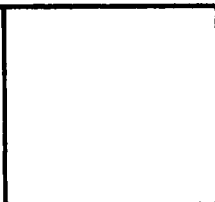


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GENERAL PRINCIPLES

APPLICATION OF ARMOR TO AIRCRAFT

METHODS OF ATTACHMENT

DISTRIBUTION STATEMENT A

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INTRODUCTION

This bulletin was prepared in collaboration with representatives of the Carnegie-Illinois Steel Corp. for the information of those concerned with the problem of attaching armor to aircraft structures. It is not intended to be final and may be augmented or revised as experience is obtained in this activity.

* * * * *

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L.C. Bibber } }

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W.L. Warner } }

1 - acc. order, 11/14/46

GENERAL PRINCIPLES GOVERNING THE APPLICATION OF ARMOR TO AIRCRAFT BOTH BY BOLTING AND WELDING

Introduction

This manual covers recommended practices for the installation of armor in aircraft by means of bolts or welded attachments as it applies to manufacturing, to the modification of existing armor installations, or to the repair and renovation of armor installations in the field.

Types of Armor

There are two basic types of armor used in aircraft. One of these types is a face-hardened armor which has been so processed as to possess an extremely hard, non-machinable face. This face is the surface exposed to projectile fire. Plate of this type cannot be formed, or flame cut, with any degree of facility. It cannot be machined on the hardened face, nor can it be welded on the hardened side without impairing the character of the armor.

The second type of armor is a homogeneous type heat-treated to a uniform hardness throughout. There are two grades in common use. One type is a machinable variety. The second type, called hard homogeneous, is heat-treated to approximately 380 Brinell and is, therefore, machinable only with difficulty. Both types can be welded satisfactorily with the proper technique and are easier to fabricate than face-hardened armor.

Identification of Types of Armor

It is very essential that the type of armor plate being used or repaired be known so that the necessary fabrication precautions may be observed. The following shop tests are suggested as possible methods to be used for identifying the type of armor.

a. File test. A file will bite into homogeneous armor plate on both sides but will bite into only the soft side of face-hardened armor plate. On the face side, the file will slip and possibly break off teeth, but not cut appreciably.

b. Saw test. A hack saw may be used similarly to a file. The blades will bite into both sides of homogeneous armor equally, and the backside of the face-hardened armor, but will jump and probably break off teeth on the face side of face-hardened armor plate.

c. Spark test. A grinding wheel will show a noticeably different spark on the face side of face-hardened armor to that obtained from the back of the armor. Homogeneous armor shows the same type of spark from both sides of the plate.

d. Punch test. A few impressions with a center punch on both sides of the plate will show the face side of face-hardened armor to be appreciably harder than the back. Both sides of homogeneous armor will show the same hardness.

Relative Workability of Homogeneous and Face-Hardened Armor

It is recommended that homogeneous armor be used in preference to face-hardened armor wherever possible, particularly for internal armor stations. There are many advantages accruing to the use of homogeneous armor such as:

- a. Homogeneous armor is drillable, machinable, etc.
- b. Homogeneous armor is weldable on either side and may be torch-cut without as great a tendency to cracking as is the case with face-hardened armor.
- c. Attachments by welding can be made where needed rather than in some less desirable location in order to avoid the face-hardened surface.
- d. The cost of homogeneous armor is less than that of hard-faced armor and it is more available with respect to various thicknesses and sizes.
- e. Homogeneous armor is more dependable structurally than hard-faced armor.

NOTE - The above advantages become very important under field conditions when emergency repairs are required.

The subject matter which follows is subdivided into two sections: Part A deals with the attachment of armor by bolting and other mechanical means; Part B covers the application of armor by the metal arc welding of attachments.

PART A

BOLTING AND OTHER MECHANICAL ATTACHMENTS

1. Size of Bolts. In the renovation of armor installations in existing aircraft, it is recommended that bolts as large as can be accommodated by the surrounding structure be utilized. In the design of new installations it is suggested that minimum of $3/8$ " bolts be used on $1/4$ " armor thickness, and that for heavier gauges of armor, the minimum bolt diameter be the thickness of the plate plus $1/8$ ". Plain carbon or low alloy high tensile steel bolts may be used for these applications.

The liability of twisting off small bolts and straining them in setting up is great. The stripping of fine threads is also very easy. For these reasons it is felt that adequate numbers of larger bolts properly placed are more effective structurally than a larger number of small ones.

2. Location of Bolts. No holes should be drilled in armor nearer the plate edge than four times the thickness of the plate. Every hole in a piece of armor decreases its effectiveness in that the tendency for cracking under projectile impact is considerably augmented. Do not locate the plate with respect to its attachments so that the shock load of projectile impact must be borne by the bolts in tension, reference Fig. #1. When the

projectile strikes a plate which imposes a tension load on attachment bolts, the kinetic energy of the bullet must be absorbed by the plate and attachments. A tremendous velocity may be imparted to the plate and bolt heads and nuts, so much so, in fact, that the bolts may break and the heads be hurled forward with great force becoming dangerous missiles. If all of the bolts are broken but one, the plate may come adrift and fall down, no longer serving its purpose.

3. Proper Application of Bolts. Locate the attachments so that the supporting structure takes the shock of impact as shown in Fig. #1. Under the conditions illustrated, velocity will be imparted to the bolt heads in the vicinity of the impact, but it is probable that sufficient bolts will remain unharmed to prevent the plate from coming adrift. The danger of these bolt heads becoming flying missiles, however, will not be completely eliminated.

4. Means of Preventing Flying Bolt Heads. If bolts or rivets must be used directly on the armor plate, mantlet plates or some other equivalent device should be used to catch the flying bolt heads and dissipate their energy. One type is illustrated in Fig. #2. The mantlet plate consists of a strip of springy sheet steel (cold rolled plain carbon steel) of 1/16" or more in thickness, and of sufficient strength to be able to absorb the energy in the bolt head and to catch it or cause it to fall harmlessly. The mantlet plates must extend continuously over several bolts so that, in the event that some of the bolt heads are knocked off, others will hold the mantlet in place. The mantlet can be lightened in many ways by perforation or making it of other shapes. The bolts may be set up with the mantlet perpendicular to the plate surface. The mantlet can then be bent into its final position.

5. Use of Clips or Lugs. In many cases it is desirable not to support the plate continuously at its edges, but to use clips or lugs as shown in Fig. #3. The liability of the bolt heads or nuts directly on the armor plate flying off and the likelihood of the plate coming adrift are just about the same as that depicted in Fig. #1. On the other hand, the bolts attaching the clips to the structure will be protected to a certain degree by the springing of the clips, and the likelihood of the supporting bolt heads flying off is not as great. The latter, however, is of no particular benefit if the bolts on the armor plate come off and the plate falls down to a position in which it is no longer able to accomplish its purpose.

If at all possible, the clips should extend around the back of the armor and around the front of the supporting structure, as shown in Fig. #4, so that the shock load would not be borne by the bolts but will be taken by the clips. The springing of the clips may be sufficient to prevent the bolt heads or nuts, relieved of the shock load, from flying off and the plate will probably remain in place. Where armor is to be supported by clips and bolts, the method shown in Fig. #5 is even more satisfactory. By thus reversing the direction of the clips so that the plate is mounted forward of the support relative to the direction of fire, the resistance to the shock of projectile impact can be improved since each of the connecting bolts will be loaded in compression. Also, when mounted in this manner, the armor plate can be made of sufficient size to cover the clips for protection against direct projectile hits.

Figure #6 illustrates a method of connecting armor at a corner by means of clips. In such cases it is desirable to use bolts with countersunk heads.

The material for clips should have a thickness (C) of approximately one-half the armor thickness. The width of the clip and the amount of lap required on the armor plate will depend somewhat on the weight of plate and size of bolts used. A minimum width of 2" and lap of similar amount is suggested as being adequate.

6. Internal Holes in Armor. Unless absolutely unavoidable, holes should never be put in the internal area of an armor plate. Holes around the periphery of the plate are not as harmful because the structural support will prevent the formation of severe bending moments. The tapping of holes makes the situation worse because threads provide stress concentrations which are potential sources of cracks. Under the violent impact of projectiles, cracks may propagate until ultimate failure of the plate occurs, as shown in Fig. #7. When the question of whether or not a hole is avoidable is being considered, one thought should always be paramount, namely, there is no value in paying the weight penalty for armor protection if that protection is vitiated by holes, bolt heads, etc. The harmful effect of internal bolt heads is more pronounced in the case of face-hardened armor.

7. Attachement of Objects to Armor by Bolts. Any bolt which is at or near the center of an armor plate is subjected to much greater inertia forces tending to snap off the head due to the greater deflection of the plate at that point. If that bolt is used to attach hinges, instruments, or other objects to armor plate, the inertia forces of the attached objects are great and will tend to break the bolts or strip the threads, resulting in detachment of the object as shown in Fig. #8. Unless it is absolutely unavoidable, objects should not be attached directly to armor by means of bolts through the plate.

PART B

WELDING

1. Precautions. Metal arc welding is the only fusion welding process which should be permitted on aircraft armor. Gas welding should not be used because the heating effect of the flame necessary to produce the weld will soften a large area of the armor plate. Brazing should never be permitted on armor because copper brazing alloys tend to produce cracks in armor plate, particularly those containing appreciable amounts of nickel. Before attempting to arc weld armor plate, it is essential that all paint and scale be removed from the plate in that portion of the plate where the weld is to be made. When gas cutting armor plate, the smallest cutting nozzle practicable should be used to minimize the heating effect on the plate. Face-hardened plate should be cut from the back side.

2. Use of Clips. With reference to the attachment by clips, as was described under Part A, BOLTING and illustrated by Figs. #4, 5 and 6, the holes through the armor plate may be avoided and the armor plate secured by welding the clips to the armor as shown in Figs. #9, 10 and 11. This type

of attachment has the advantage that the bolts through the armor plate are eliminated and the clips can be attached to the plate after the armor has been heat treated, thus simplifying assembly.

The method of attachment shown in Fig. #12 forms a more rigid support than that of Fig. #10, and is probably more practicable for welding than bolting because of the space requirements for the bolt heads.

3. Attachments to Armor. Where removable objects are to be attached to armor plate, a device similar to that shown in Fig. #13 or some variant thereof should be used. This method helps greatly in avoiding the occurrence shown by Fig. #8 because when the armor plate is struck there is sufficient elasticity in the clip to cushion the shock enough to prevent the bolt from breaking or the threads from stripping. Objects so attached have withstood the shock of a number of adjacent hits of heavy projectiles successfully.

Where objects which need not be removable are attached directly to the armor plate, the method illustrated by Fig. #14 should be used. Fillets less than 1/4" in size and less than 1" in length should not be permitted for such attachments. These welds may be continuous or intermittent, depending upon the loads involved. Members or clips used for attachment should be at least 1/4" in thickness to permit of the 1/4" minimum fillet, but can be as small in area as possible or can be of perforated metal (punched full of lightening holes) of sufficient cross-section to carry the load.

Attachments should never be welded to the face side of face-hardened armor. Welding on the face of such armor will cause cracks alongside of the weld which may result in ultimate failure of the plate, either under the stresses resulting from gunfire, or from vibration or other structural loads. This effect is shown by Fig. #15.

Flanges of attaching lugs, clips, or other parts to which the weld is applied should have sufficient mass so that they will not be completely melted away by the heat of the arc. Small nuts, bolts, and other small parts should not be welded because the heat of the arc may destroy them.

4. Splash Plates. Figs. #15 and #16 illustrate the weaknesses of certain welded corner joints in face-hardened armor. A connection similar to that shown by Fig. #17 is preferable to avoid welding to the face of the face-hardened plate.

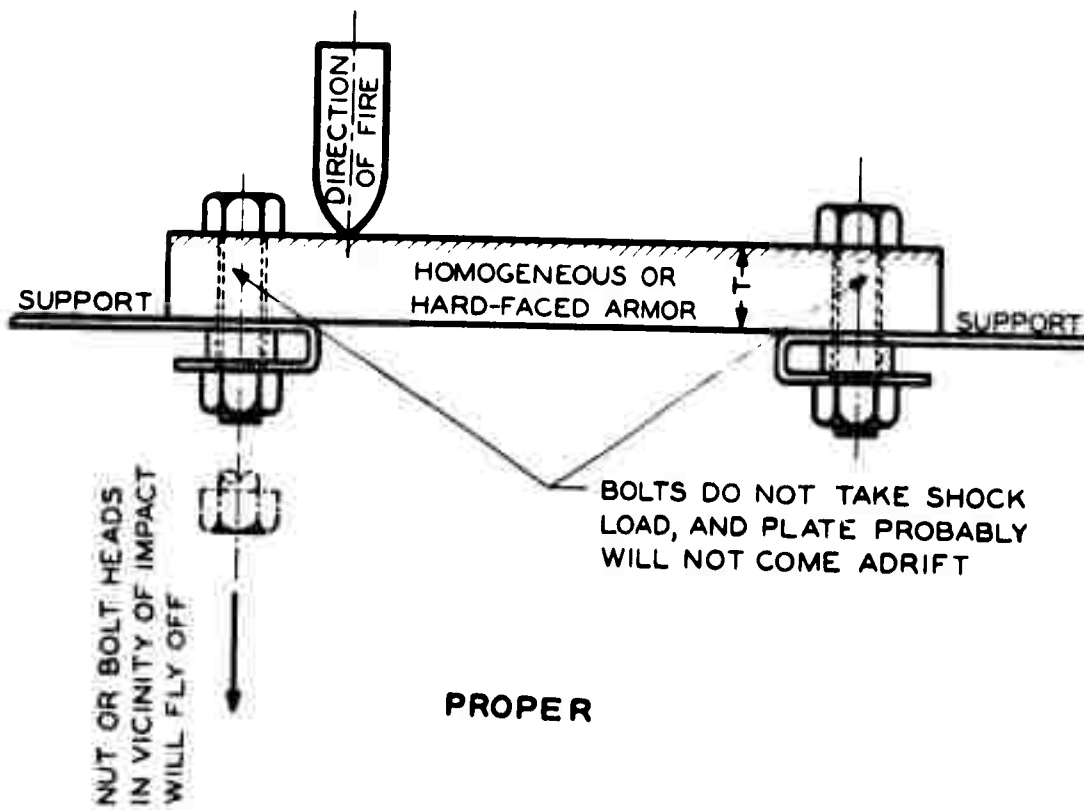
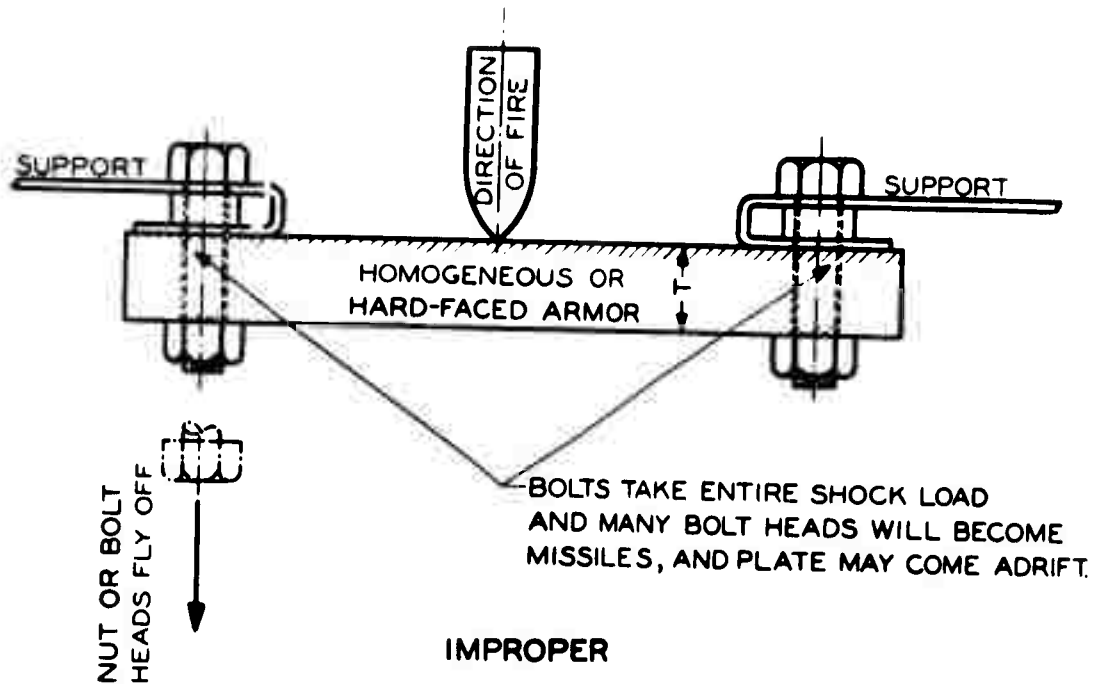
5. Attachment of Studs by Metal Arc Welding. Studs of 3/8" or greater diameters can be attached to homogeneous armor or the rear of face-hardened armor by metal arc welding. A continuous, generous fillet is run around the base of the studs which is held in close contact with the plate during the welding.

6. Repair of Cracks in Armor or Joining of Two Pieces of Armor. Two pieces of homogeneous armor may be joined in a butt weld using a double vee 45° bevel. Cracks in homogeneous armor can likewise be repaired by grinding out the crack to a double vee preparation with a 1/8" root opening and filling the groove from both sides with weld metal.

Face-hardened armor can be joined to another piece of face-hardened armor or a piece of homogeneous armor, or cracks can be repaired in face-hardened armor by welding a backing strap covering the joint onto the rear of the face-hardened armor. The dimensions of the butt strap recommended are as shown in Fig. #18.

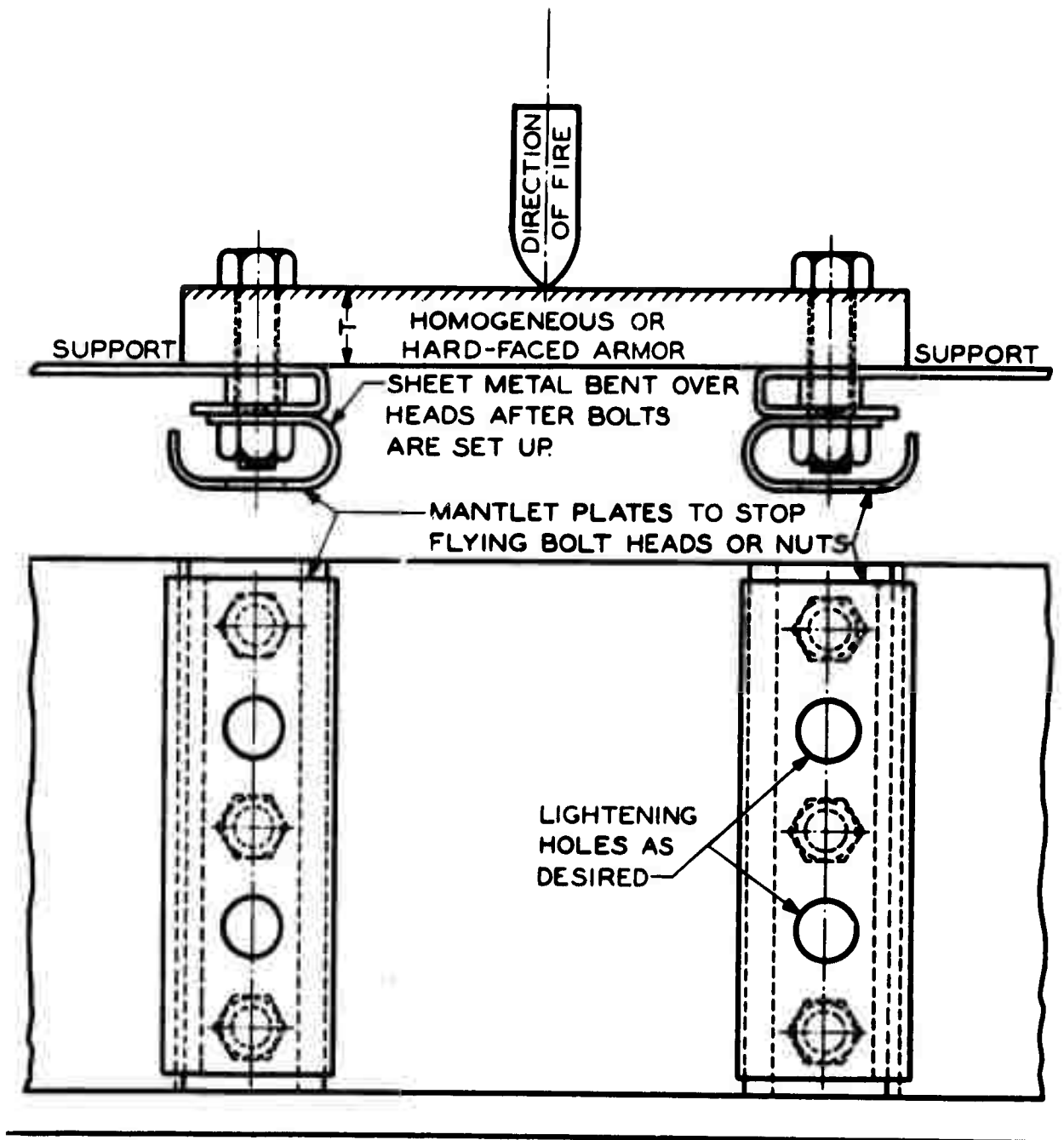
7. Electrodes. All welding to either face-hardened or homogeneous armor should be performed with 25/20 or modified 18/8 stainless steel electrodes. Commercial grades of mild steel electrodes should never be used because either the weld or the plate or both are apt to crack. It is believed that two sizes of electrodes, namely, 1/8" and 5/32", will be sufficient for any welding in the application of armor to aircraft.

NOTE - Spot welding can be used advantageously for the attachment of clips or angles to homogeneous armor or the rear of face-hardened armor. The equipment required, however, must possess an adequate temperature or timing control so that the spot zone can be softened following the original welding cycles. The spot welding of armor is not practicable for field repair and is suitable only in the fabrication of the original assemblies for installation in aircraft.



ATTACHMENT OF ARMOR

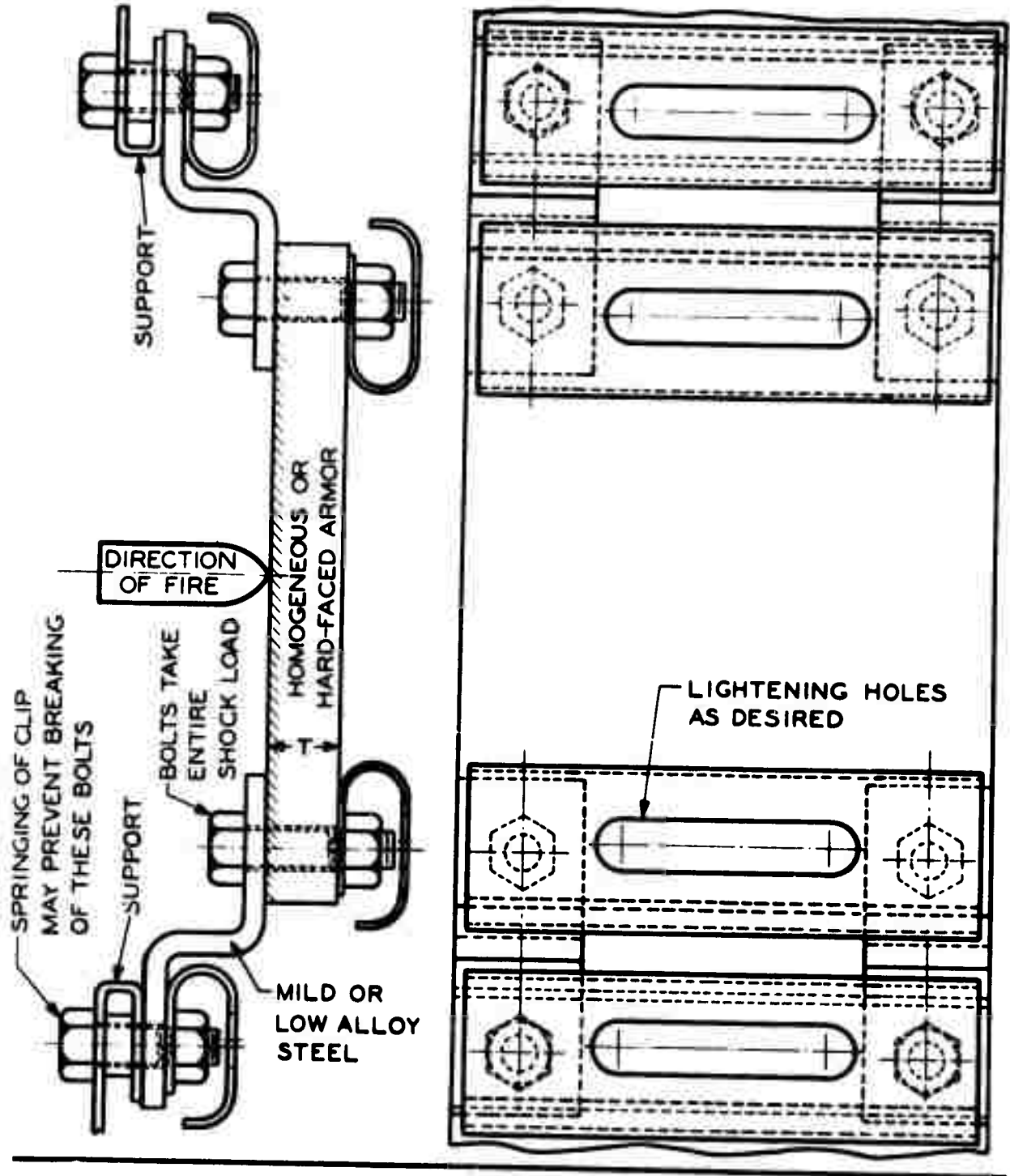
FIG. #1



MANTLET PLATE PROTECTION FROM FLYING BOLT HEADS AND NUTS

W.A. 639-4336

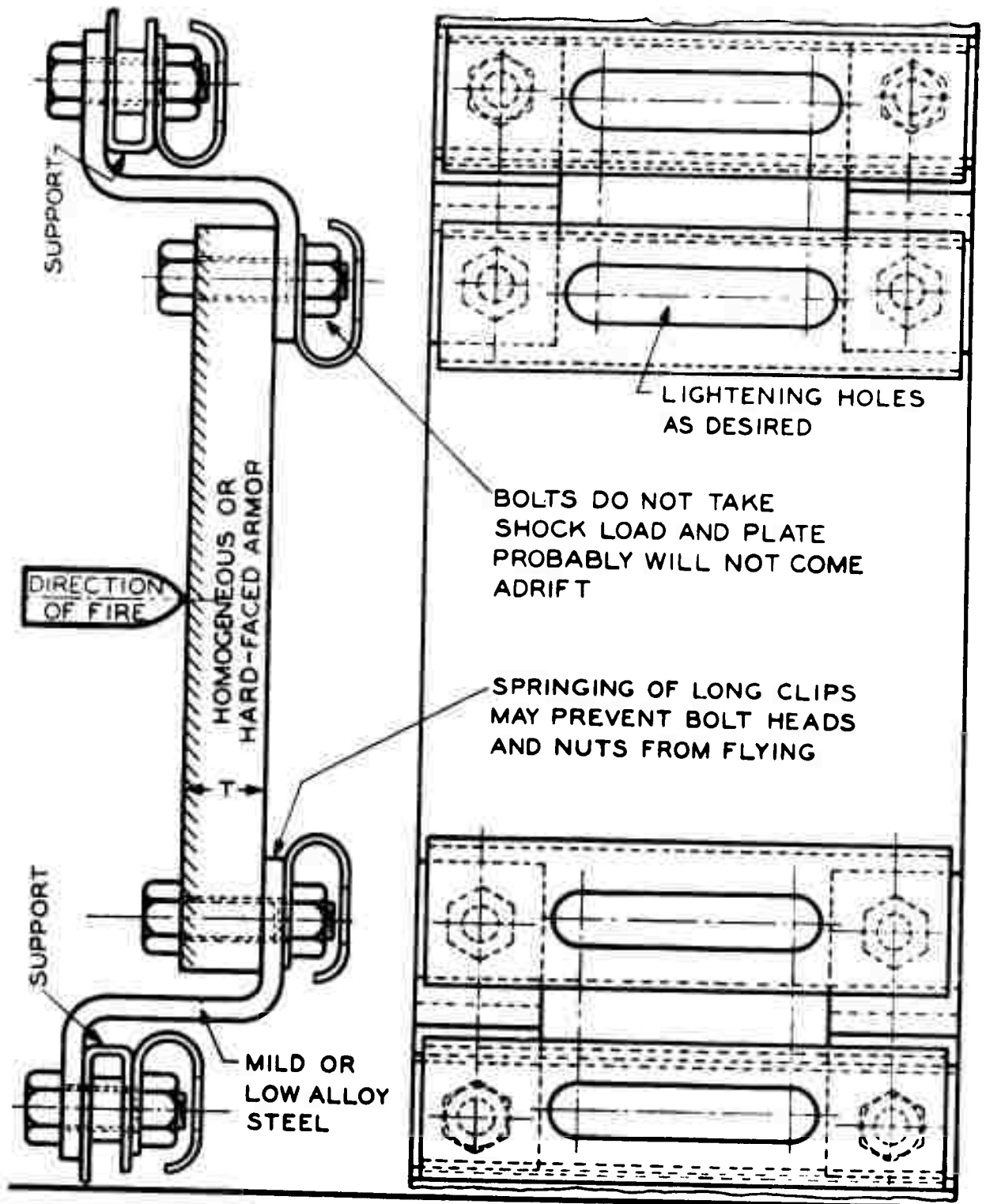
FIG. 2



UNDESIRABLE SUPPORT OF ARMOR BY CLIPS

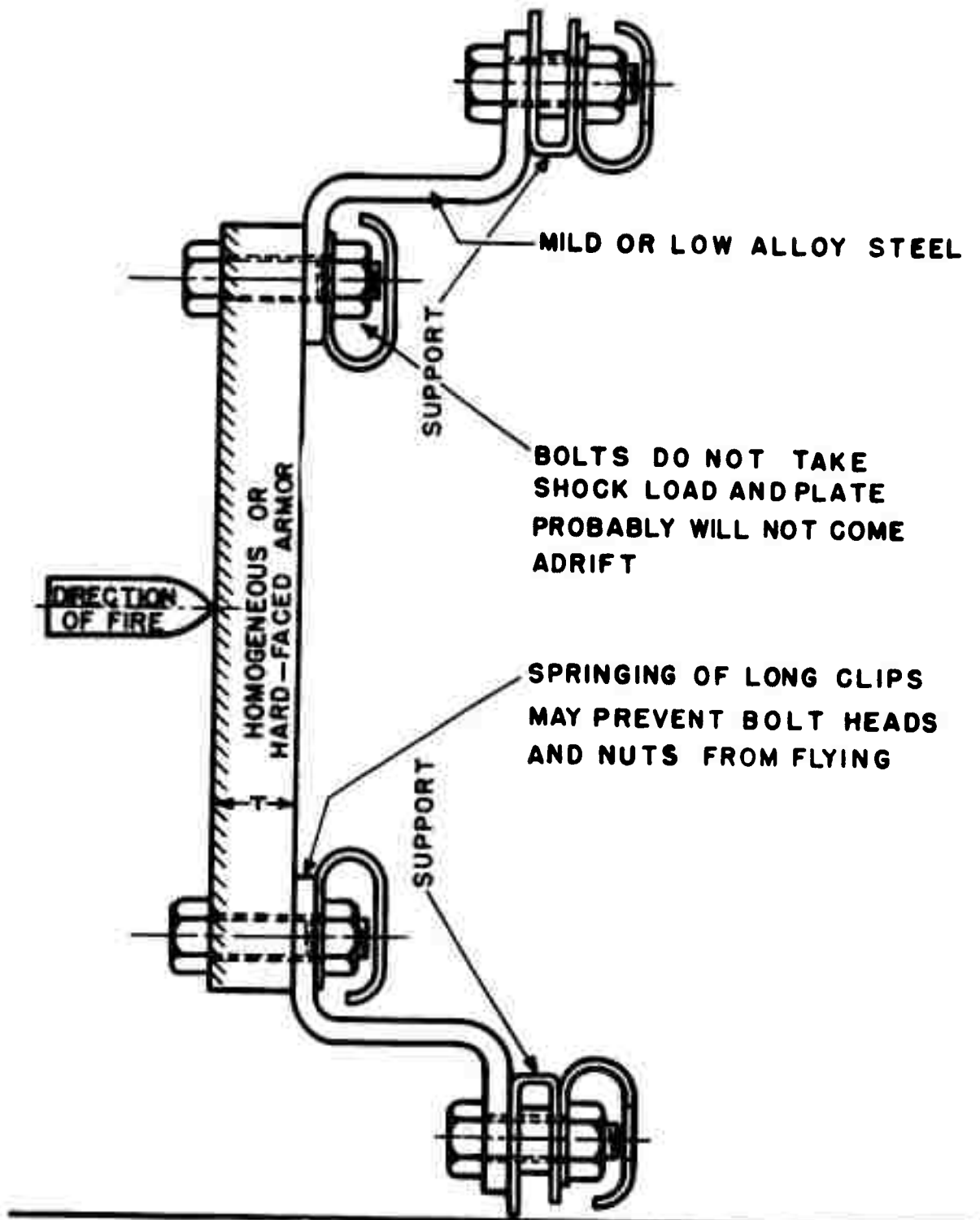
W.A.639-4337

FIG. #3



SATISFACTORY CLIP ATTACHMENT OF ARMOR BY BOLTING

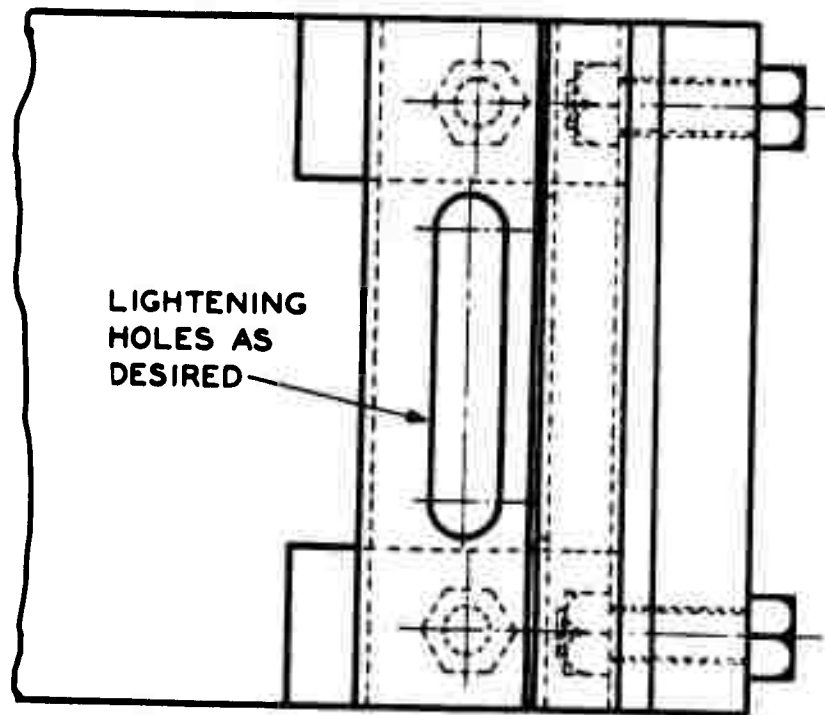
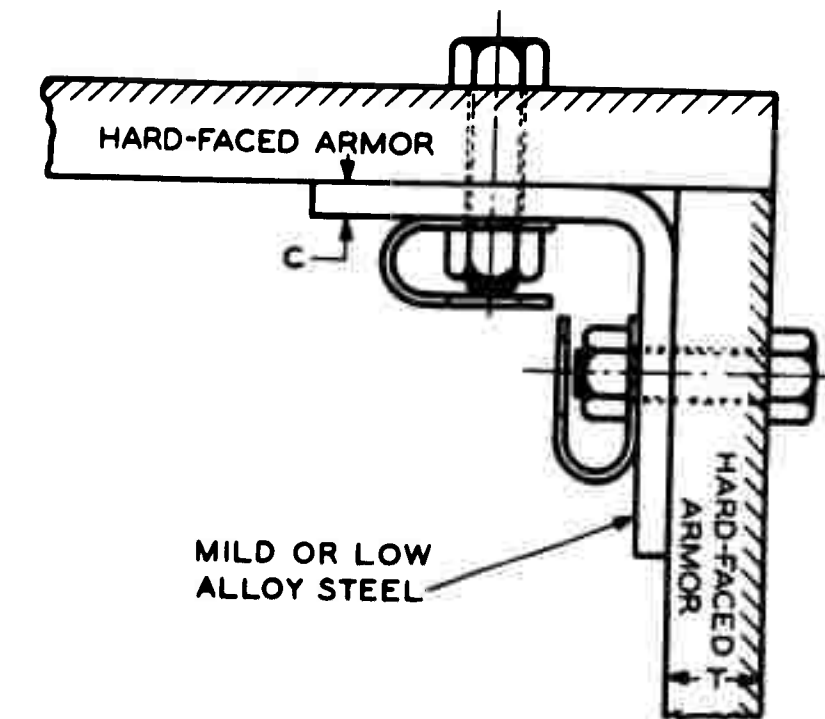
FIG. #4



**SATISFACTORY CLIP ATTACHMENT
OF ARMOR BY BOLTING**

FIG #5

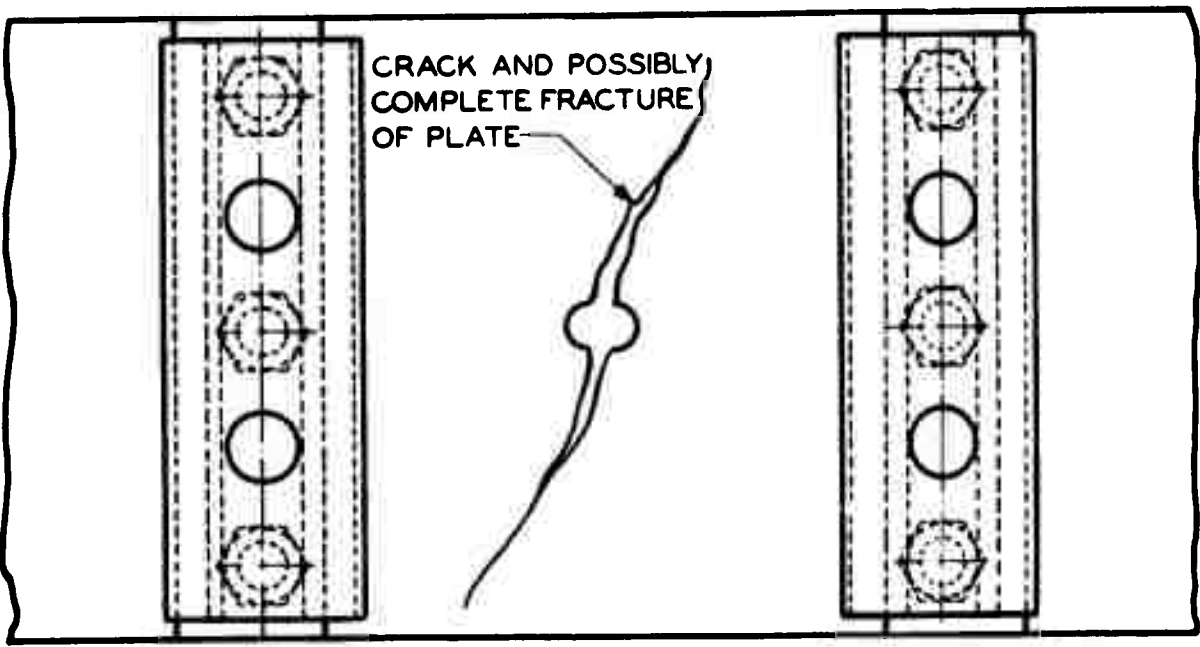
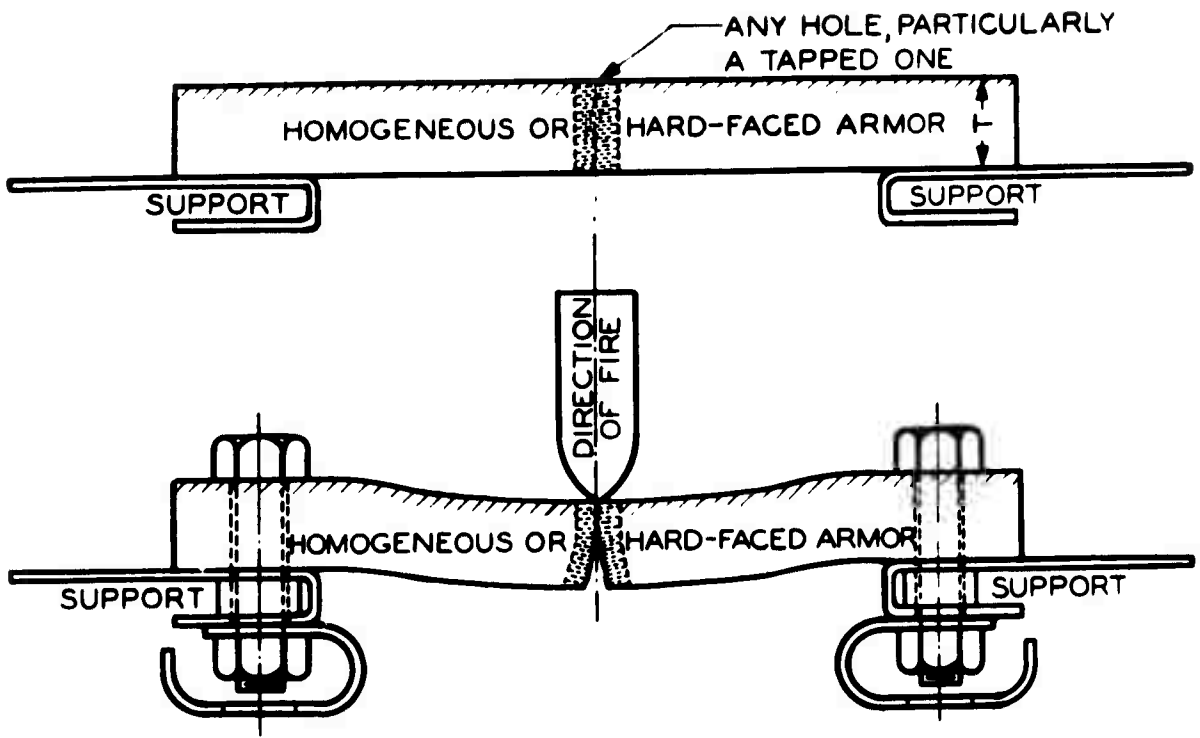
W.A.639-4339



BOLTED CORNER JOINT IN HARD-FACED ARMOR

W.A.639-4340

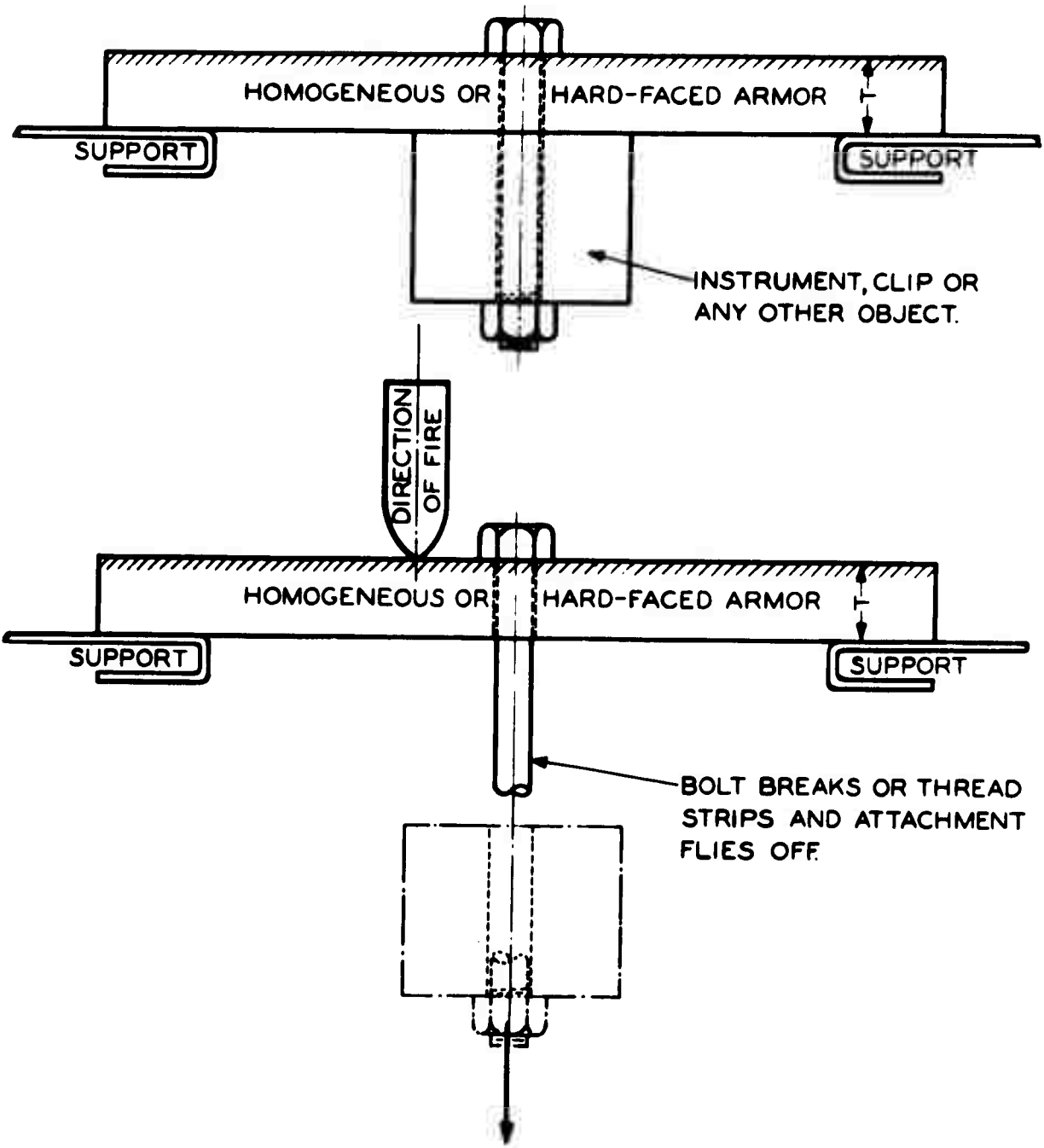
FIG. 6



EFFECT OF HOLES IN ARMOR

W.A. 639-43-41

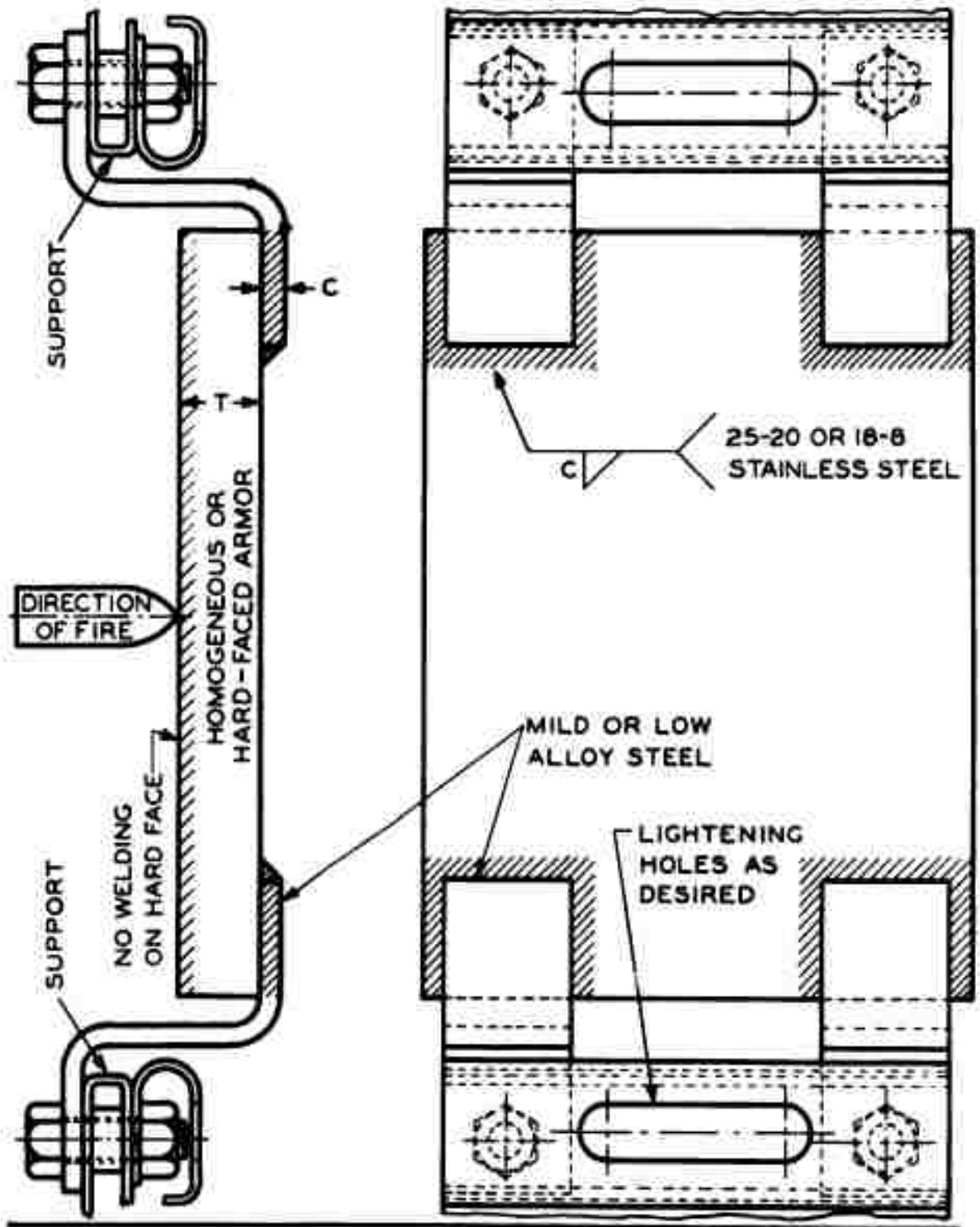
FIG. 7



IMPROPER ATTACHMENT OF OBJECTS TO ARMOR

W.A.630-4342

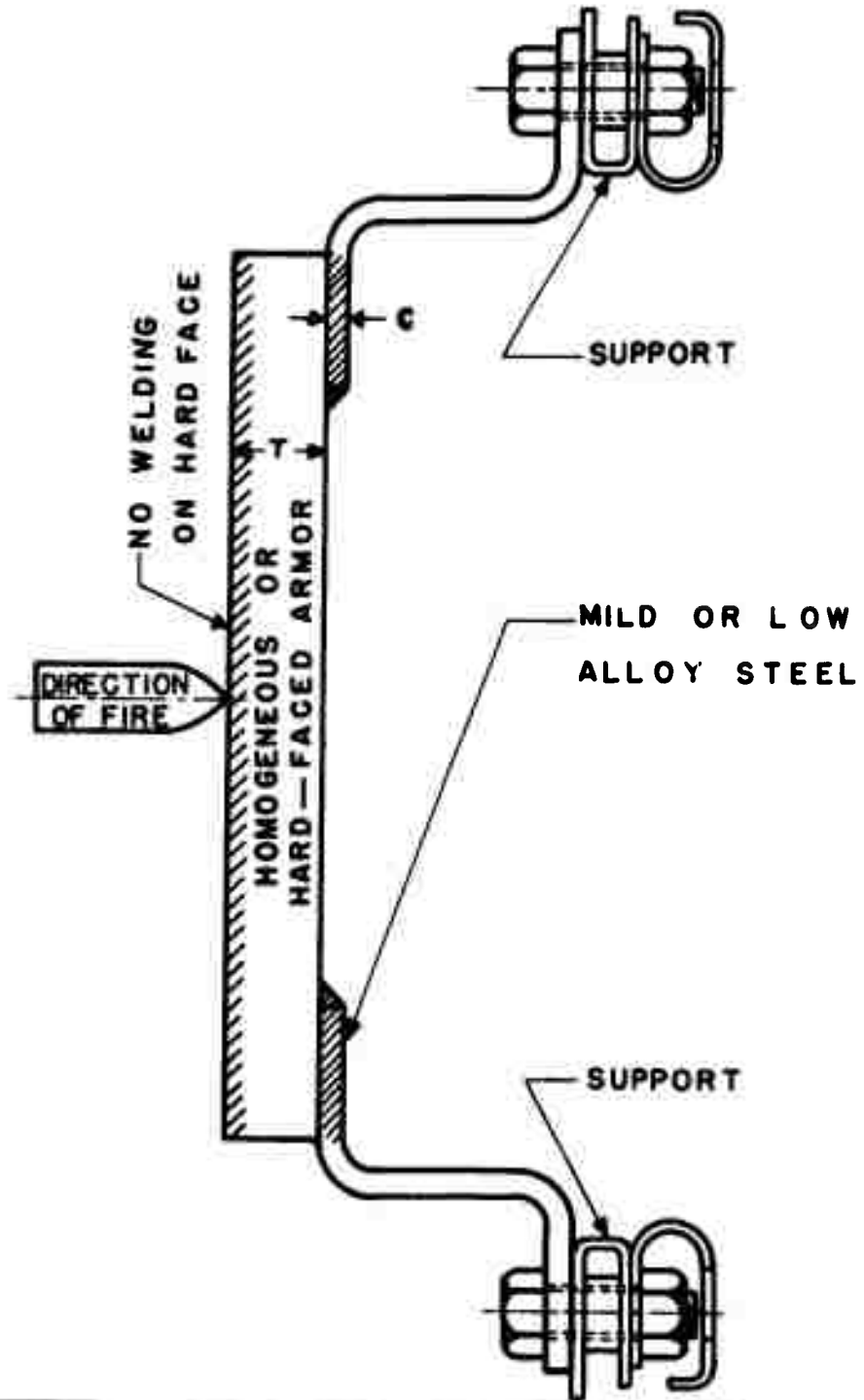
FIG. 8



SATISFACTORY CLIP ATTACHMENT OF ARMOR BY WELDING & BOLTING

W.A.639-4343

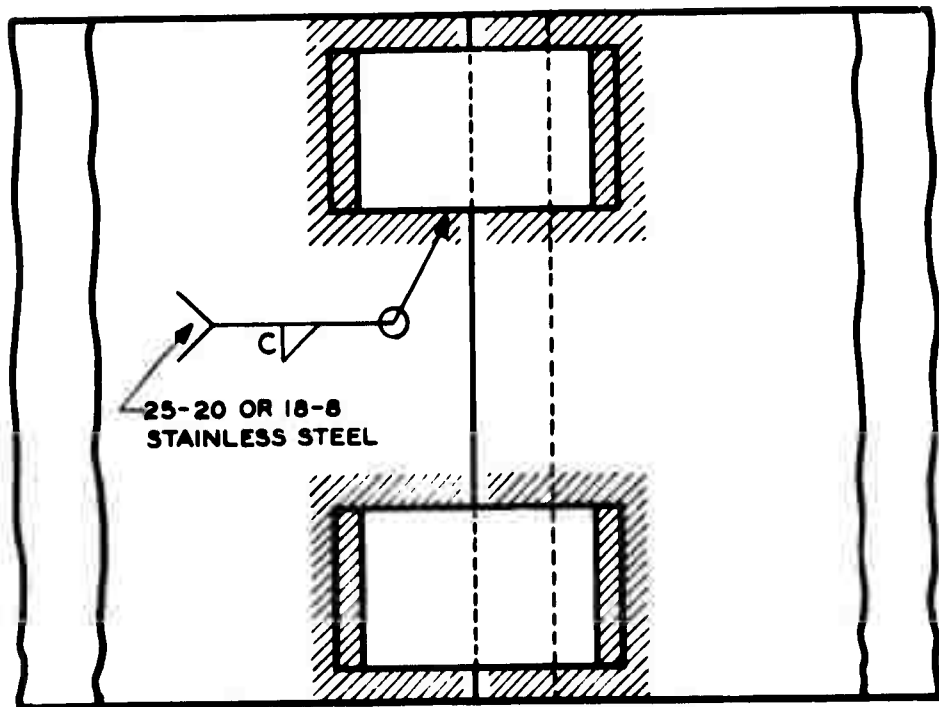
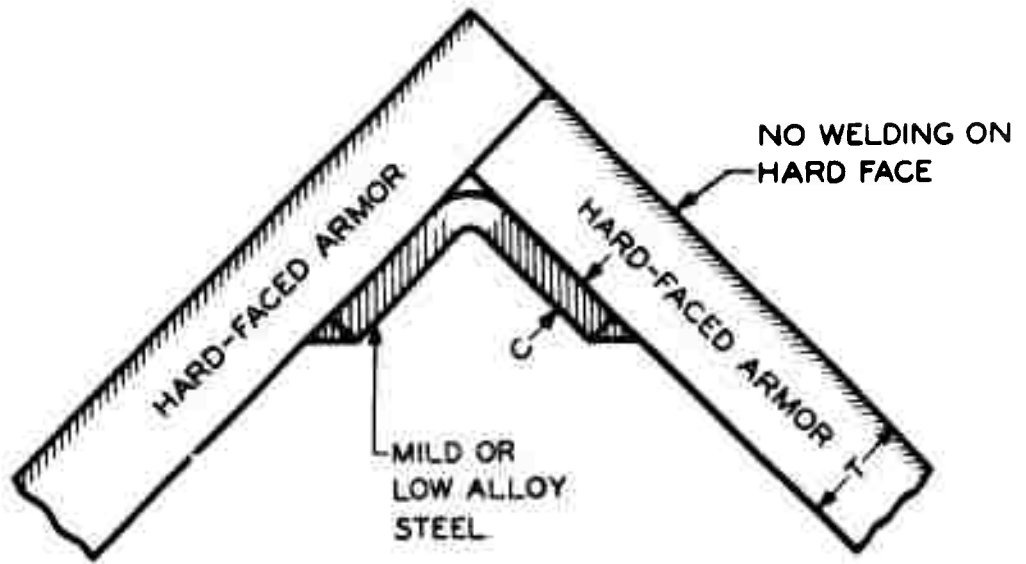
FIG. #9



**SATISFACTORY CLIP ATTACHMENT
OF ARMOR
BY WELDING & BOLTING**

FIG #10

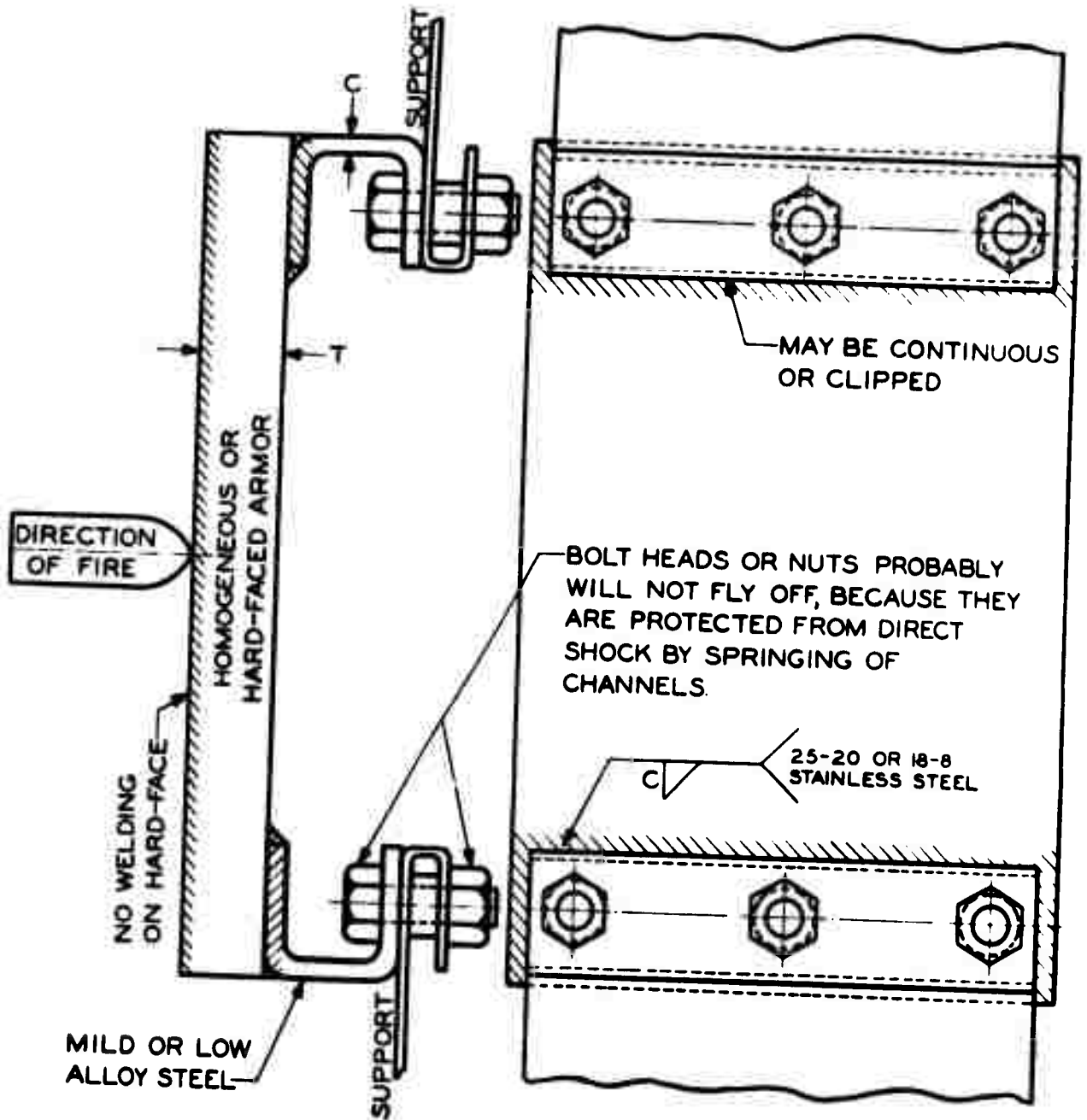
W.A.639-4344



SATISFACTORY HARD-FACED ARMOR CORNER JOINT WITH WELDED CLIPS.

W.A. 639-4345

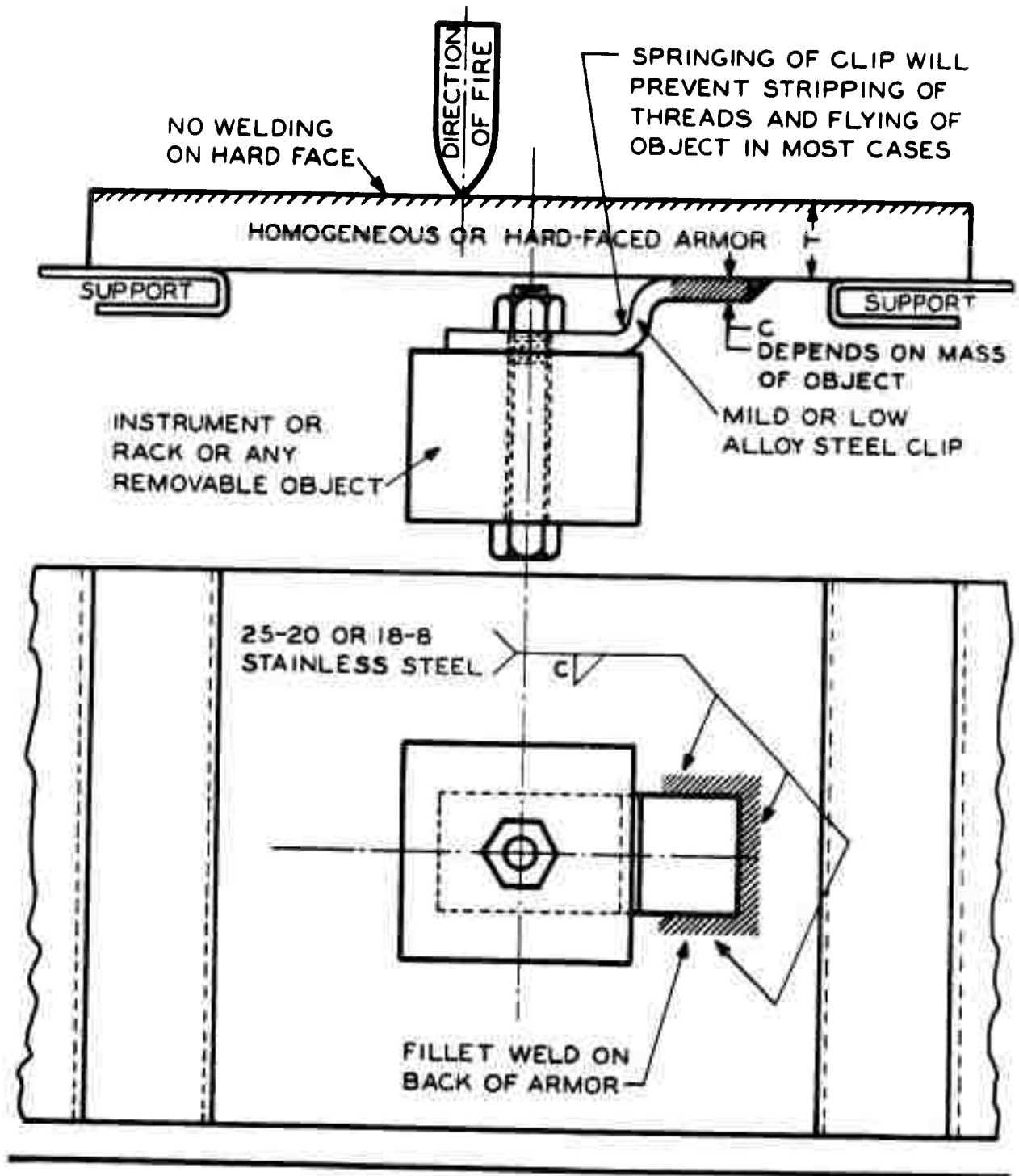
FIG. #11



**ATTACHMENT OF ARMOR
BY COMPRESSION CHANNELS OR CLIPS**

W.A.639-4346

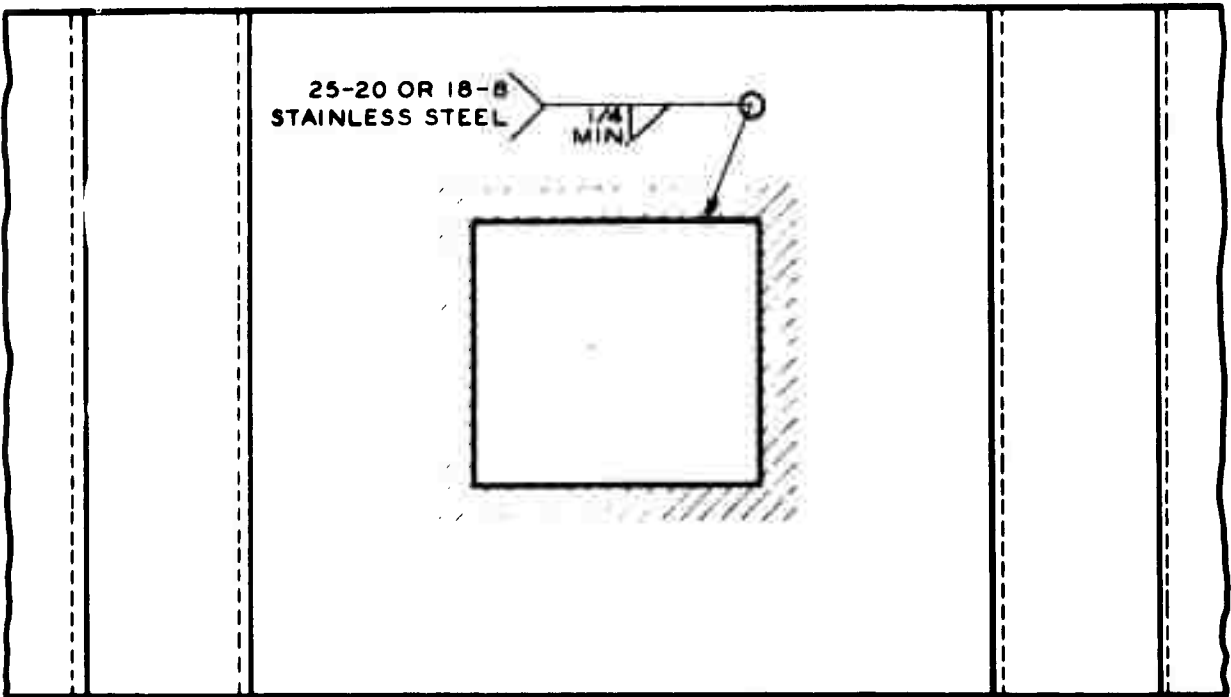
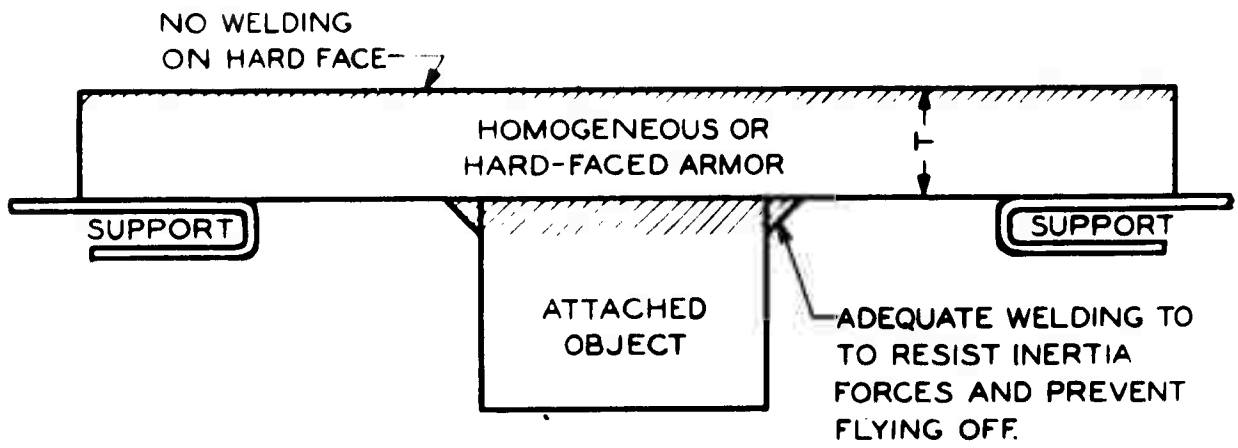
FIG. #12



WELDED ATTACHMENT OF REMOVABLE OBJECTS TO ARMOR

W.A. 639-4347

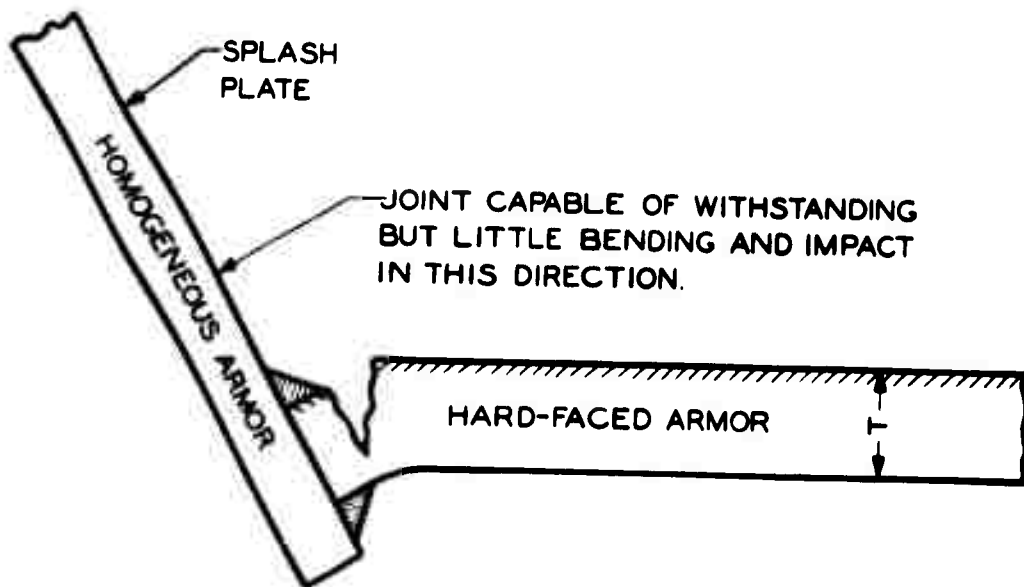
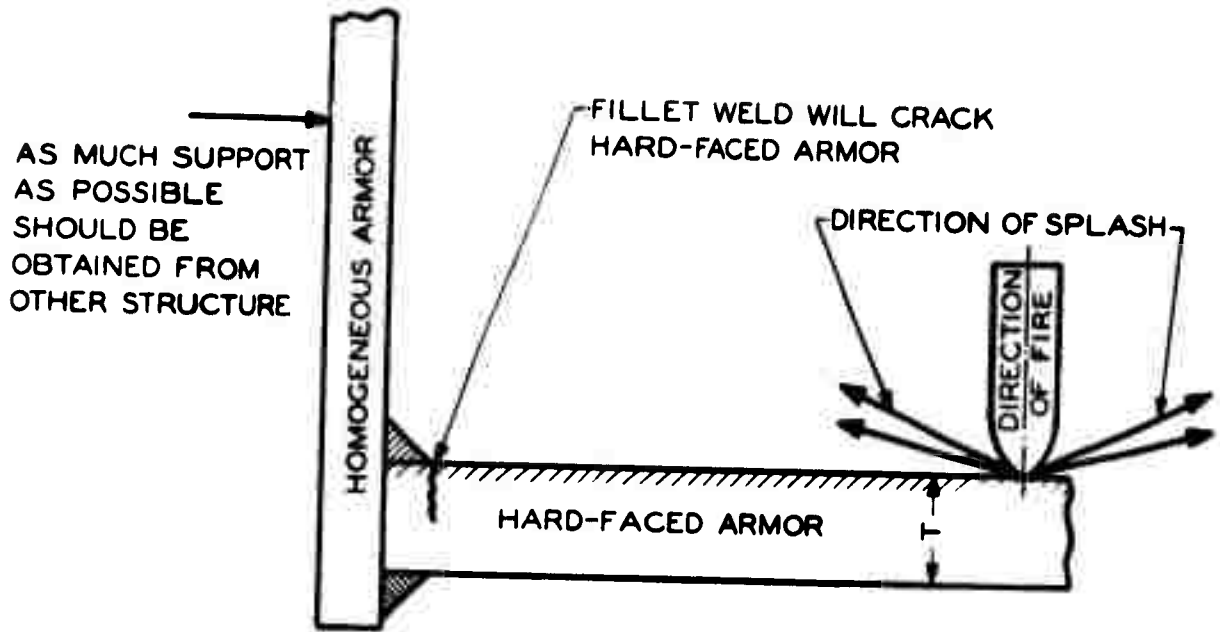
FIG. 13



DIRECT ATTACHMENT OF OBJECTS BY WELDING TO ARMOR

W.A. B.H.

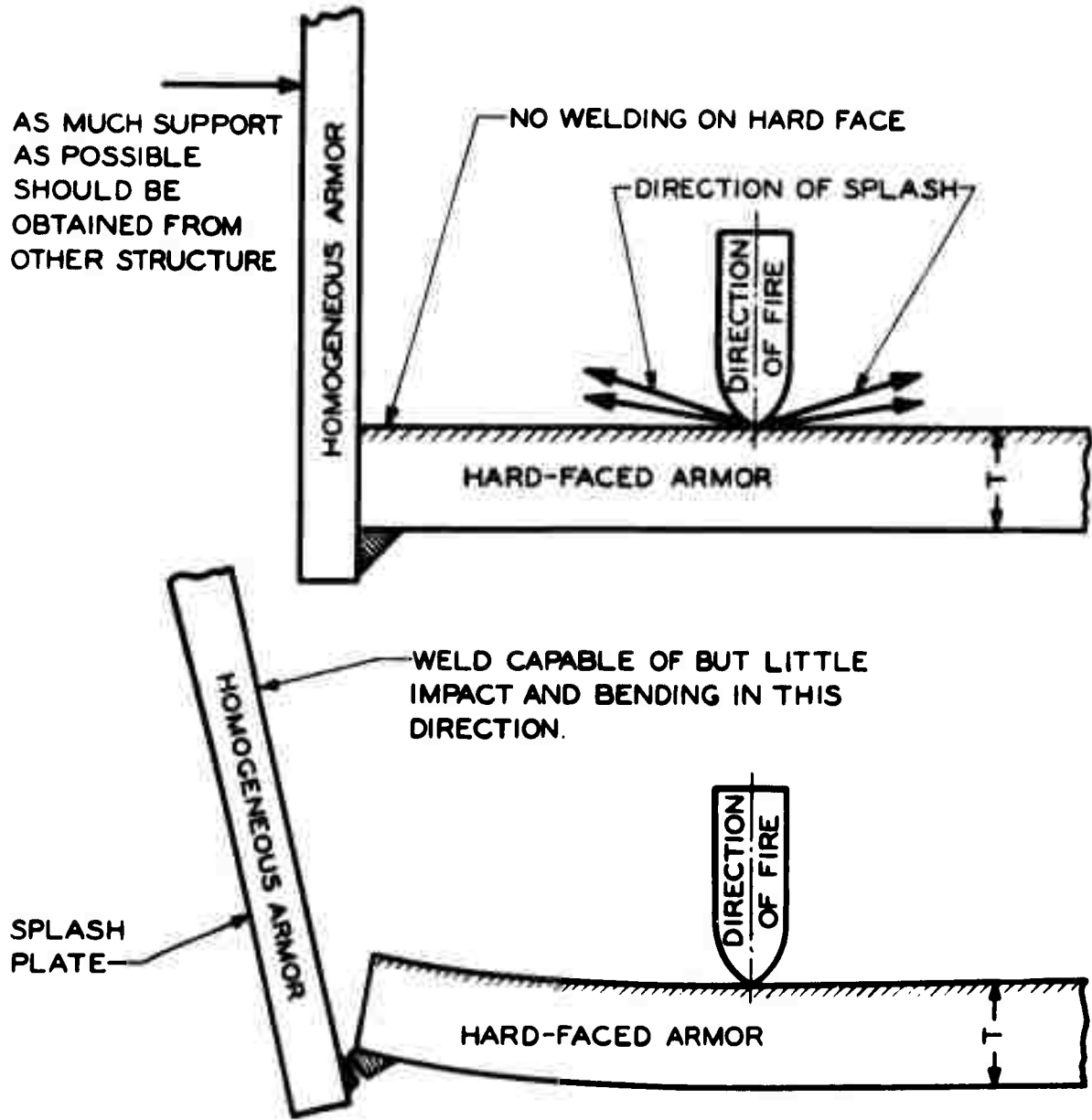
FIG. #14



**IMPROPER WELDED CORNER JOINT
BETWEEN HARD-FACED AND HOMOGENEOUS ARMOR.**

FIG. #15

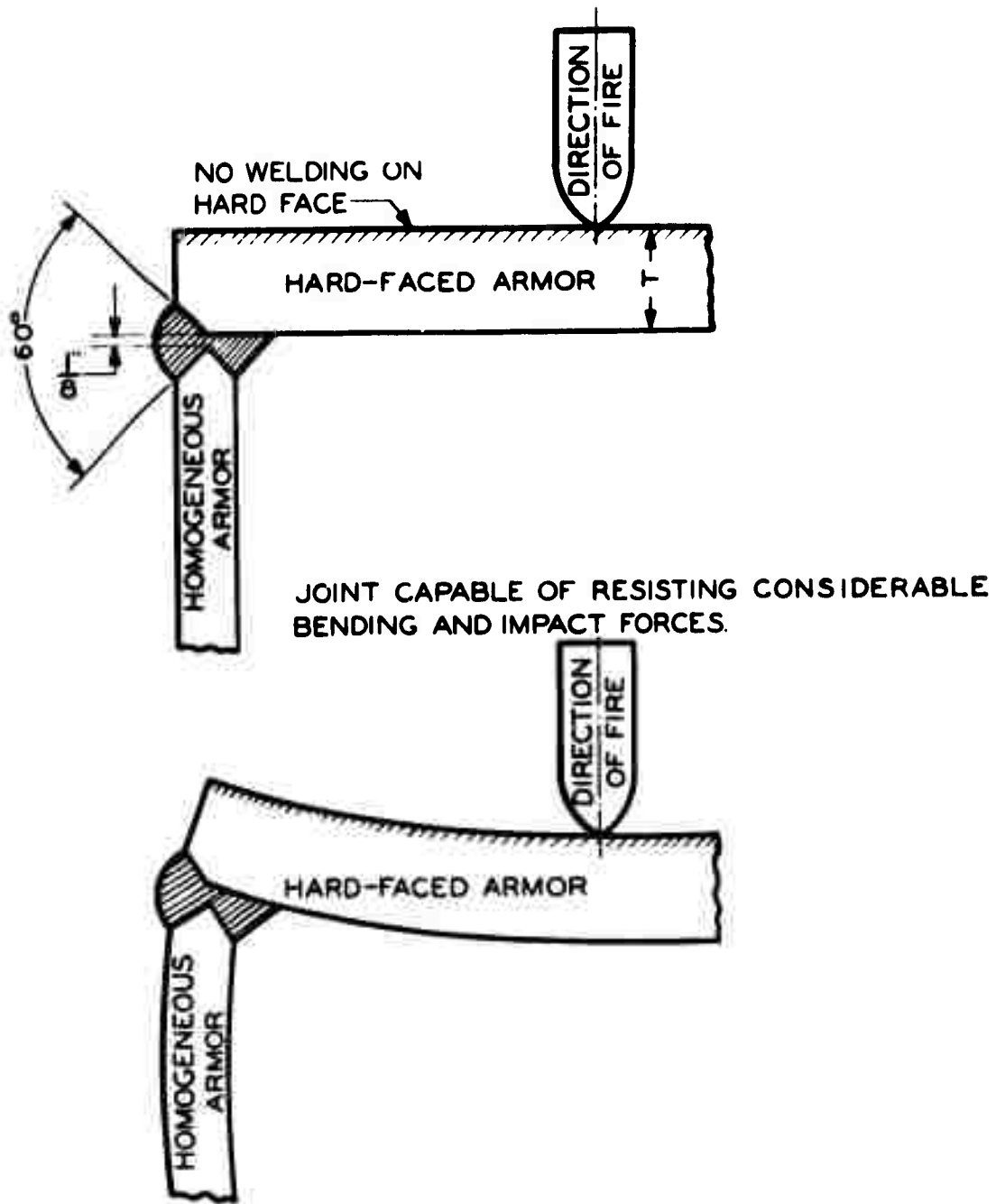
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**UNDESIRABLE WELDED CORNER JOINT
BETWEEN HARD-FACED AND HOMOGENEOUS ARMOR**

W.A.639-1350

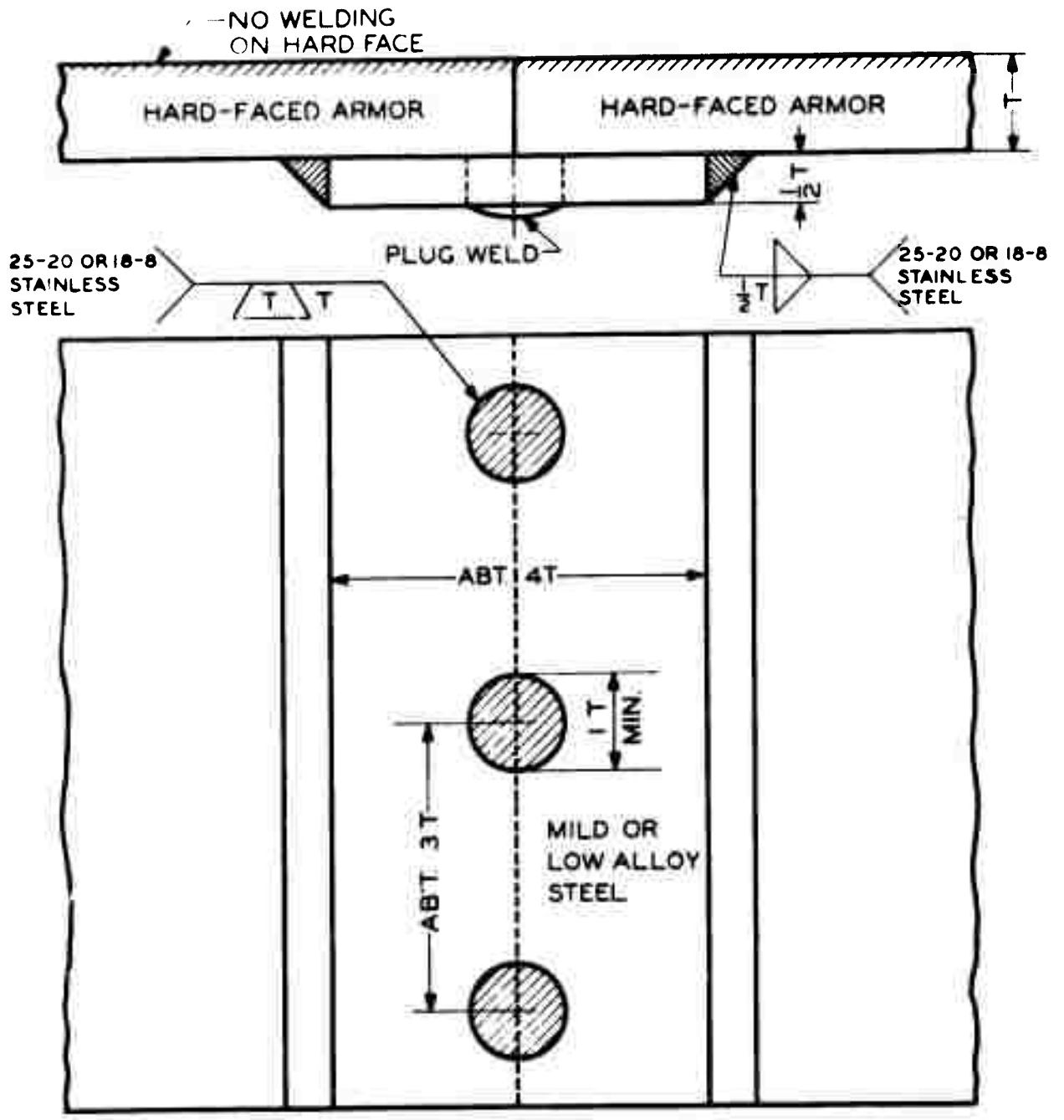
FIG. 16



**PROPER CORNER JOINT
BETWEEN HARD-FACED AND HOMOGENEOUS ARMOR**

W.A.639-4351

FIG. #17



**WELDED STRAPPED BUTT JOINT
ON HARD-FACED ARMOR**

W.A.639-435C

FIG. #18