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STRAIN GAGE WATERPROOFING METHODS AND INSTALLATION OF GAGES ON PROPELLER STRUT OF USS SARATOGA (CVA 60)

by

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INDUSTRIAL DEPARTMENT

RESEARCH AND DEVELOPMENT REPORT

April 1958

Report 1146

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Prepared for Presentation at the Annual Meeting
of the Society for Experimental Stress Analysis
San Diego, California, October 9-11, 1957
SESA Paper No. 362

April 1958 Report 1146

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ABSTRACT

This paper describes new waterproofing techniques and materials for protection of strain gages and associated wiring. Certain synthetic rubber compounds and two wax products have been found to be very satisfactory waterproofing materials. Techniques for the use of these materials are described in detail. In addition to providing good waterproofing, the synthetic rubber compounds afford considerable mechanical protection from turbulent water flow, underwater explosion shock, particle abrasion, and direct mechanical contact.

Details are given for an entirely new method for protecting gages on the exposed surface of underwater ship hull plates and hull appendages. One of several such applications, consisting of five strain gage locations on one of the propeller-shaft struts of the USS SARATOGA (CVA 60), is discussed.

INTRODUCTION

Many experimental research and testing projects conducted at the David Taylor Model Basin and at various locations in the field require that strain gages be operated in water for varying periods of time. The problem of providing adequate waterproofing for such installations led to the initiation of a comprehensive investigation of waterproofing materials and to the development of techniques for efficient use of these materials. Much has been accomplished in the past on the problem of waterproofing strain gages for installation on large surfaces such as ship hull plates.[1-5]

An entirely new technique has since been developed for waterproofing strain gages on the exposed underwater hull surfaces of ships.[6] Essential details of this new technique, "The Dean Shim Cap Method" of gage waterproofing, are presented in later sections of this paper.

Successful strain gage protection methods are largely based on the choice of proper techniques and materials. Certain criteria for choice of materials are as follows: (1) Materials for waterproofing resistance wire strain gages should be free from moisture, active acids, and salts, since these might cause corrosion of the gage elements or the connecting leads; (2) Materials should also be free from solvents that might adversely affect the gage bonding cement. Water absorption, if any, should be at a very slow rate; (3) Materials should be pliable over a wide range of temperatures and should adhere tenaciously to metallic surfaces; and (4) it is desirable that the materials be rugged enough to provide some mechanical protection for the gages, yet additional stiffness and bulk must be kept at an absolute minimum. These are major requirements. They are not necessarily compatible with one another. Nevertheless, they provide standards which aid in the evaluation of waterproofing materials.

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[1]References are listed on page 11.

Results from actual field use of the materials and techniques presented in this paper have been very successful. Delicate strain gage balances for ship model work[7-9] protected with Di-Jell 171 (soft wax) will withstand submergence in still water for as long as two to six months. 3-M synthetic rubber compounds are used where turbulent water flow is expected. Gages and wires on the exposed surfaces of hydrofoils protected with 3-M compounds have withstood water flow at velocities of 60 knots.

A detailed report is given later in this paper for one such waterproof strain gage application on an after propeller shaft strut of the USS SARATOGA (CVA 60).

Some of the text material, with illustrations, included in this paper was discussed by the author at a session of the Strain Gage Techniques Panel during the spring meeting of S.E.S.A. at Cincinnati, Ohio, on 15 April 1954.

GENERAL CONSIDERATIONS

Resistance wire, SR-4,* strain gages that are immersed in water or used in humid atmospheres must be completely protected from moisture if they are to function properly. The effect of moisture or water in contact with the gage is to produce an undesired electrical leakage path, shunting the gage elements to one another and to the metal on which the gage is mounted, i.e., "ground." This usually results in a decrease in gage sensitivity and a shift in bridge-balance zero. Depending on the magnitude of these changes, the measurement accuracy may be seriously impaired or the gage installation may be completely unusable. Moisture also gradually weakens nitrocellulose cements with which paper gages are assembled, and destroys the bond between the gage and the mounting surface. Bakelite base gage material and bakelite cement usually withstand the effects of moisture, but exposed gage wires are still adversely affected.

The initial resistance to "ground" of a properly applied and dried strain gage, either paper or bakelite, will usually be in the order of 1000 to 10,000 megohms. There is little adverse effect on the electrical response of the gage as long as this leakage resistance does not fall below about 25 megohms, the tolerable lower limit being dependent on the accuracy and stability requirements of the particular test at hand. The effectiveness of any waterproofing coating is judged by the degree to which it helps maintain this high leakage resistance when gages are exposed to moisture or submerged in water.

One vital factor in the waterproofing problem is the length of time over which the gage is to be submerged. Ideally, the waterproofing should be good indefinitely, and this remains the ultimate goal of this investigation.

One particular caution should be noted here in regard to the measurement of high resistances associated with strain gage circuits. Many commercial megohmmeters or "meggers" employ high-voltage potentials (in the order of 500 volts) at the probe terminals in order to

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*Trade Mark of Baldwin-Lima-Hamilton Corporation.

obtain a readable current on an indicating meter. If such high potentials are applied to a strain gage circuit, a very high potential gradient is set up because of the minute spacing between gage wires and the mounting surface. This may result in an electrical breakdown at weaker spots in the insulation. A carbonized path results, the leakage resistance is permanently lowered, and the gage installation may be completely ruined. The above possibility can be avoided by using megohmmeters that employ low terminal potentials. One such instrument for this resistance measurement is the General Radio Company Type 729-A Megohmmeter. This is a very useful, portable, battery-operated instrument.

SYNTHETIC RUBBER COMPOUNDS

The two synthetic rubber (polysulfide) compounds found most useful and versatile are Minnesota Mining and Manufacturing Company* products identified as EC-864 and EC-801.** Each has to be mixed with an accelerator, EC-807, before use to effect self-vulcanization. Both materials have a viscosity, prior to curing comparable to that of a viscous paste. When cured, both are very resilient and tough, hardness ranges from 50 to 60 Shore "A" Durometer at 70 F. The flexibility and adhesive properties are good for temperatures as low as –50 F, and the compounds remain firm up to 250 F.

EC-864 can be built up to a good thickness in one coat and may be applied to vertical surfaces without resulting sag. When cured, this material has a rough, dull surface and shows good resistance to lubricating oils and to many solvents. EC-801 is not so viscous and requires multiple coating to develop a thick section. It has a smooth, shiny surface. EC-801 meets military specifications MIL-S-7502 for contact resistance to aircraft fuel and oil. It is recommended for use on small flexures and balances, but it may introduce excessive hysteresis in delicate low-range balances or flexures. Ordinarily, both 3-M materials are entirely satisfactory for use on larger flexures and balances as well as on heavy structures, such as on ship hulls.

SYNTHETIC WAX PRODUCTS

The two most versatile wax products tested are Di-Jell 171 and Zophar Mills C-276 Di-Jell is a soft wax which is applied in paste form and does not require melting for application. Zophar Mills C-276 is a viscous syrup when melted. At ordinary temperatures it is tough, sticky, and tenacious.

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*Names and addresses of suppliers for the various products mentioned throughout the report are listed at the end of this paper (Table 1).

**Manufactured by the Thiokol Chemical Corporation under the trade name "Thiokol" (R), these products are compound and distributed by a number of suppliers; see Table 1. The trade name 3-M Brand and the EC- designation are those of the Minnesota Mining and Manufacturing Company.

TECHNIQUES OF APPLICATION

In the following sections, specific instructions are given for the use of synthetic rubber and wax compounds in the waterproofing of strain gages.

It is assumed that the reader has a prior knowledge of the general techniques of gage mounting. The choice and handling of connecting wires are discussed in detail in TMB Report 797 (Reference 7) and this should be reviewed when planning a gage installation. Special techniques for mounting bakelite gages on curved surfaces and on stainless steel are discussed in Reference 9.

SYNTHETIC RUBBER COMPOUNDS

Before the actual application of these materials, test batches of the compounds and primers should be tried on the specific type of metal on which the gages are mounted. The bonding characteristics of the materials can be observed and the application procedures perfected.

The following step-by-step procedures are for the application of 3-M compounds over gages mounted on carbon steel, stainless steel, or "ST" types of aluminum:

1. Carefully clean the gaging areas to ensure that all surfaces to be waterproofed are free from grease, oil, and fingerprints. After the gages are mounted and dried, scrape off excess cement from the metal around the gages to within 1/16 inch of the gage. Using absorbent cotton dampened with acetone, swab around the gage and up and down the wires until a fresh piece of cotton shows no discoloration. Discard cotton swabs as they are used, and do not contaminate the solvent bottle with used swabs. Care must be taken to keep the solvent from any direct contact with paper-base gages. Bakelite-base gages may be swabbed directly.

2. For paper-base gages, apply a wax buffer precoat of Zophar C-276 or Di-Jell 171 to extend at least 1/4 inch beyond the perimeter of each gage. This prevents direct contact of the 3-M compounds with the gages. It has been found that direct application of these compounds over paper-base gages tends to lower the gage leakage resistance. Bakelite gages ordinarily do not require this precoat.

3. If EC-864 is to be used as the principal coating, a single thin coating of a 3-M metal primer should be applied next. No primer is needed for EC-801 as it contains added bonding resins. EC-853 primer* may be used for all steels, including stainless, and for "ST" types of aluminum. Brush the primer over the area of freshly cleaned metal around the gage. The primer need not be applied over the wax buffer coating nor over bakelite gages, but should cover all adjacent bare metal surfaces thoroughly. Allow the primer to dry for at least 1 hour

*Primer EC-853 should be thinned 50 percent with methyl isobutyl keytone.

at room temperature, or longer if the humidity is high. Mild heat (110 to 130 F) will speed the drying. No adverse effects have been noted if the primer is allowed to dry for an extended time prior to application of a 3-M compound, provided the installation has been kept free of oils, fingerprints, dust, etc. Clean the plastic insulation on connecting wires with acetone, and prime thinly with EC-1217.* Clean the rubber insulation with acetone and naphtha solvent, then prime thinly with EC-853. Primer application brushes should be washed out with acetone.

4. Prepare the material for the final waterproof coating by mixing either EC-864 or EC-801 base with EC-807 accelerator. Mix ten parts by weight of the base to one part of the accelerator in absoutely clean mixing vessels. Do all mixing thoroughly. (If the accelerator has settled out in storage, stir or shake jar vigorously until any top fluid is completely blended.) EC-864 may be mixed in clean cans or bowls. EC-801 requires more thorough mixing. On a flat surface, such as a slab of safety glass, stir and "fold in" the accelerator with a stiff spatula. Do not permit the accelerator to dry out around the edges and flake into the fresh mix. Do not mix more material than can be used in the next 30 minutes. EC-864 and EC-801 are available in 1-pint cans, and the proper quantity of accelerator is furnished in separate glass jars.

5. Next apply the mixed compound over the gage area with a putty knife or spatula, and build up the desired thickness. The thickness usually required is approximately 1/8 inch. Possible adverse hysteresis effects, space clearances, expected submergence period and general conditions should all be considered in determining the thickness that should be built up. The materials can still be shaped up to 2 hours after application. The surface becomes firm and tack-free in about 12 hours, and the compounds are completely cured in 24 to 36 hours at room temperature. The curing process is an internal chemical reaction. However, high humidity contact, such as on a rainy day, will tend to speed curing. Speedier oven cures are obtained at a given temperature by placing in the oven an open container of water with a large surface area.

6. If the surface of EC-864 requires smoothing, trowel with a spatula dripping wet with alcohol before complete curing. After curing, the surface may be sanded. EC-801 does not respond to such working, but may be overcoated with EC-864 either when freshly applied or after complete curing. These materials will bond to each other in either order.

7. After the 3-M compound has cured, apply several coats of Herecrol RC-9 primer as a surface sealer. This is a quick-drying (10 to 20 minutes), glossy-surface, synthetic material that provides sealing protection over the main waterproofing compound. Stir or shake primer and apply by brush.

*Primer EC-1217 should be thinned 50 percent with methyl isobutyl keytone.

WAXES

1. Mount the gages in the usual manner. Prepare gages, connecting wires, and sealing space around the gages for the application of wax in the same manner as outlined for the rubber compounds.

2. If possible, warm the metal sealing area to between 125 and 150 F. A heat lamp is satisfactory for this purpose.

3. In the case of Di-Jell 171, knead the wax at room temperature or slightly warmer. "Butter" the kneaded wax over the gage and metal sealing area with the blade of a screwdriver, knife, or spatula. The buttering technique overcomes the layer separation effects that are common when Di-Jell 171 and many other waxes are melted and brushed on. As with rubber materials, the exact thickness required for waterproofing will depend on the contemplated gage service. Avoid leaving any "pin holes" and "pipe lines" in the wax. Be especially careful to check the easy-to-miss area underneath gage connecting wires.

4. In the case of Zophar C-276, melt the wax by heating to about 220 F. Then brush the wax over the gages and connecting wires. This wax, as well as many other types, may loosen from a surface after several months, because of gradual contraction of the wax.

COMBINED USE OF RUBBER AND WAX COMPOUNDS

The synthetic rubber and wax compounds may be applied in combination to good advantage on certain gage installations, thus utilizing the best properties of both.

One example is the use of a wax buffer precoat on paper-base gages before EC-864 or EC-801 is applied, as described above.

THE DEAN SHIM CAP METHOD OF GAGE WATERPROOFING

This technique has been developed by the author at the Taylor Model Basin to provide a means of waterproofing strain gages on the outside hull plates of full-scale ships and hull appendages with the introduction of an absolute minimum additional mass or stiffness to the plate. Since its development, many tests have been conducted by the Model Basin that could not have been otherwise accomplished successfully by previous methods.[10,11]

The method used to waterproof the strain gages is illustrated in Figure 1. The gage is first mounted, dried, wired, and coated with Di-Jell 171 wax, then a partial coating of 3-M EC-801 synthetic rubber is applied. A cap of thin stainless-steel shim stock 0.002 inch thick is rolled on and pressed down into the fresh 3-M waterproofing compound, and then a final coating of synthetic rubber is applied over the entire placement.

Before water can penetrate this installation and reach the strain gage, it must follow a path parallel to the specimen surface and pass through several inches of waterproofing. The stainless-steel shim cap provides an impervious barrier to moisture from other directions.

When used with EC-864, the stainless-steel shim cap requires a primer such as EC-853. It does not generally require a primer coat when EC-801 is employed as the waterproofing compound.

STRAIN GAGES ON USS SARATOGA SHAFT STRUT

A specific example of the use of the Dean Shim Cap Method is shown in Figures 2 through 10. Strain gages were mounted on one of the after-propeller shaft struts of the USS SARATOGA, a FORRESTAL-Class aircraft carrier, while the ship was under construction at the New York Naval Shipyard. Figure 2 shows a drydock view of the portside propulsion system. The strut instrumentation took place on the starboard side.

A formal Model Basin Report (1133) on the analysis of the trials data has been prepared by the Structural Mechanics Division.[11]

STRUT INSTRUMENTATION

Original scheduling plans called for the ship's initial sea trials to be made four to six months after the strain gage installation was made. During the intervening time between installation and the sea trials, the drydock was re-flooded and the waterproofed strain gages were exposed to continuous salt water immersion and to violent water flows created by the propellers during dockside trials. Thus, valuable strain gage life expectancy was unavoidably being consumed. Limited drydock availability time for the instrumentation of the strut was attributed to tight production schedules required in finishing the ship's construction. The builders' sea trials were not run during the four to six month period, but eight and nine months later! Instead of one sea test for the ship, there were two! All strain gages functioned satisfactorily during both trials. The ship trials consisted of various speeds steaming ahead and with periodic full rudder positions (port then starboard) at full speed.

Strain measurements were made at four locations on the after strut for the number two shaft and one on the hull. Vibration studies were made at three locations in the same strut configuration. The approximate physical size of the struts is 18 feet long by 3 feet wide by 6 inches thick at the center. Figure 3 locates the instrumented struts and shows the path of the connecting cables from the test area to the instruments on the hangar deck. Figure 4 shows two of the five separate gage locations. The other two gages are directly opposite the gages shown on the face of the strut. Strain gage locations 1 and 2, and 3 and 4, each contained two complete four-arm bridges; one bridge for bending, the other for axial load. Strain gage location 5 contained a single four-arm bridge and was so arranged to measure total strain at a point on the hull on the same line as the strut longitudinal axis. In order to help give the reader a greater insight into the vast proportions of a super-carrier, together with the tremendous organization and effort that it takes to make such a gage installation, Figure 5 was included.

PREPARATION AND INSTALLATION OF GAGES

Scaffolding erected by the New York Naval Shipyard for the project was of tremendous value. This type of work should not be attempted without adequate scaffolding. Figure 5 also reveals the large number of shipyard personnel on the scaffolding who were required to perform much of the necessary preparatory work for the installation.

Often the ''normal'' conditions of surface-ship plating are hidden beneath the smooth layers of flame-sprayed, powdered Thiokol and Navy Hot Plastic Shipbottom. These were melted and burned off with the flame of an acetylene torch. In order to get a bright, smooth, satisfactory, gage-mounting surface, a considerable amount of grinding was done with pneumatically driven, coarse, emery grinding wheels. The results of the early phases of the grinding operations are shown in Figure 6. Figure 7 is a composite photograph which shows clearly the specially prepared, pit-free, gage mounting surfaces. Figure 7 shows some of the badly pitted surface still remaining on the periphery of the brightly cleaned areas. The initially roughly ground surface was smoothed by changing the emery wheels to emery sanding disks. Thus, a satisfactory gage mounting surface, as shown in Figures 7 and 8, was obtained. Hull conditions are not usually as bad as the condition of the strut castings which were gaged.

UNIQUE GAGE CABLING

The composite Figure 7 also reveals clearly the general pattern and method of handling the complexities of the instrument cable problem. The connecting cable problem on several earlier and similar strain gage projects was handled successfully by passing a cable through the hull via specially installed stuffing tubes. However, the strut instrumentation did not lend itself to such a simple procedure. Consideration was given to piercing the hull in the area of the struts. This plan was abandoned because of the complex structure of the traditional multiple hulls of these larger ships. Each of the inner-bottom hulls would necessarily require individual sets of stuffing tubes for each of the seven separate multiconductor cables in order to reach the temporary instrument compartment. It became quite obvious that it would be very much the better plan to keep the cables on the outside of the hull and pass them up and over the hangar deck, thence to the instrument space. This plan was quickly adopted, and the half-rounded free-flooding pipe conduit provided an ideal housing to completely protect the plastic-jacketed cable from mechanical damage. Short lengths of steel pipe, 6 inches in diameter, were slit open with an acetylene torch and electric-welded to the hull. They were so placed that they formed a free flooding continuous conduit on the hull from the strut area to the stern, up the stern hull plates (as shown in Figures 3 and 5) and to a junction box at the aft area of the hangar deck.

The conduit was not extended down the strut as it was felt that the vibration of the strut would, in time, loosen the conduit. Instead, closely spaced cable clamps provided an adequate flexible anchor for the cables. The requirements of the test were such that bulky mechanical protection, such as heavy welded or gasketed steel boxes, for the gages could not be used.

STRAIN GAGE MOUNTING

All strain gages used were Baldwin-Lima-Hamilton SR-4 Type AD-3, some of which can be seen mounted in the test areas in Figures 7 and 8. Each strain gage location had a dummy gage block which was cemented in place by using a very small amount of 3-M rubber (EC-801). The cement was placed only under one end of the block.

The gages were mounted with Duco cement in the conventional manner and air-dried with heat lamps until a leakage to ground reading of approximately 10,000 megohms per gage was obtained. The gages were wired and all circuits checked out completely before any waterproofing was applied. Each circuit in turn was checked out satisfactorily by balancing a Baldwin SR-4 portable strain indicator into each circuit at the end of the long instrument cables up on the hangar deck. To obtain direct verification of the response to known loads, yard personnel loaded the strut and propeller shaft by rigging and pulling on ropes in the appropriate directions. Thus, the response of each gage circuit to loads of known direction was verified.

After all gage circuits had been tested and found to be functioning properly, the waterproofing was applied. The waterproofing technique used was the shim cap method, as presented earlier in this paper. There are numerous other applicable waterproofing methods which are more fully reported in David Taylor Model Basin Report 797, the third and revised printing.[7]

SUCCESSFUL SEA TESTS

A week after the installation on the shaft struts was completed, the drydock was flooded. It remained flooded almost continuously for the next two months while the various engine rooms were being completed. During the later months the ship was floated and dockside trials were made. All of these various propulsion system tests helped to use up the valuable life expectancy time of the entire submerged instrumentation system.

The SARATOGA went to sea for two different builders' sea trials eight and nine months, respectively, after the strain gage system was installed. All strain gages functioned satisfactorily, and much useful test data were obtained. Two of the five gage locations, 1 and 2, closest to the boundary-line region of the propeller race began to fail halfway through the second group of sea trials. The water velocity in the region of gages 1 and 2 is about 15 percent greater than the free-stream water velocity.

Gage locations 3, 4, and 5 remained useful during all of the various sea tests. At some unknown date between the last time they were used, nine months after installation, and re-dry-docking of the ship fourteen months and many thousands of miles travel later, they had succumbed to the infinite patience of the sea. Figures 9 and 10, made in January 1957 during dry-docking after builders trials, show that gage locations 1 and 2 had been eroded completely away and that locations 3 and 4 had a small remnant of the waterproofing. Locations 3 and 4 are out of the propeller race area and were in a boundary-layer area where the water velocity is 12 to 15 percent less than free-stream velocity. However, gage location 5, which was on the hull surface and still good after 14 months was exposed to about 40 percent less than free-stream water velocity. On dissecting this well-worn shim cap waterproofed gage area (note in Figure 9 the solid black triangular patch worn back from leading edge of waterproofed gage), it was discovered that the gage leakage resistance measured in excess of 1000 megohms.

It is interesting to note here that even though the entire waterproofed placements of gage locations 1 and 3 (shown in Figure 10) were gone, the dummy gage blocks cemented in place were still firmly anchored with the 3-M cement and had not "soaked off."

In Figure 10, several cables can be seen in a broken and ruptured condition. This, in all probability, was caused by constant propeller action in the area, and probably not by debris.

CONCLUSIONS

The materials and techniques outlined in this paper are suitable for the protection and waterproofing of strain gages in a variety of applications, and have proven themselves useful in field applications. They have made possible a number of test programs which could not have been otherwise successfully completed.

A detailed report has been given of a most unusual and unique strain gage instrumentation of a propeller shaft strut. The installation was virtually unaffected by an unexpected long pretest submersion time. The gages were underwater almost nine months before their intended test use occurred. These underway strain and vibration tests mark the first successful utilization of strain gages under such adverse conditions.

It is interesting to note here that in all of the multitude of waterproofing techniques developed and reported in the literature so far no single material or technique has been found which is distinctly superior to all others for general use in waterproofing strain gages. Di-Jell 171 wax, introduced by the author in America in 1953, has gained widespread acceptance as a general type of "soft" waterproofer. The search for the ideal material continues. Perhaps this paper will stimulate further work by others.

The author welcomes comments.

ACKNOWLEDGMENTS

For advice, information, and assistance contributed during the long period of time covered by the development of the waterproofing, the author wishes to express thanks and sincere appreciation to Messrs. Frederick B. Bryant and Vernon E. Benjamin of the Instrumentation Division of the David Taylor Model Basin.

Thanks and sincere appreciation are also extended to the many shops of the New York Naval Shipyard and to the personnel who assisted in the preparation for the instrumentation of the shaft struts of the SARATOGA. Acknowledgment is also made to Model Basin personnel who participated in the strut instrumentation, Messrs. William H. Leyda, E.H. Busi, and C.D. Sullivan. Mr. Francis F. Vane directed the overall measurement program and Mr. C.H. Kinsey was project manager from the Structural Mechanics Laboratory of the Model Basin.

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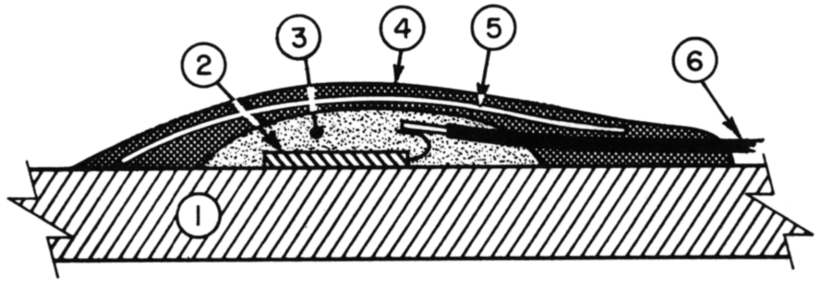
TABLE 1

Source List for Supplies Mentioned in Report

Product	Supplier
Multi-conductor cables Navy types MCOS-2 (two-conductor shielded), MCOS-6 (two sets of two-conductor shielded), and TTRS-4 (four sets of two-conductor shielded). All cables have waterproof plastic jacketing.	Anaconda Wire and Cable 423 Investment Building Washington, D.C. Simplex Wire and Cable 79 Sidney Street Cambridge 39, Massachusetts
Chemicals	
Acetone (General cleaning)	Local chemical supply houses
Naphtha solvent (General cleaning)	Local chemical supply houses
Methyl Isobutyl Keytone (Thinner for EC-1217, EC-853)	Local chemical supply houses
Di-Jell 171 (Soft wax)	L. Sonneborn Sons, Incorporated Building Products Division 404 Fourth Avenue New York 16, New York Astor, Boisselier, Lawrence, Ltd. 1 Lancaster Place, Strand London W.C.2, England
Primer, Herecrol, RC-9	Heresite and Chemical Company Manitowoc, Wisconsin
Sealers and primers, 3-M (All items with prefix "EC-")	Minnesota Mining & Manufacturing Company 411 Piquette Avenue Detroit 2, Michigan
Stainless-steel shim stock (Type 302)	Precision Steel Warehouse, Incorporated 4409-25 West Kinzie Street Chicago 24, Illinois
Stainless-steel soldering flux and Rosin flux remover	Division Lead Company 7742 West 61st Place Summit, Illinois
Strain gages, SR-4	Baldwin-Lima-Hamilton Electronics & Instrumentation Division 42 Fourth Avenue Waltham 54, Massachusetts
Zophar C-276 (Wax)	Zophar Mills, Incorporated 112-130 26th Street Brooklyn, New York



(1) Metal Specimen under Test

(2) Mounted SR-4 Strain Gage

(3) Soft Wax Di-Jell 171 or Zophar Mills Wax C-276

(4) 3-M Synthetic Rubber (Self-Vulcanizing Rubber)

(5) Stainless Steel Shim Cap 0.002 Inch Thick

(6) Connecting Cable

Figure 1 - The Dean Shim Cap Method of Waterproofing Strain Gages

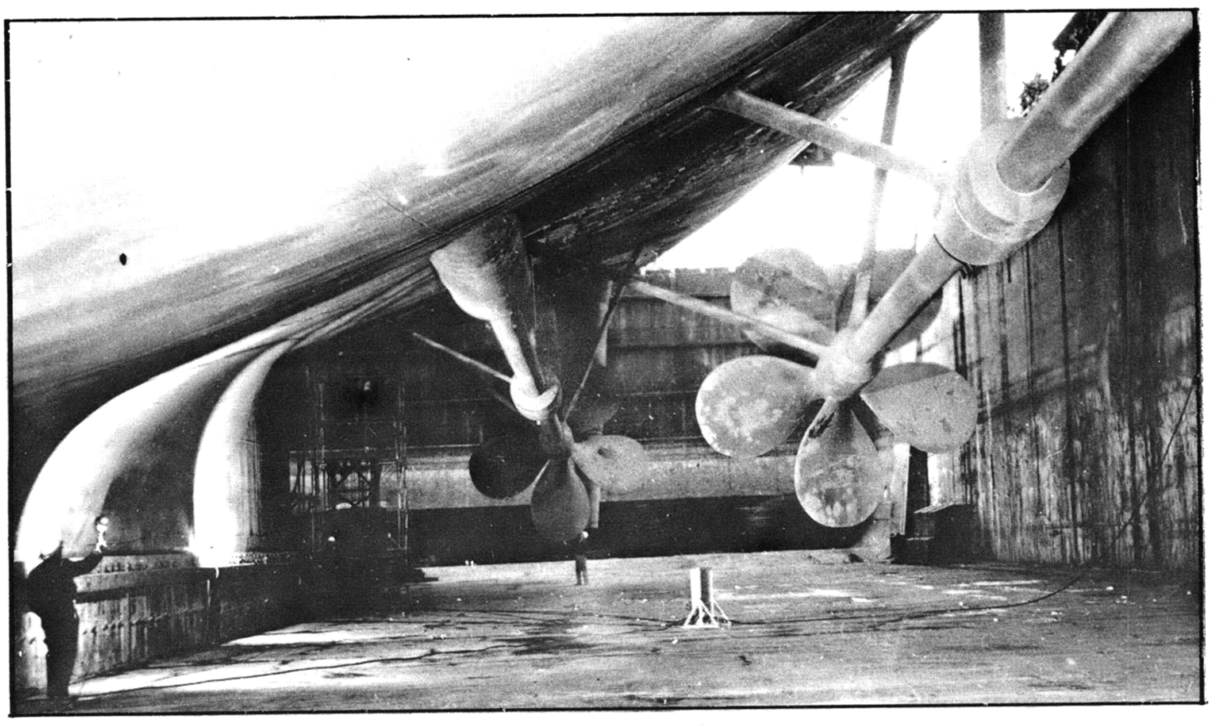


Figure 2 - Drydock View of the Propulsion System of the USS SARATOGA (CVA 60), a FORRESTAL-Class Aircraft Carrier

This is a clear view of the port side showing shafts 3 and 4. Strain gage installation was located on the opposite side of ship on shaft system number 2. Note author beneath propeller blade; shipyard photographer is at the keel line on the left.

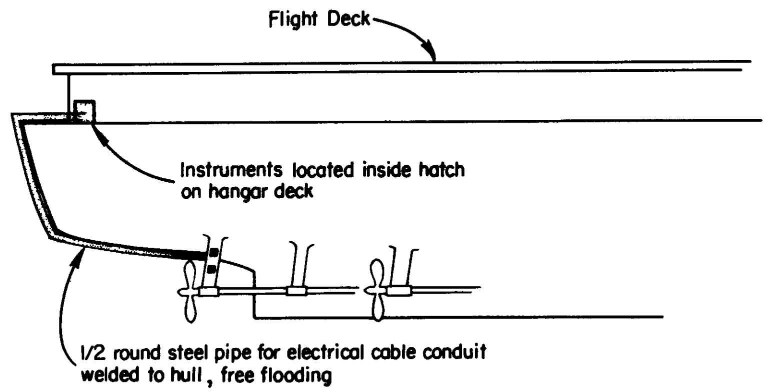


Figure 3 - Broadside Sketch of USS SARATOGA Showing Instrumentation Position Squares on After Strut

The instrument cables from the propeller shaft strut area were run inside the temporary free flooding half-round conduit on the stern. Use of this conduit avoided the problem of piercing the multiple inner-bottom hull for seven cables.

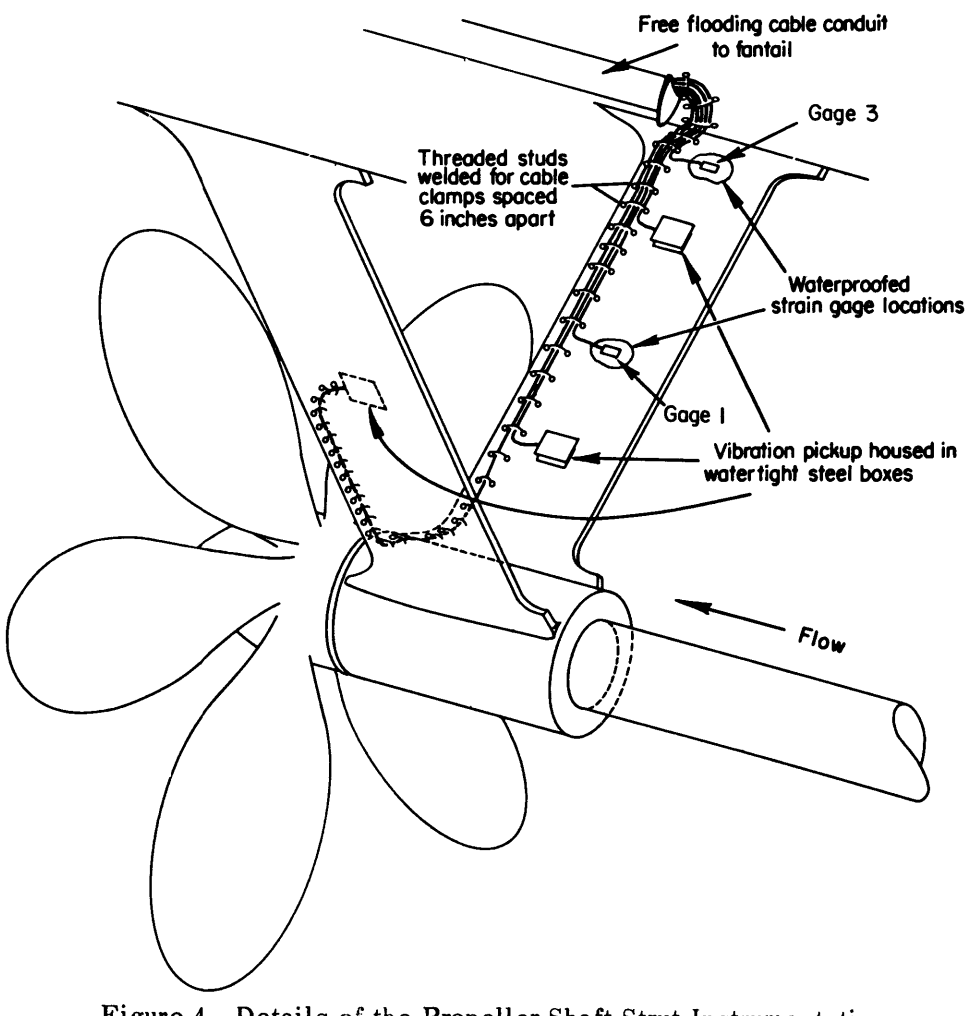


Figure 4 - Details of the Propeller Shaft-Strut Instrumentation

By referring to Figures 4 and 5 a complete picture of all gage locations may be formed.

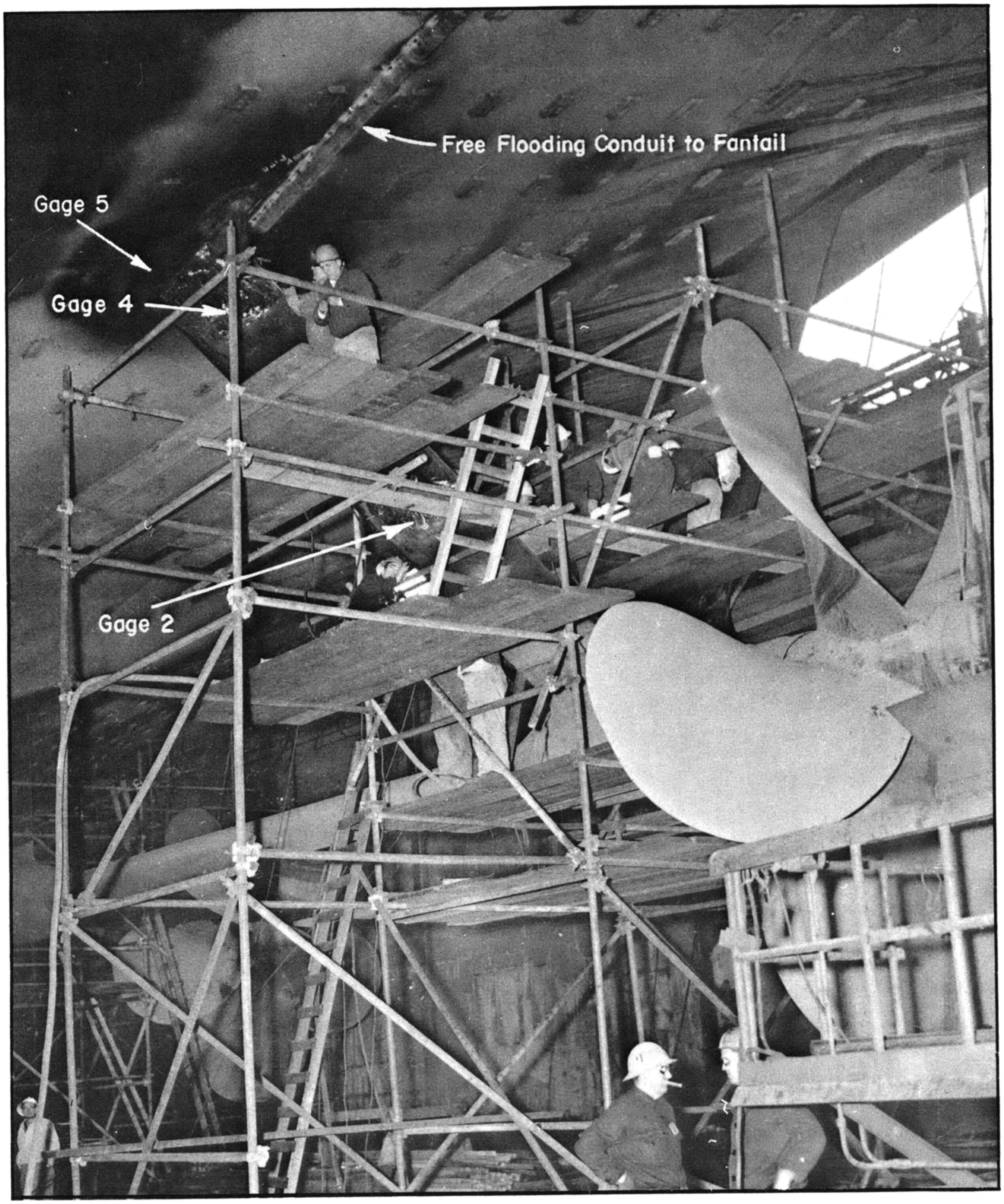


Figure 5 - Scaffolding Surrounds the After Propeller Shaft Struts of Shaft Number 2 for Strain Gage Installation

Note size of propeller and proximity of gage installation to propeller.

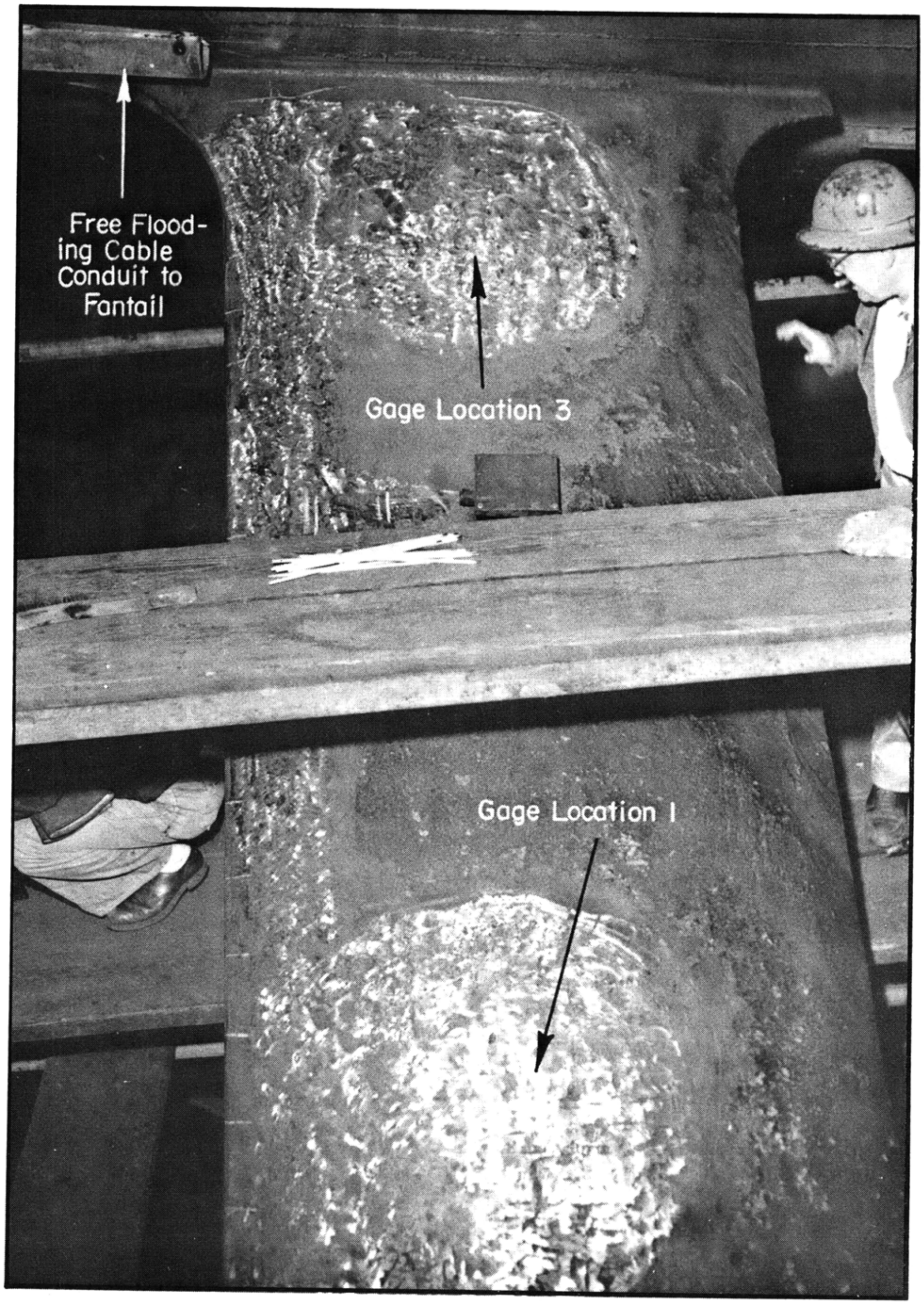


Figure 6 - The Large, Bright, Metal Circles, Partially Prepared by Rough Emery-Wheel Grinding, Allow for Proper Sealing Around the Gages for Waterproofing

Surface prior to clean-up operation was pitted and scarred. Such a pitted surface is normal in ship construction, but is a nightmare for proper strain gaging.

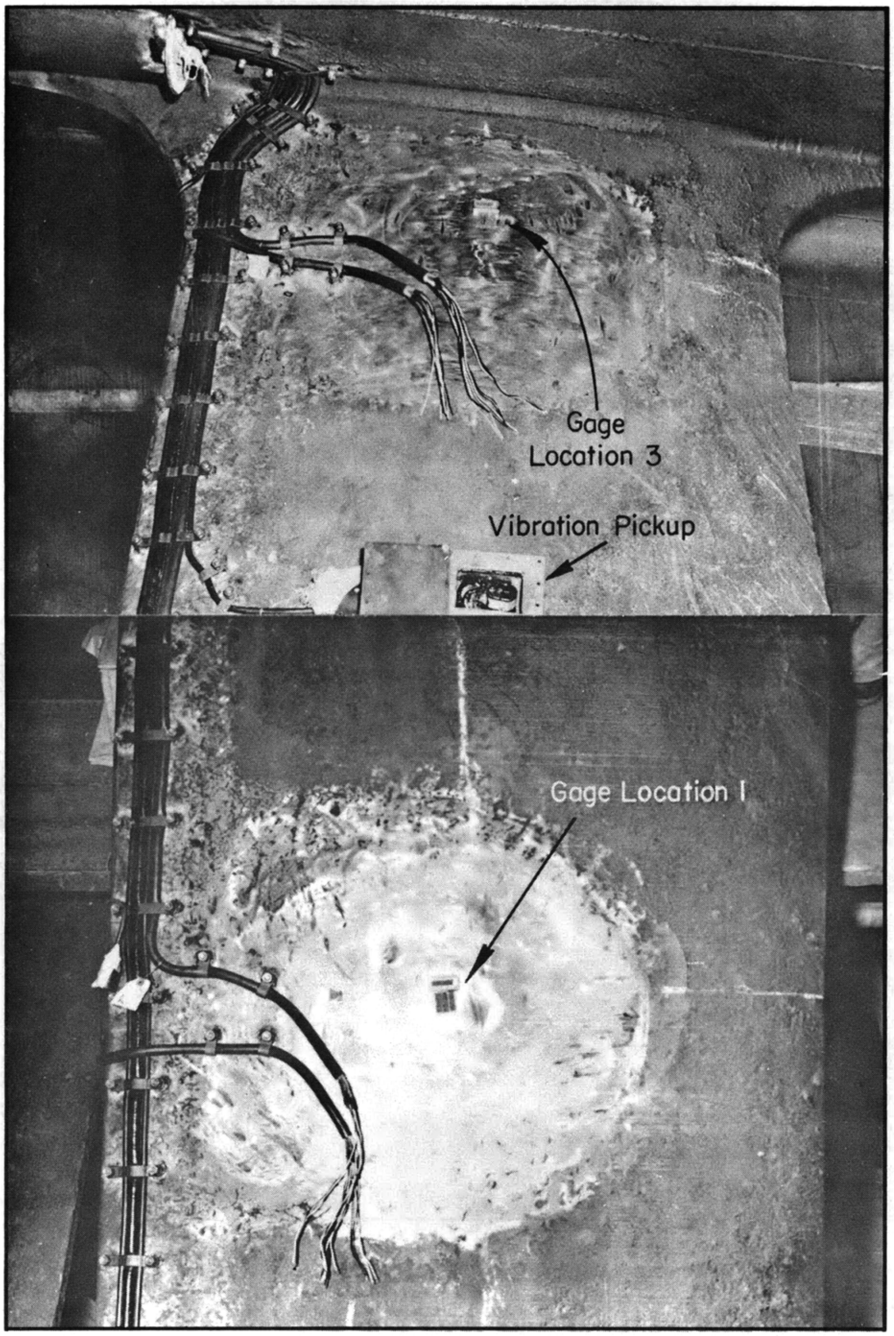


Figure 7 - This Composite Photograph Shows Gage Locations 1 and 3

Note that the grinding operation made a clean, bright, and pit-free surface in comparison to Figure 6. Cable clamp straps are at a 6-inch interval.

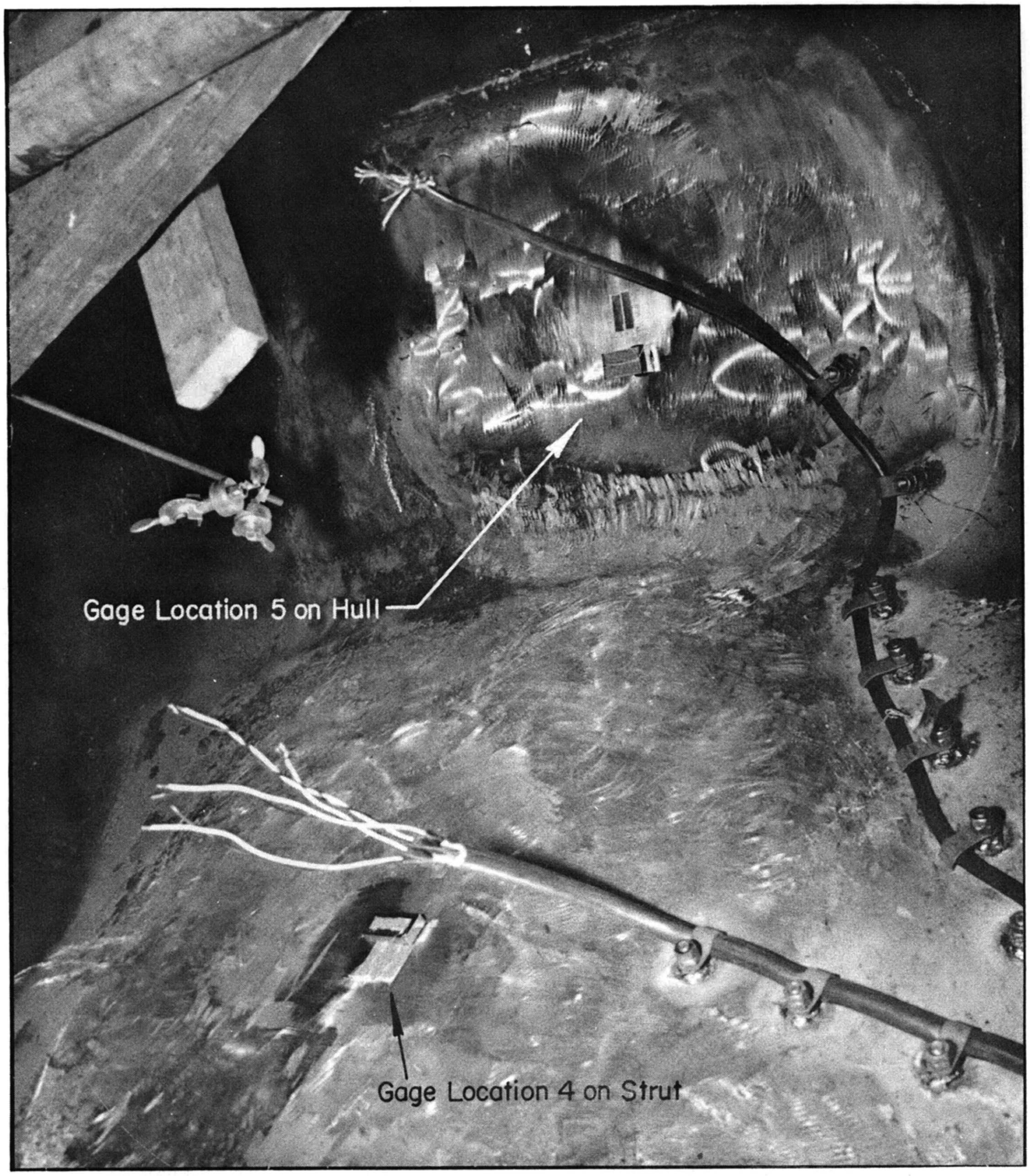


Figure 8 - This View Shows Gage Locations 4 and 5

Note the bright, pit-free surfaces and the close spacing of cable clamps. Refer to Figure 9 for an after-the-test view of this same area.

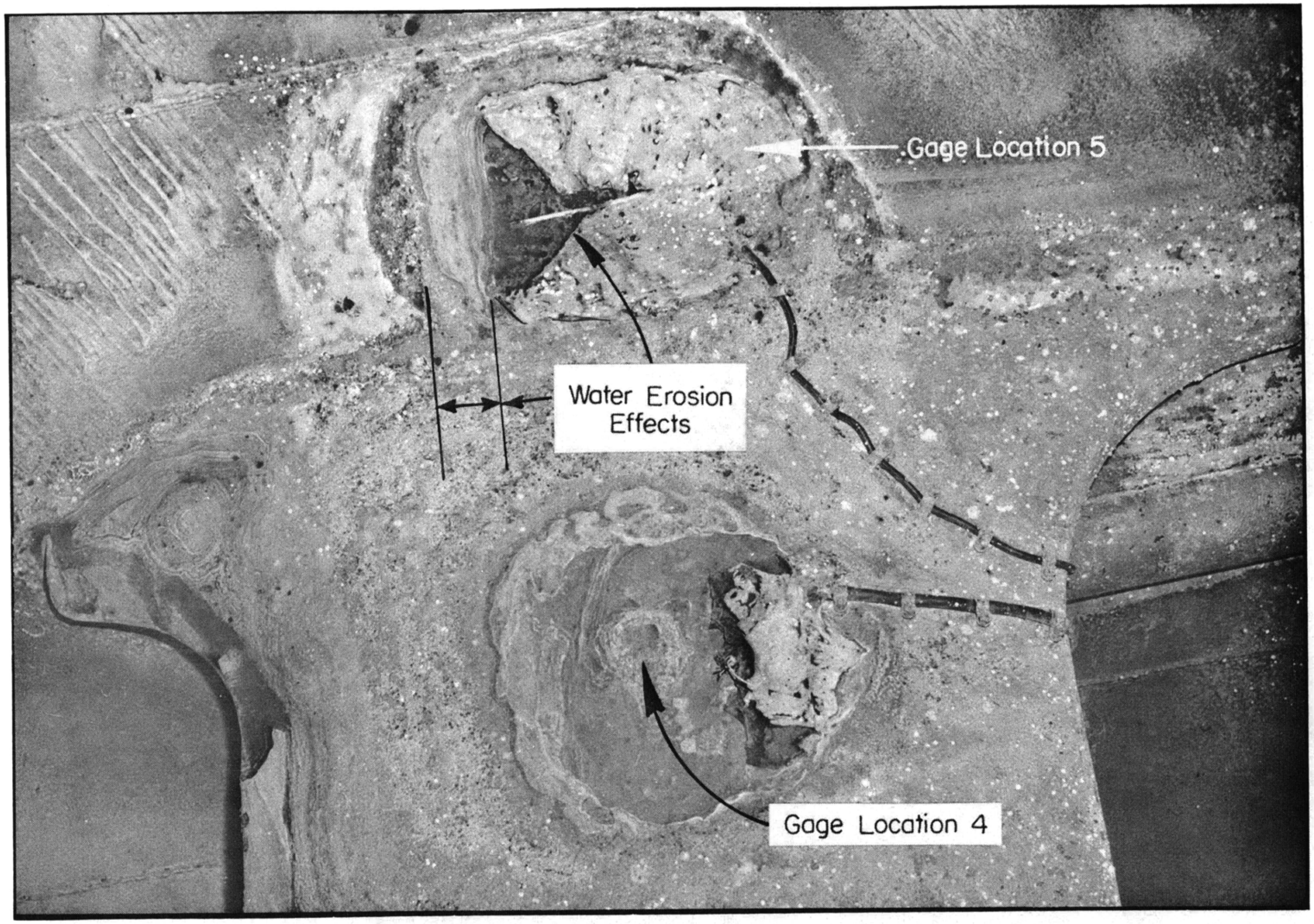


Figure 9 - This Photograph Was Taken When Ship Was Re-Dry-Docked Fourteen Months After the Installation

Ship's cruise had included a trip to the Mediterranean. Cable rupture occurred subsequent to vibration and strain measurements. Cable failures were due to long term erosion effects of high-velocity water flow in the way of the propellers.

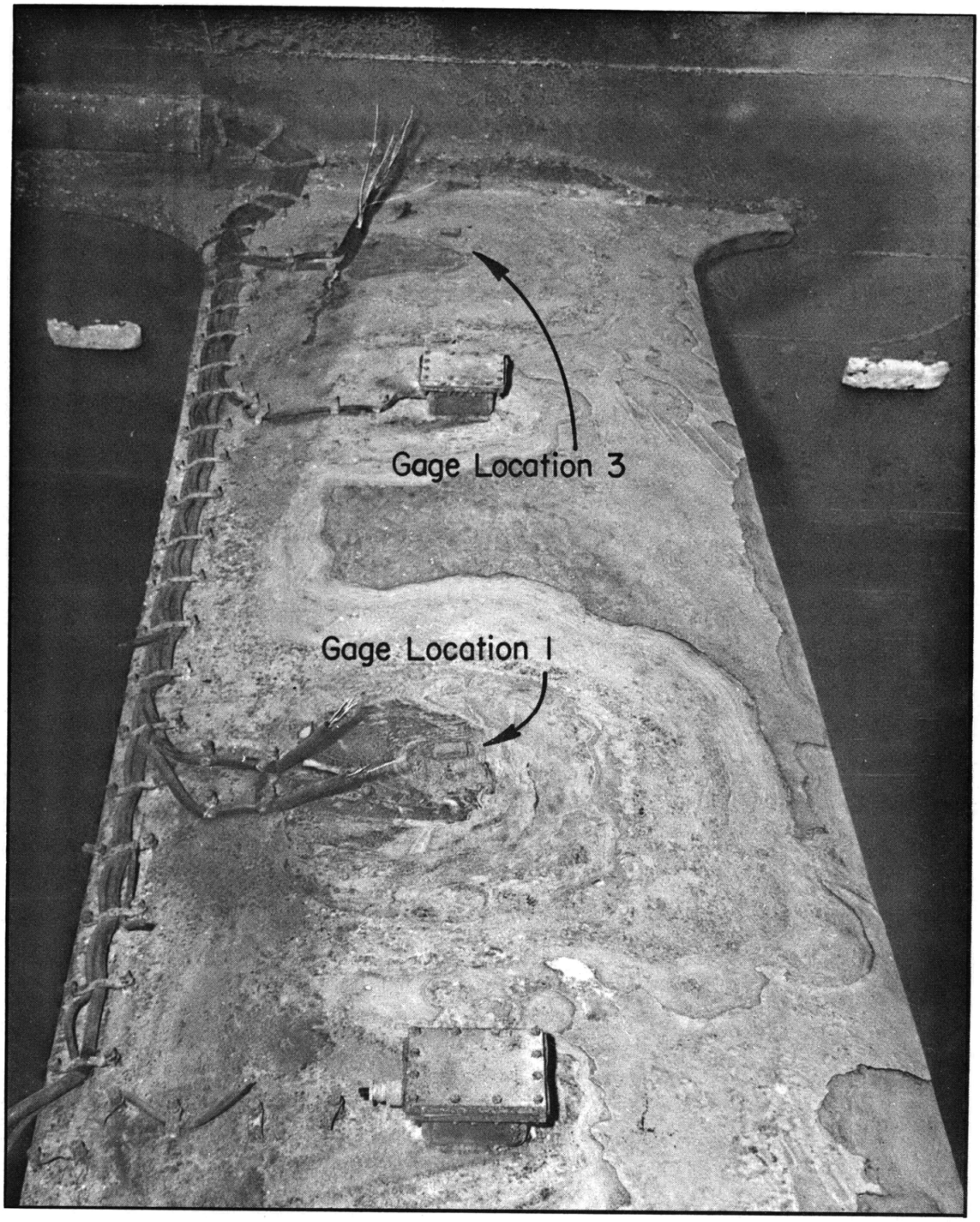


Figure 10 - A Comparison of Gage Locations 4 and 5 Indicates That Ultimate Failure of Waterproofing Was Due to Mechanical Erosion and not to Soaking

White dots all over strut area are from early formation of barnacles. White rectangular zinc blocks are there for corrosion protection and operate on the cathodic principle of corrosion of the least noble of two metals in an electrolyte.

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