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The condition of the support structure for hydrophone 4-7 of the Barking Sands Test Range, Kauai, Hawaii was analyzed after 52-1/2 months exposure to seawater at a depth of 5270 feet. The types and severity of corrosion on the various structural components are described and analyzed. A prediction of the additional lifetime to be expected from similar structures at this location is made. Recommendations for extending the useful lifetimes of similar structures at this site are made.

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INTRODUCTION

On 1 June 1967 hydrophone 4-7 of the Barking Sands Range, Kauai, Hawaii, was emplaced at a depth of 5270 feet. The temperature at this site averages 3°C, the oxygen content 2 ml/l and the salinity 34.6 ppt. On 13 October 1971, 52-1/2 months later, the hydrophone and its support structure were recovered. This report is an analysis of the condition of the hydrophone support structure after recovery. This analysis is based upon visual observations and measurements made several weeks after recovery, and chemical analyses of the structural components and microstructural observations made on polished sections of the components.

Description of Structure

The hydrophone support structure, when assembled, is approximately 15 feet high and 12 feet in diameter at its base. A sketch of the structure is shown in Figure 1. The structure was constructed from aluminum alloy bar, plate, channel and extruded tubing, and from PVC, steel, and Ni-Cu alloy 400. Spectrochemical analyses of the aluminum components showed that they were Aluminum Magnesium alloy 5086 which contains nominally 4% Magnesium. Microstructural analysis of polished component sections showed the plate and tube to be in the strain hardened and stabilized condition (H-32) while the channel and bar were in the as extruded condition (H-111). Welds on the aluminum structure were also analyzed and found to conform to the chemical specifications for alloy 5086. Weld deposits of this composition can be obtained by using the filler wire alloy 5356 as specified. Chemical spot tests confirmed that all fasteners were made from Nickel-Copper alloy 400(67% Ni-33% Cu).

Visual Observations and Discussion

Virtually no fouling was found on the sturcture immediately upon recovery. The only fouling noted was a scattered covering of hydroids, as shown in Figure 2. These common deep ocean animals have not been shown to affect the corrosion of underlying materials. Traces of these organisms remained on the structure after drying.

Three basic types of corrosion were found on the structure; galvanic corrosion, pitting corrosion and crevice corrosion. Of these, galvanic corrosion caused the most severe damage, pitting attack caused somewhat less severe damage and crevice corrosion, while even less severe from a structural standpoint, caused the most widespread attack.

Galvanic Corrosion

The most prominent area where galvanic corrosion had occurred was on the counterweight support pan located at the base of the mast. PVC insulators had been used to electrically isolate the painted steel counterweights from the pan. However, this isolation was not complete and there was, as evidenced by the severe galvanic corrosion shown in Figure 3, an electrical connection between the counterweight support, the Ni-Cu fasteners and the painted steel counterweights. This electrical connection was indicated not only by the condition of the support pan but by the lack of significant attack on the counterweights, even at the areas of paint damage. This attack had resulted in complete penetration of the .250" thick pan in over 25 separate places. Some areas of penetration were up to 1/2 square inch in area. This penetration was usually at areas where either crevice or galvanic attack had caused corrosion of the weight pan as shown in Figure 4. Metallographic inspection of sections cut from the counterweight pan showed intergranular attack typical of that found in strain-hardened and stabilized (H-32) 5086 aluminum alloy. The uncorroded material showed a continuous precipitate of Mg_2Al_3 adjacent to the grain boundaries. This precipate is anodic to the surrounding material and its micro-galvanic corrosion leads to intergranular attack of 5000 series aluminum alloys. Such intergranular attack is undesirable from two aspects. First, components subject to intergranular attack usually corrode faster than those subject only to transgranular attack. Second, due to the difficulty in measuring the depth and extent of attack, such measurements are likely to result in conservative evaluation of corrosion damage. The severity of the attack noted on the bottom of the counterweight support pan can also be partially attributed to the exposure of the pan to the bottom sediments which are normally more aggressive to 5086 aluminum alloy than the seawater above.

The other areas of galvanic corrosion on the structure were of a more subtle nature. They were a result of welding. Although the galvanic ptoential of the weld bead deposited using 5356 welding wire is closely matched with the potential of the 5086 parent material the match is not exact. Also, welding of 5000 series aluminum alloys can result in an area on the parent material adjacent to the weld bead which is anodic to both the weld bead and the unaffected parent material. On this structure, attack of the weld beads and of the adjacent heat-affected zones was noted at all welded joints. The severity of this attack varied from nearly complete deterioration of the welds to etching of the welds with slight deterioration of the adjacent heat affected zones. Figure 5 shows the severe weld attack noted at the yoke pivot. The weld used to attach the boss to the pivot plate is nearly corroded away. Typical weld attack with accelerated attack in the heat affected zone adjacent to the weld bead is shown in Figure 6. Metallographic examinations of joint sections showed that the corrosion of the weld beads was intergranular.

There was a continuous precipitate of Mg_2Al_3 at the grain boundaries of the weld bead. In the heat affected zone adjacent to the weld bead there was a thin layer where Mg_2Al_3 had precipitated adjacent to the grain boundaries to form a continuous network. Intergranular corrosion was noted in this zone. Attack in the heat affected zone of some joints was up to .086" deep.

Pitting Attack

Pitting attack on boldly exposed areas of some components of the structure resulted in structurally severe damage. The most severely pitted components were the base ring braces and the yoke. Pitting of the base ring braces, as shown in Figure 7, initiated at the edges of the members and had progressed up to 1" into them at several areas. Metallographic inspection of the base ring brace channel and bar did not show any continuous precipitate at the grain boundaries. The corrosion was transgranular. The clips at the ends of the braces where the base ring was attached were also severely corroded as shown in Figure 6. This attack also initiated at the edges of the clips. Metallographic inspection of sections of these clips revealed a continuous network of Mg_2Al_3 precipitated at the grain boundaries and the usual attendant intergranual attack. The severity of the attack on the base ring braces can be partially attributed to the exposure of the braces to the bottom sediments.

In several areas on the yoke, pitting attack had caused penetration of the .125" thick tube wall. Figure 8 shows a pitted section of the yoke. The pits initiated primarily on the outside of the tube but several internal pits were noted. Metallographic inspection of sections from the pitted areas showed intergranular precipitation of Mg_2Al_3 and the usual attendant intergranular corrosion.

Crevice Corrosion

At all points on the structure where there were crevices, crevice corrosion was found. In most areas the attack was not severe. However, in other areas the attack was significant. The area most adversely affected by crevice corrosion was the point where the base ring braces were attached to the mast. Even though the crevices at this joint were sealed with room temperature vulcanizing silicone rubber compound some seawater entered the crevices. This resulted in attack such as shown in Figure 9. In this area the attack was up to .095" deep. Metallographic inspection of sections from this area showed that the channel sections at the base-ring-brace to mast joints had corroded transgranularly. The microstructure of the uncorroded material was typical of as extruded (H-111)

5086 aluminum alloy. Intergranular precipitates were absent. Another area where crevice corrosion had resulted in significant damage was under the taped-on identification plate on the mast. As shown in Figure 10 this attack was moderately severe. The maximum measured depth of attack was .065". Metallographic inspection of sections from this area of the mast as well as areas of crevice attack on the yoke and base ring clips showed a microstructure typical of 5086 aluminum alloy in the strain hardened and stabilized (H-32) condition. This microstructure includes a continuous network of Mg_2Al_3 precipitated adjacent to the grain boundaries. Components with such microstructures were subject to intergranular crevice corrosion.

Another area where crevice corrosion had resulted in significant damage was under the compound used to cover the welds on the structure. This compound was applied in an attempt to minimize attack at these areas. However, as shown in Figure 6, attack under the compound was more severe than at adjacent areas.

Fasteners and Non-Metallic Components

The Nickel-Copper alloy 400 fasteners used to assemble the structure, as shown in Figure 11, were not significantly attacked. The only attac' noted other than a slight tarnish was slight crevice attack under the heads and on the threads of a few fasteners. This attack was structurally insignificant. The PVC base ring and couplings as well as the various non-metallic insulating sleeves and washers used on the structure were not significantly affected by their exposure at depth. Damage to the base ring was mechanical, and as evidenced by the lack of fouling on the damage-exposed surfaces, and probably occurred during recovery.

Summary and Conclusions

The 5086 aluminum alloy components of the hydrophone support structure were attacked by galvanic, pitting and crevice corrosion. The most significantly attacked components were the counterweight support pan and the base-ring braces. The counterweight support pan was penetrated in many places by intergranular galvanic corrosion due to an electrical connection between the steel counterweights and the support pan. The severity of this attack can be expected to at least double in an additional 4 years exposure. Failure of the pan in from 2 to 4 years is predicted. The base-ring braces were also significantly corroded. The 1" penetration of the braces was due to transgranular pitting and can be expected to sever the members in an additional 5 to 7 years exposure. The intergranular pitting on the base ring attachment clips can be expected to sever these connections in from 5 to 7 years. Thus the additional lifetime to be expected from the remaining structures in the array depends primarily upon the overturning moment applied to the structure. If this moment is small, an additional lifetime in excess of 5 years is predicted. However, if this moment is large, the structures may be subject to overturning in as little as 2 years additional exposure.

These predictions are based primarily on the results of deep ocean corrosion tests performed by NCEL. These tests show that 5086 alloy corrodes differently in the low oxygen environments found at intermediate depths in the Pacific Ocean than it does when exposed to highly oxygenated surface waters. Not only are the corrosion rates higher at depth but they increase with time. The bottom sediments were found to be more aggressive than the seawater just above them. Specimens showing intergranular precipitation and corrosion corroded at a faster rate than those which corroded transgranularly.

Recommendations

The lifetimes of similar structures can be increased by several modifications to the existing design.

1. Complete isolation of dissimilar metals must be achieved. Inspection of assembled structures to assure isolation is recommended.

2. Elimination of contact between the bottom sediments and any aluminum structural members is recommended.

3. Elimination, by design, of any unnecessary crevices is recommended.

4. The continued use of 5086 aluminum alloy as the most corrosive resistant aluminum alloy is recommended. However, 5086 alloy in the as extruded (H-111) condition is preferred to other conditions where intergranular precipitation and its associated accelerated attack is possible.

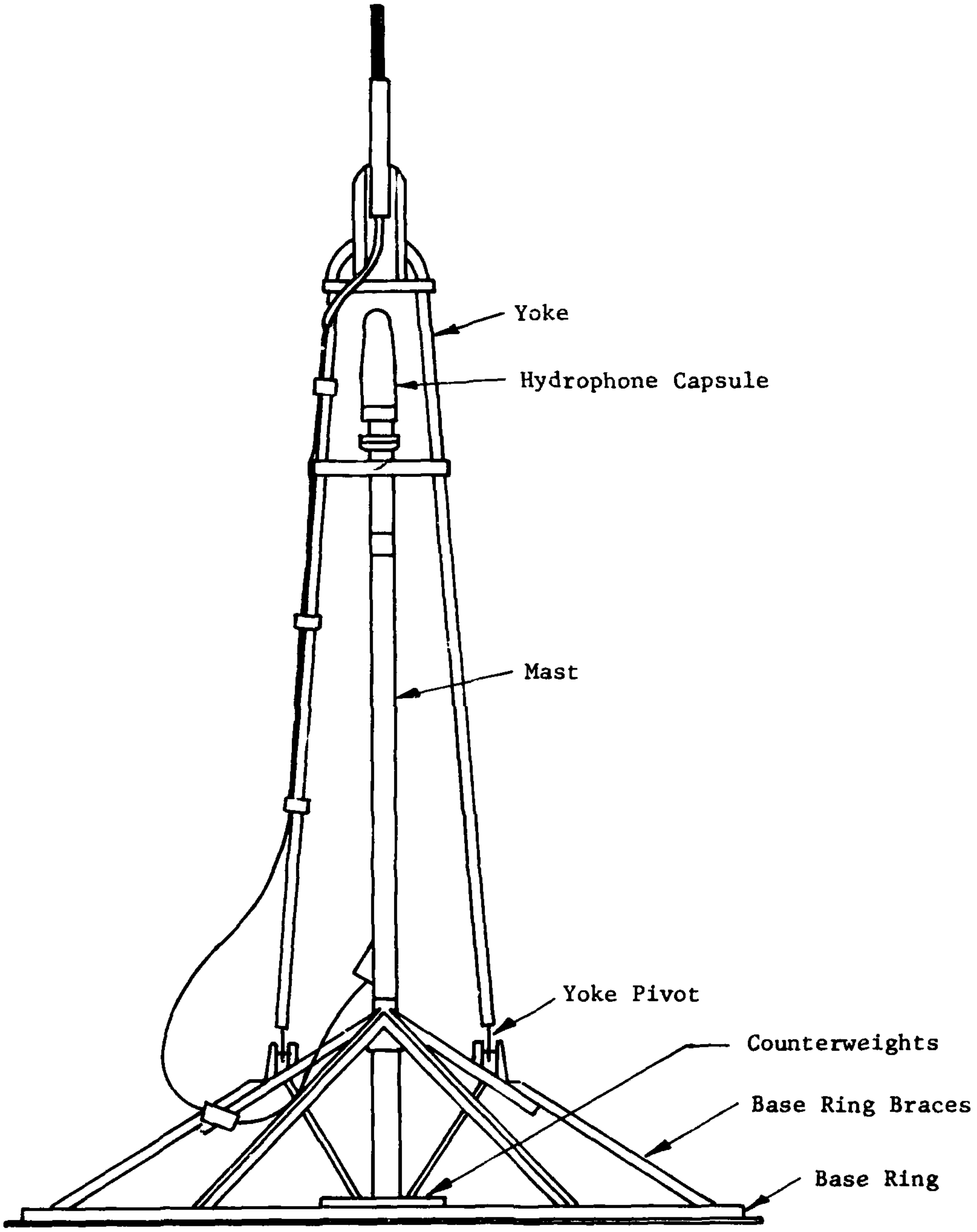

Figure 1. Hydrophone support structure.

Figure 2. Hydrophone, showing extent of fouling.

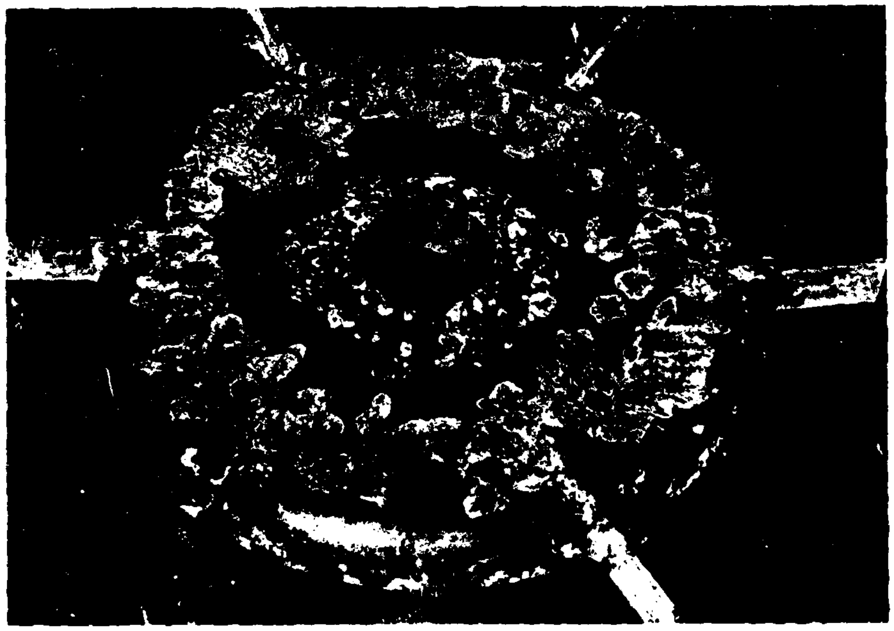

Figure 3. Condition of outside of counterweight pan.

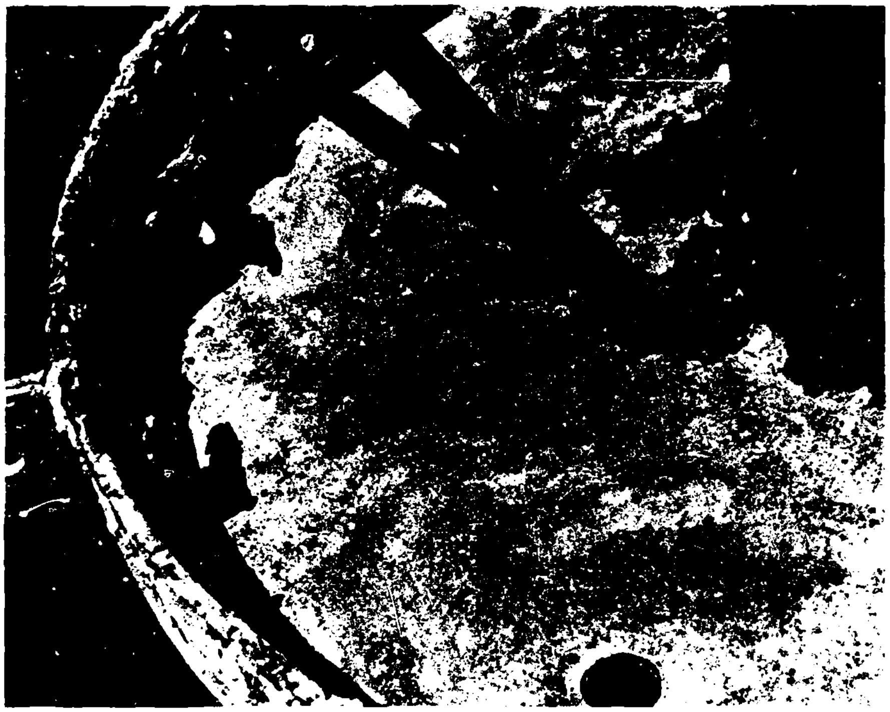

Figure 4. Condition of inside of counterweight pan.

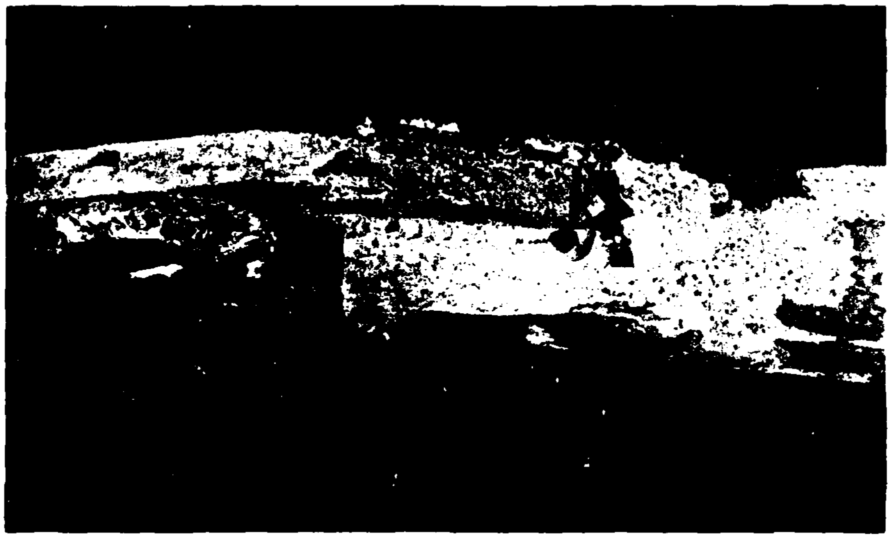

Figure 5. Severe weld attack at yoke pivot.

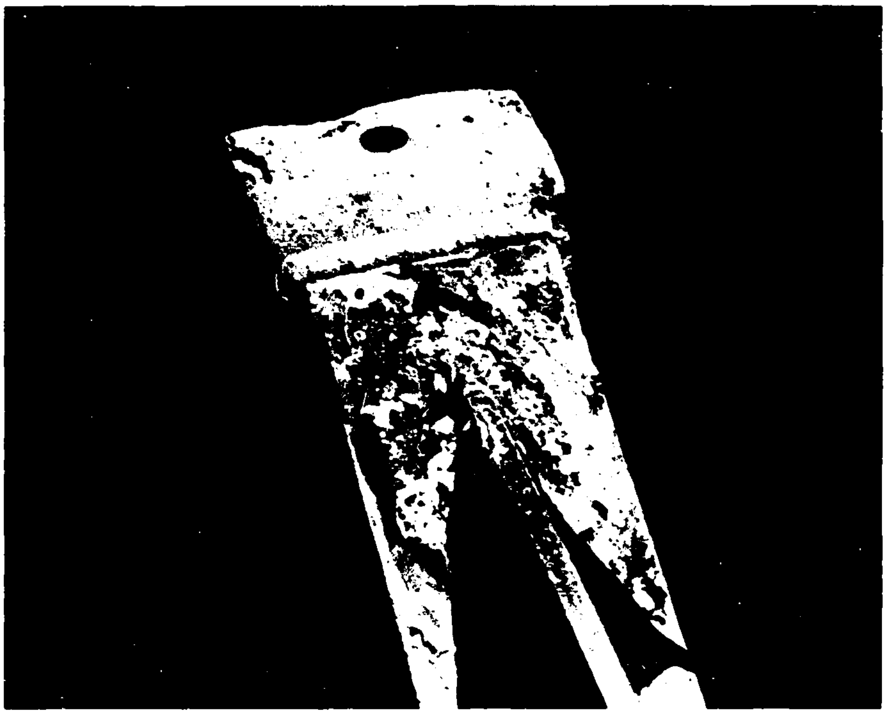

Figure 6. Weld attack at base ring clip.

Figure 7. Pitting on base ring brace.

Figure 8. Pitting on yoke.

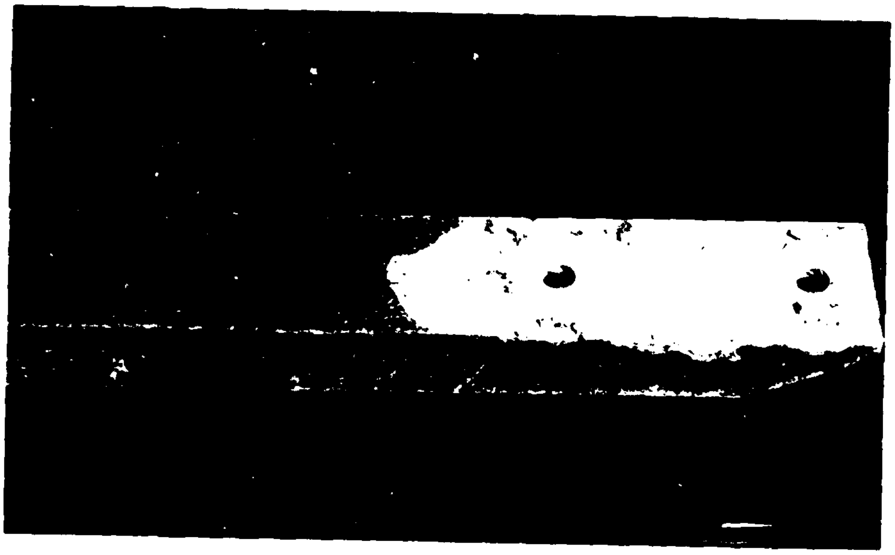

Figure 9. Crevice attack on base brace.

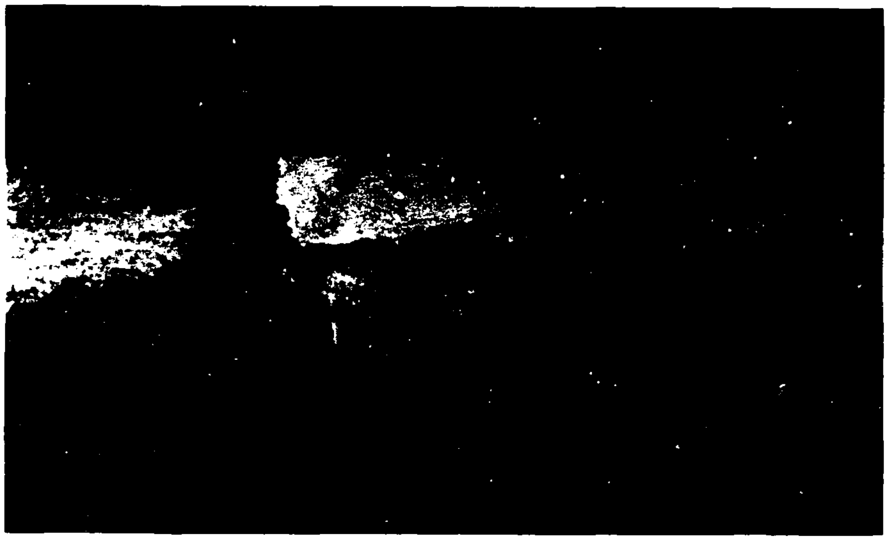

Figure 10. Crevice corrosion on mast.

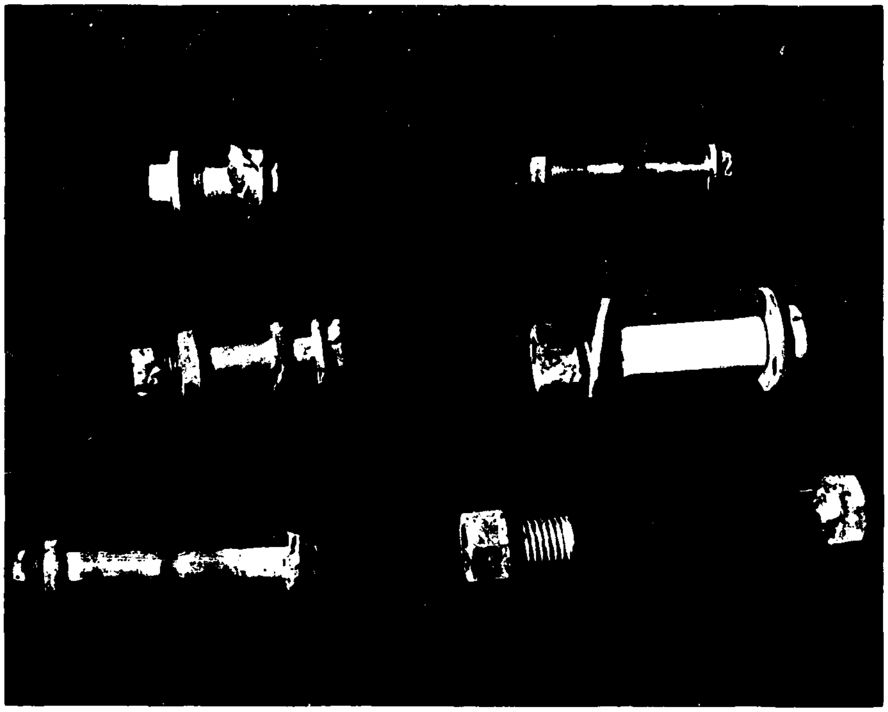

Figure 11. Fasteners and insulators.