped so that use was made of the cavity effect. The pipe was subject over the whole periphery to the explosive attack characteristic of the cavity effect. The quantity of explosive in the standard cutting charge, before any modifications had taken place, was $5\frac{1}{2}$ ozs. A number of experiments with this charge in air had shown that the cutting power was adequate. The present trial was expected to show if the underwater shock would modify the shape of the cut ends. Alterations to the weight of the charge were envisaged in order that the underwater shock effect could be controlled and its usefulness or otherwise estimated.

Thesealing charge was in two halves, each carried in an air-tight container of tin plate, the two containers were hinged together in such a manner that they could be made to encompass the pipe. Inside the container there was a $\frac{3}{4}$" steel plate upon which the explosive charge was situated. Between the steel plate and the pipe there was an air space. The action of this charge was that when the explosive was brought to detonation, it projected the heavy steel plate through the air space so that it came into violent contact with the pipe. As a result of this, the pipe was indented, and since this indentation was occurring simultaneously from the two sides of the pipe by virtue of firing the two halves of the charge together, the pipe was expected to be sealed.

Details of the Standard Pair of sealing charge s and of the unmodified cutting charges are in the Appendix

TABLE of RESULTS

	Charge	Cutting Result	Sealing Result
1.	Cutting $5\frac{1}{2}$ oz. shaped charge with radial primer	pipe cut and closed. Longitudinal crack open for $\frac{1}{2}$".	
2.	Cutting 8 oz. shaped charge with radial primer	Pipe cut and closed. Two longitudinal cracks. Fluting.	
3.	Cutting As expt. No. 1 Sealing Standard Pair.	As Expt. No. 1	Pipe indented over 16" and crushed flat over 2". Corrugated at edges of the crushed portion. A longitudinal crack on each side. Edges of cracks pressed close against ppposite sides of pipe so that there is very restricted access to inside of pipe - if any at all.
4.	Cutting $3\frac{1}{2}$ oz. shaped charge with tangential primer. Sealing. Standard Pair	Pipe not cut cleanly all round. Broken off aver. abt. 1" and lip formed on one half only otherwise the pipe was closed satisfactorily.	Result similar to No. 3
5.	Cutting $5\frac{1}{2}$ oz. shaped charge with tangential primer. Sealing. Standard Pair	No cutting whatever. Charge or primer displaced during launchimg Pipe recovered in one piece, but clip loosened.	Result similar to No. 3
6.	Cutting Repeat of No. 5 Sealing Standard Pair with an empty container on each side for air boxes	Satisfactory cut, pipe practically sealed.	Sealing O.K. No longitudinal cracks. Side indentation less severe than in Nos. 3, 4 and 5, tendency only to edge corrugations.
7. 8.	Fired together Cutting No charges Sealing 7. As no. 6 8. one half of Standard Pair		7. Result similar to No. 6 8. Result - pipe sealed but also bent through 45° Splitting of edges of flattened portion.

NOTES ON THE RESULTS

1. Cutting Charges

The results obtained with Experiment 1 showed that the pipe was cut, and in addition, the ends were swaged together so that the end of the pipe looked like the nose of a shell from a field gun.

The second Experiment was, therefore, performed with a charge somewhat increased in weight, but fitted to the same former. The result showed that the extra charge increased the fluting of the pipe and caused two longitudinal cracks.

In the third Experiment, therefore, the same weight of charge was used as in Experiment 1. The result of firing this charge was very similar to the result of Experiment 1. In both cases, there was one point at which the indentation of the pipe was greater than elsewhere and it was observed that this corresponded to the position of the point of indentation (a Nobel's 1 cm. primer). It was decided to modify the initiating system so that the axis of the Nobel primer was not pointing at the pipe.

Some of the explosive was removed from the cutting charge used in Experiment 4 and the primer was placed in a position tangential to the pipe. The result of this was that the pipe was not properly cut out through its periphery, a fracture occurring at a point beneath the primer forming a lip of about 1" where it had been torn apart instead of being cleanly cut. Except for this, the cutting end of the pipe was very satisfactory in that there was little fluting and the only cracks were those due to the formation of the lip, which appeared to have torn back for a short distance.

In Experiment 6, the charge used was the 5½ oz. charge, but modified so that the primer was placed tangentially to the circumference of the pipe. With this charge, not only was the pipe satisfactorily cut, but it was practically sealed in addition.

2. Sealing Charges

In Experiments 3, 4 and 5, the standard pair of cutting charges was used. In each case the pipe was crushed flat at the point where the steel projectiles inside the charge had hit it. The pipe was, however, indented over a considerably greater length and this is probably due to the underwater shock from firing the charge near the pipe. A further phenomenon which occurs under water firing but not in air, is that where the pipe is crushed flat, there is corrugation at the edges, so that the pipe is not squashed exactly flat, ~~but in the manner which can be seen in Fig.~~ In addition, in each case there ware longitudinal cracks up to 6" long in the flattened portion of the pipe. The edges of these cracks had blown back against the interior of the opposite surface of the pipe so that despite the presence of the cracks, the pipes were very nearly sealed.

Although these seals would probably be satisfactory for normal use, it was decided to carry out experiments to improve them. Therefore, in Experiments 6 and 7, the standard pair of sealing charges were fired after they had had air boxes of tin plate fastened on each side of them. This was in order to reduce the waterborne shock, which was thought to be responsible for deforming the pipe so that the corrugations occurred when the pipe was sealed by impact with the projectile plates. In addition, it was hoped that the longitudinal splits would disappear (on the assumption that they had their origin in the same mechanism)

In both Experiments 6 and 7 there were, in fact, no longitudinal cracks. The indentation of the pipe was less severe and the end corrugation was very much less marked than in Experiments 3, 4 and 5. It appears, therefore, that the use of an air box each side of the standard charge improved its performance from the point of view of getting an undistorted seal.

Experiment 8 was included in order to see the effect of omitting one half of the standard pair. The pipe was flattened but also bent through about 45° due to the unbalanced application of the explosive force. The flattened portion of the pipe had split at the edges.

CONCLUSIONS

1. Cutting Charge

A 5½ oz. charge will cut the pipe satisfactorily. Tangential initiation reduces cracking and gives a closed end to the cut pipe; hence there is a possibility that the sealing charge could be dispensed with entirely.

2. Sealing Charge

The standard pair sealed the pipe, although there were cracks formed which, however, would not allow the ingress of any but the smallest objects.

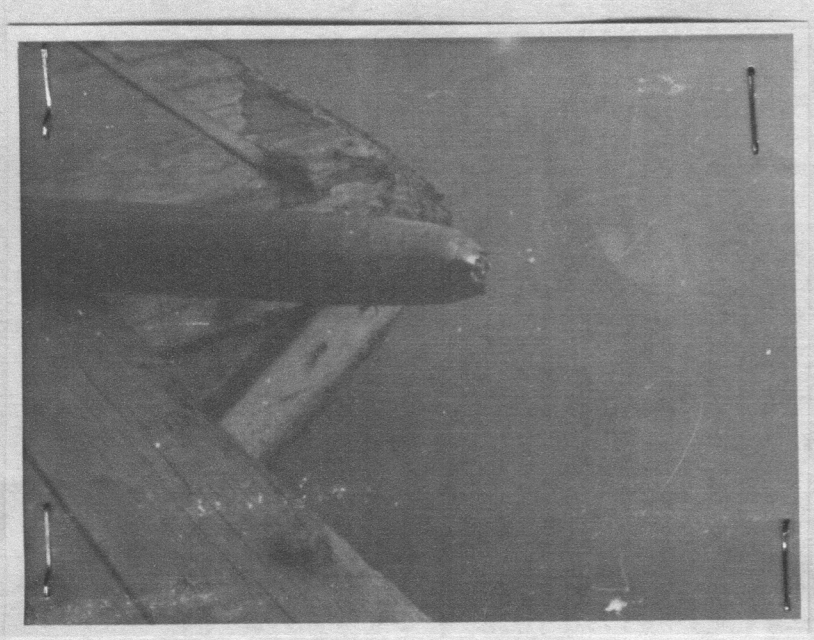
Flanking the standard charge with air boxes did not reduce the efficacy of the seal, but avoided the longitudinal cracking and, to some extent, avoided the edge corrugation.

3. The use of unbalanced charges bends the pipe.

RECOMMENDATIONS

(i) 5½ oz. cutting charge modified to take a tangential primer should be used as the cutting charge.

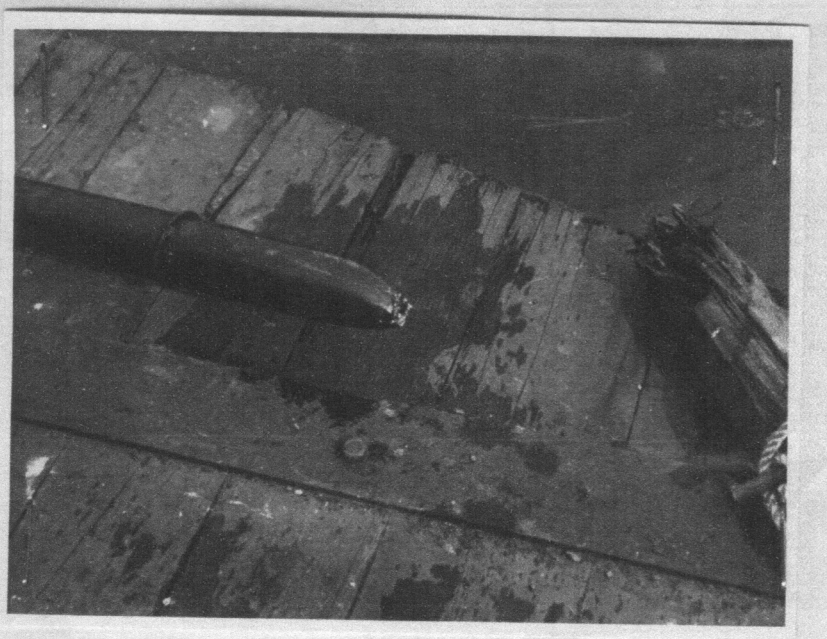
(ii) If the sealing produced by the cutting charge above is inadequate, then a special sealing charge should be developed, incorporating the air box used in Experiments 6 and 7.



5½ oz. P.E. in special cavity charge.

The pipe has been severed and practically sealed

EXPERIMENT 1. Cutting only

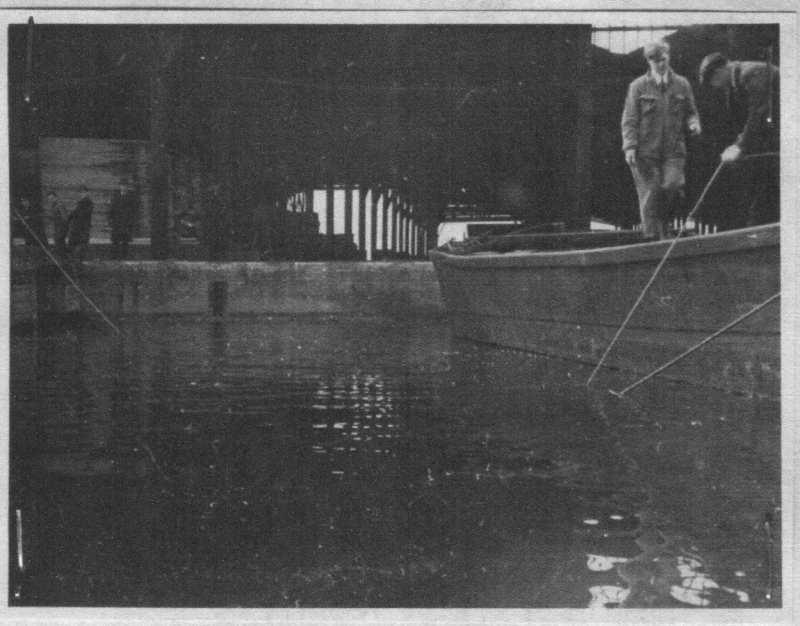


8 oz. P.E.
in special
cavity charge.

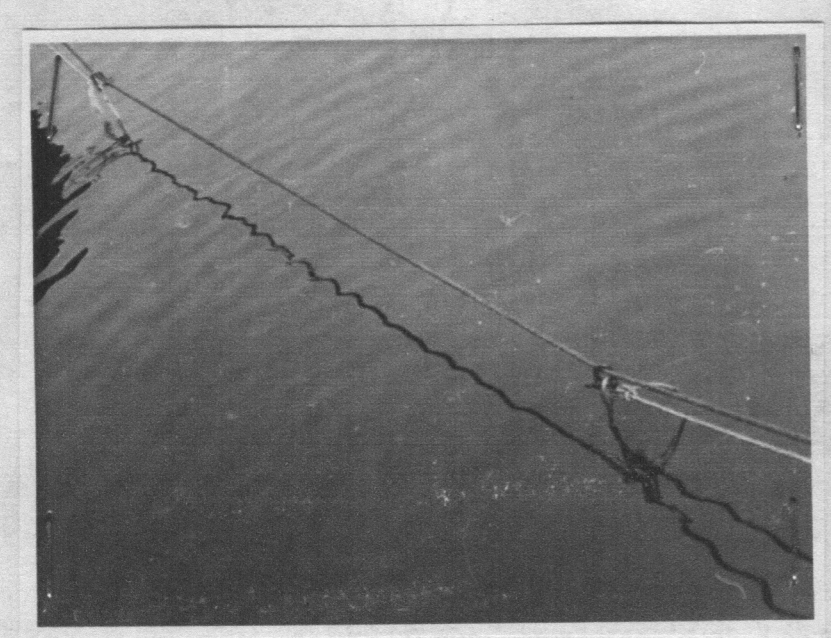
The pipe has been severed and practically sealed although there are cracking and fluting.

Fluting

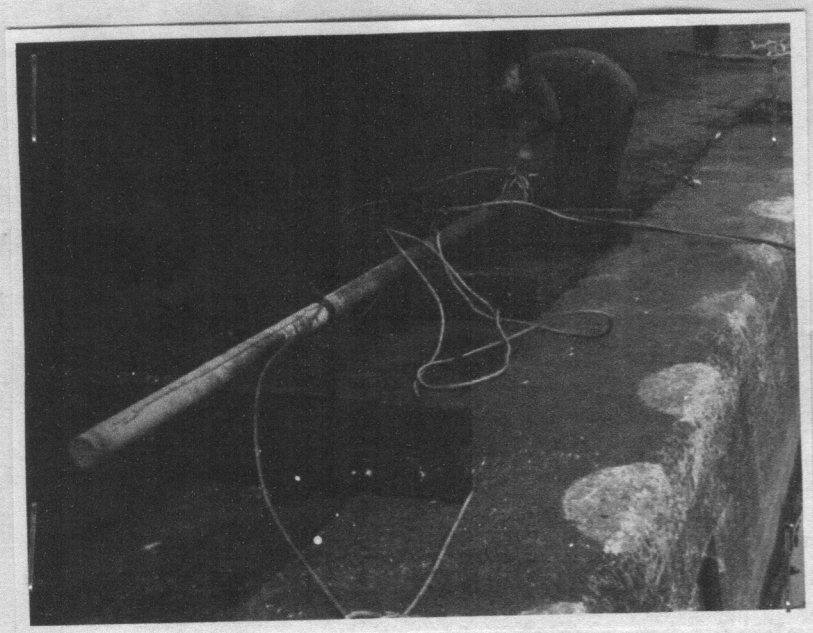
EXPERIMENT 2.



Typical method of suspending the pipe and charges.

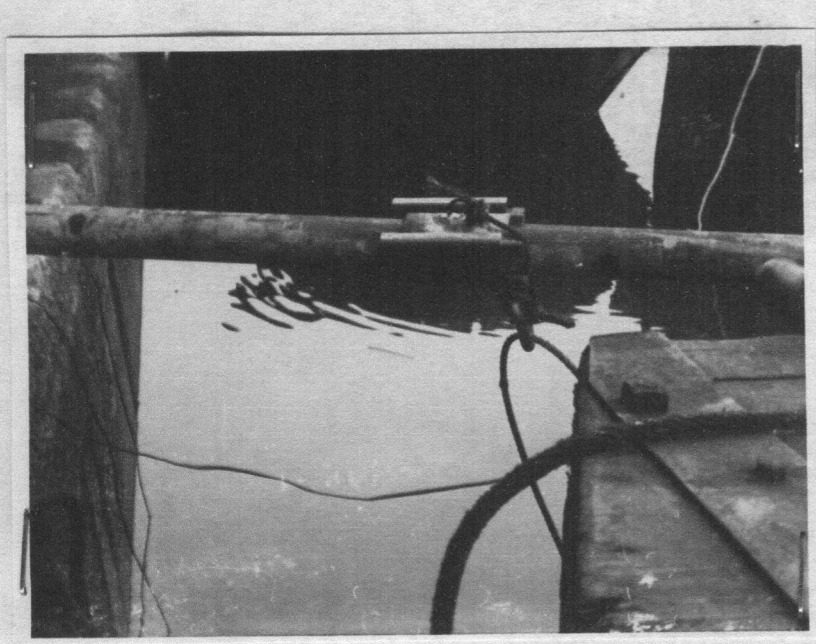


EXPERIMENT 3

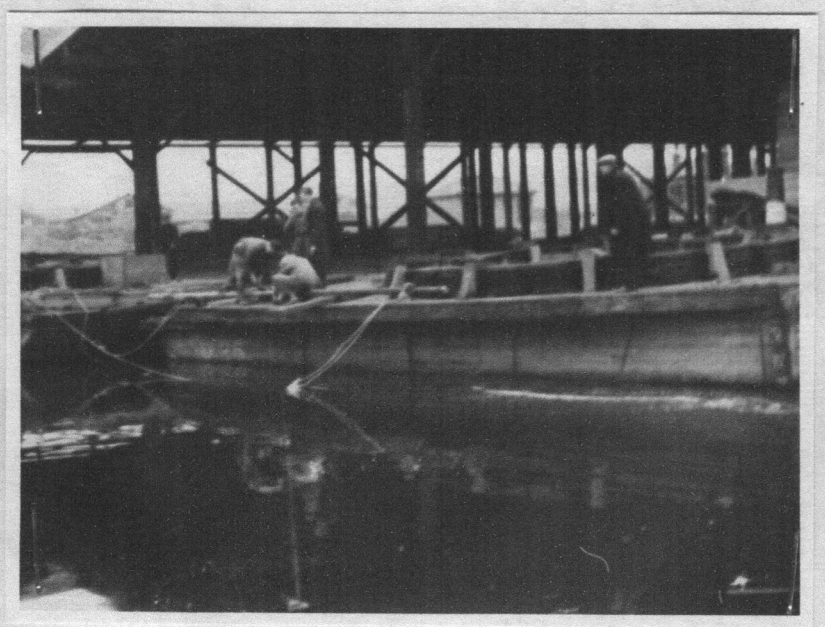


Securing slings to length of pipe.

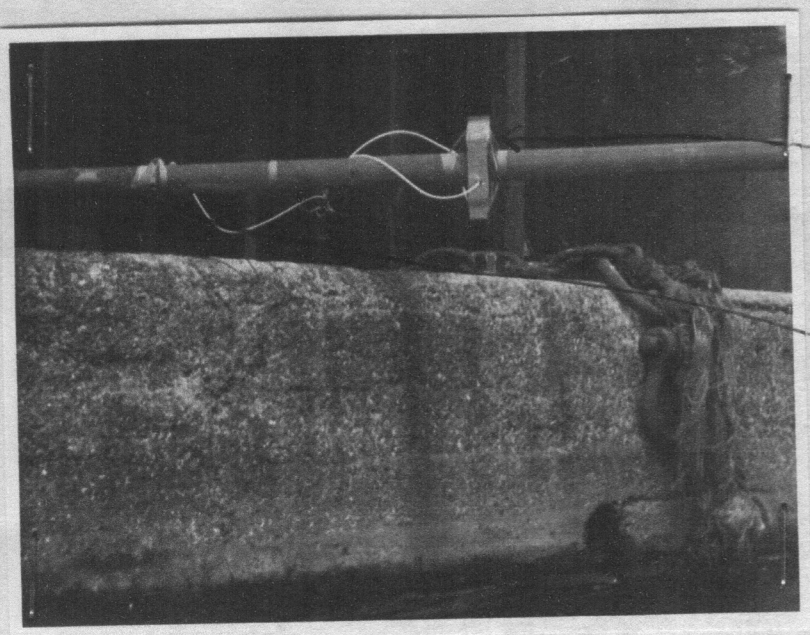
Improvised clips in use.



P.W.D. type of clip to be used in service

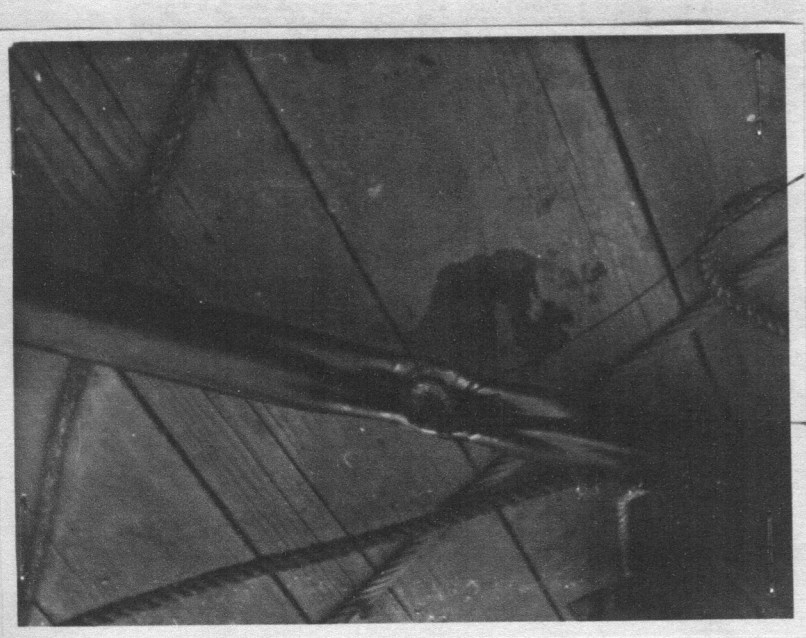


Preparing the charges before launching.



Sealing Pair

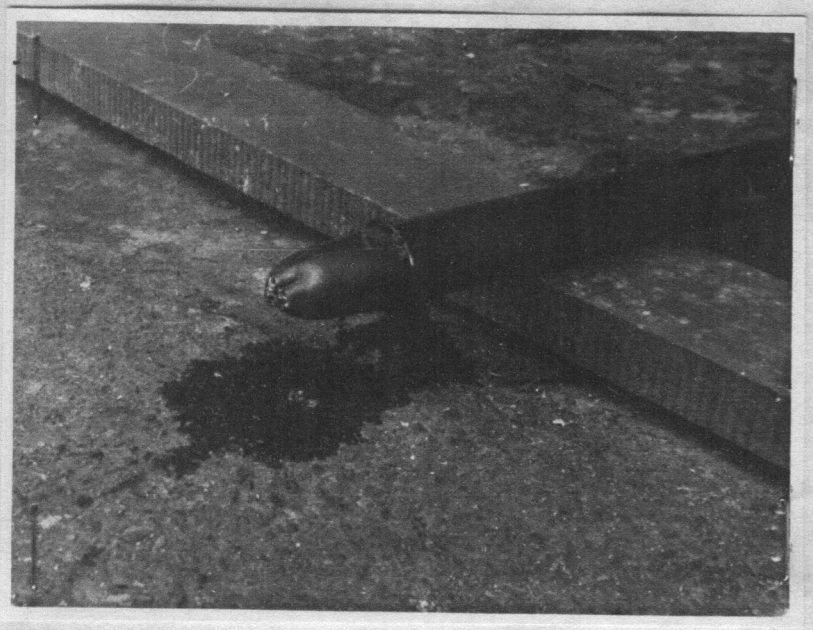
Cutting Charge



Longitudinal Crack

Sealed over 2" length of pip. Corrugation at edge is not visible

EXPERIMENT 3.

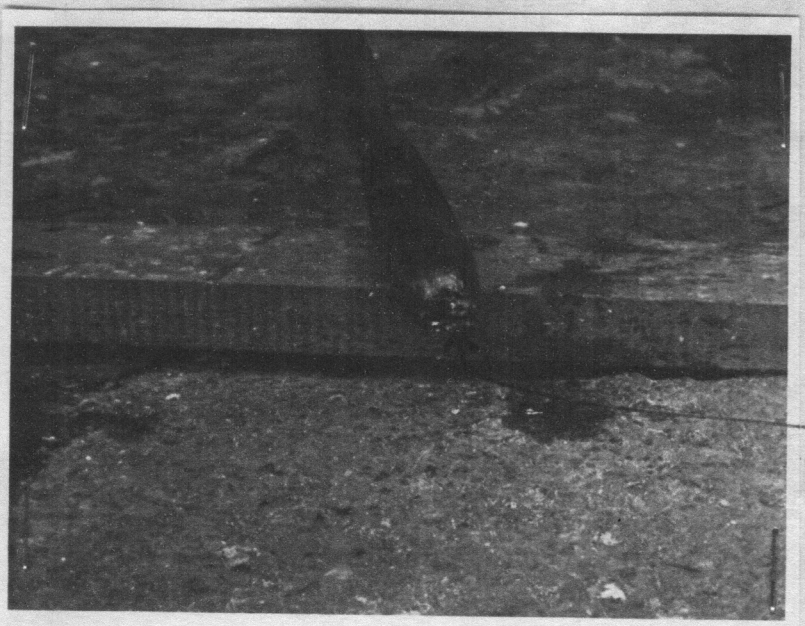


$5\frac{1}{2}$ oz. P.E. in special cavity charge.

Cut end of pipe

Cut end of pipe, showing the swaging-in of the cut ends.

EXPERIMENT 3.

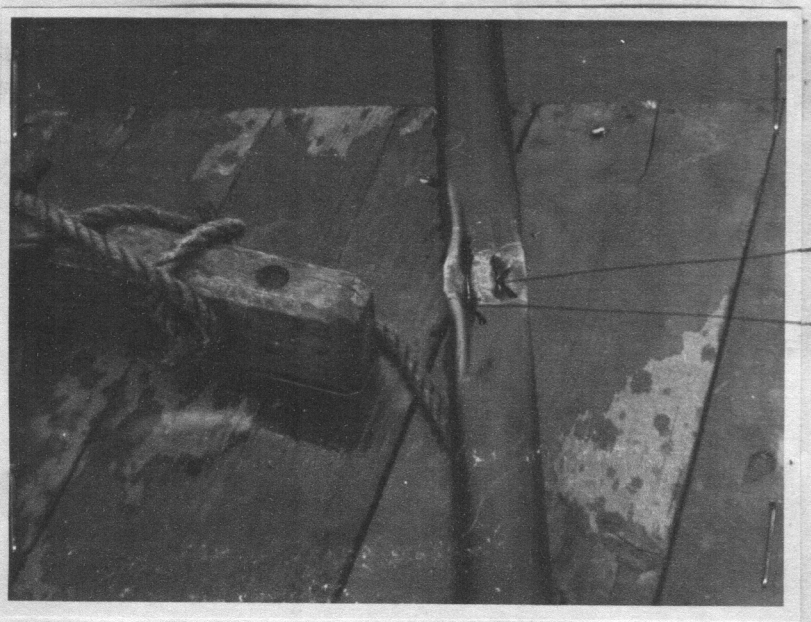


$3\frac{1}{2}$ oz. P.E. in special cavity charge.

Primer placed with its axis tangential to the pipe.

Lip torn back

Cut end of pipe. In this case the swaging-in does not appear to be complete, probably due to the lip formed by the incomplete cut.



Standard pair of sealing charges.

Longitudinal cracks

EXPERIMENT 4.

Effect of standard pair of sealing charges.

Sealed over this length

Edge corrugations.

EXPERIMENT 4.

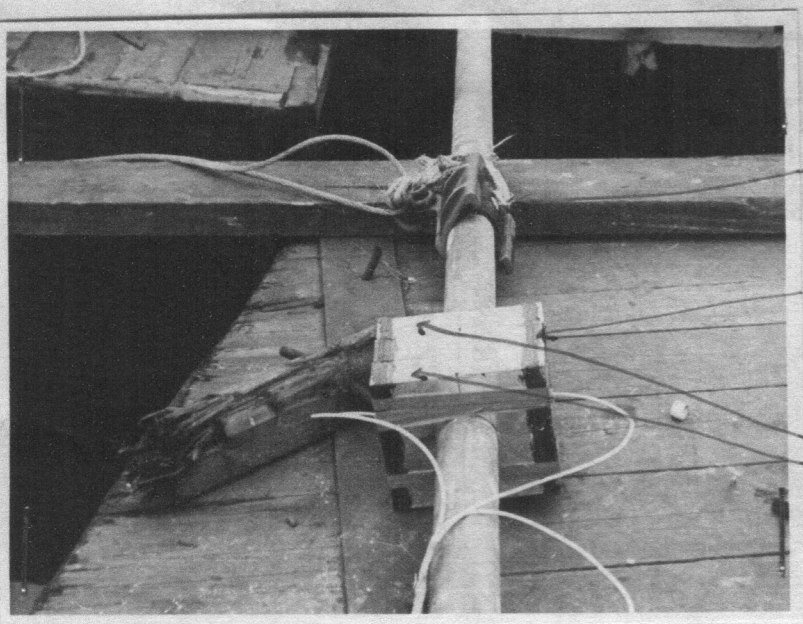
Sealed over this length.

Longitudinal crack

Edge corrugations

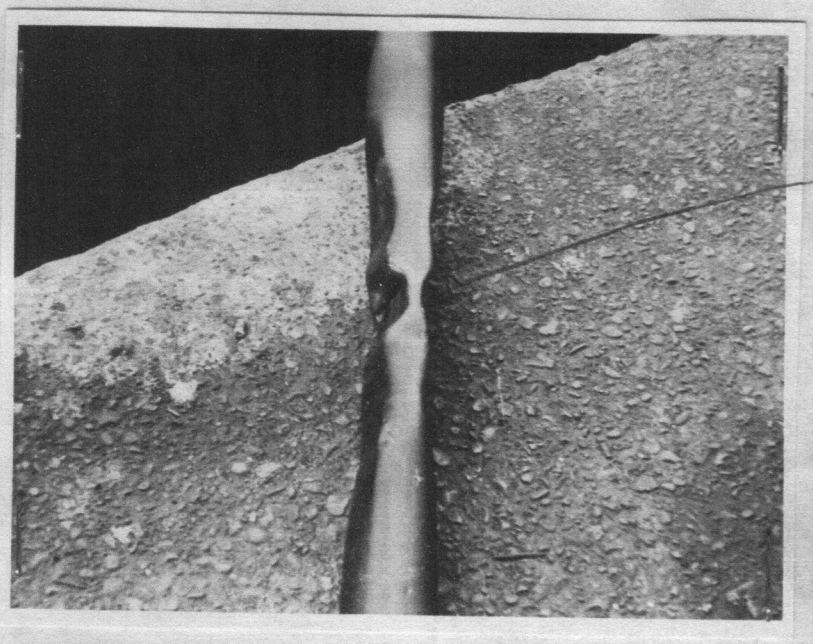
Effect of standard pair of sealing charges.

EXPERIMENT 5.



EXPERIMENT 6. Standard pair of sealing charges flanked by empty boxes to give air space at the sides.

EXPERIMENT 6. Result of firing charges above. Note absence of longitudinal cracks and considerable reduction of indentation.

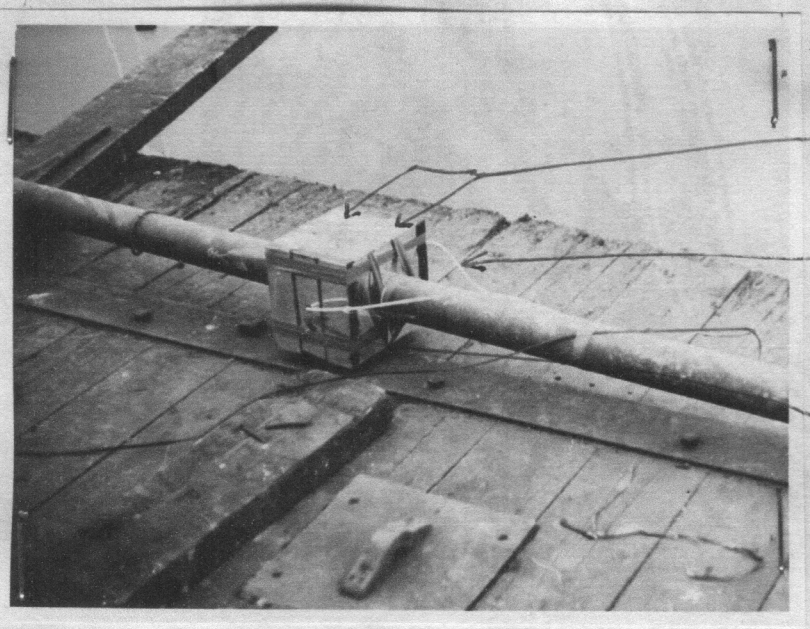


No edge corrugation.

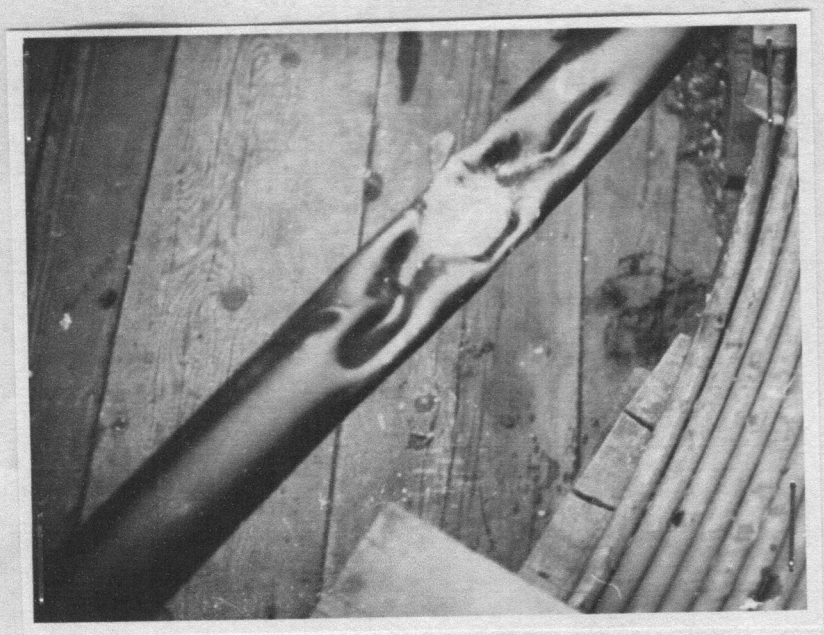
EXPERIMENT 6. Result of firing standard pair of sealing charges flanked by air boxes.

5½ oz. of P.E. in cavity charge with tangential primer.

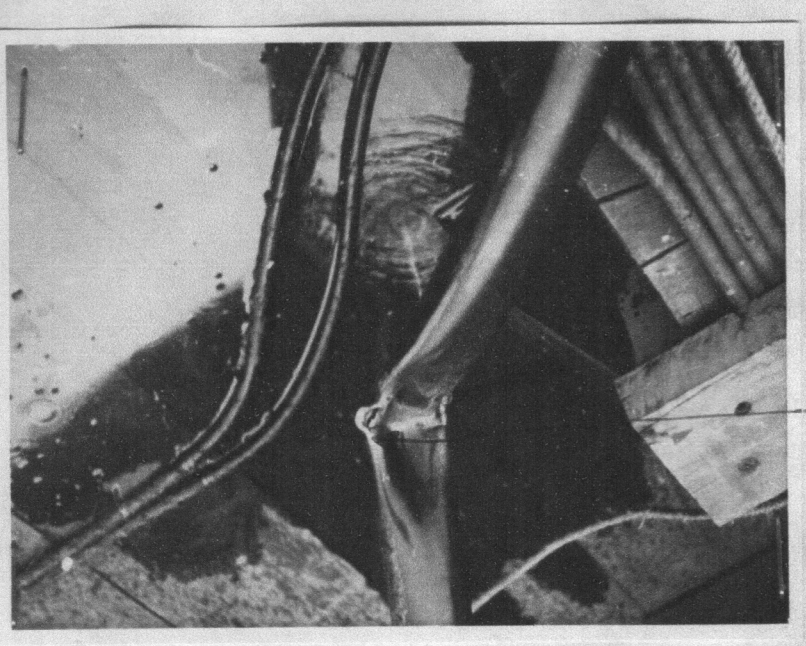
EXPERIMENT 6. Result of firing above charge. Pipe is well sealed. The dark patches are not holes but shadows.



EXPERIMENT 7 Charge with side air boxes as in Experiment 6



EXPERIMENT 7 Note absence of longitudinal cracks.



Half a standard pair of sealing charges

Edge cracking

EXPERIMENT 8 Result of half a standard pair. Note the deflection of the pipe as a whole due to the unbalanced explosive forces.