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Strain measurements on concrete surfaces

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Technical Note (National Research Council of Canada. Division of Building Research); no. TN-114, 1952-01-22

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No. 114

TECHNICAL NOTE

NOT FOR PUBLICATION — FOR INTERNAL USE

PREPARED BY W.R. Schriever CHECKED BY N.B.H. APPROVED BY H.F.L.

PREPARED FOR Inquiry Reply DATE Jan. 22, 1952

SUBJECT : Strain Measurements on Concrete Surfaces

Often in the design of plain or reinforced concrete structures the magnitude and distribution of the loads are not accurately known. Further uncertainties as to actual stresses may arise as a result of simplified design procedures, particularly in cases of structurally indeterminate systems, and of building materials which do not exhibit elastic properties.

It is sometimes desirable therefore to attempt to ascertain the actual stresses in the finished structures, although this may be difficult especially where the loads consist of slowly changing forces, such as horizontal and vertical earth pressures, swelling and shrinkage pressures of soils under shallow building foundations, and tunnel pressures.

Various methods of measuring strains in concrete are in use. Some of these use electrically operated gauges, often consisting of special applications of the electrical resistance wire strain gauge; others use mechanical extensometers. Frequently surface strains only are measured but in more extensive investigations strains are measured also by gauges embedded in the concrete or fastened to the reinforcing bars.

The purpose of this Note is to describe one method only, namely the measurement of surface strains by means of an 8-inch Metzger extensometer, shown in Fig. 1. The writer wishes to acknowledge with gratitude the assistance in this work received from the staff of the Research Laboratories of the Hydro-Electric Power Commission of Ontario.

Measurements by this method have just been started on concrete slabs used as "floating" foundations for 2 experimental basementless buildings. It is expected that movements of the ground due to shrinkage and swelling of the soil will be the deciding factor in stressing the concrete. The extensometer readings, however, also include strains due to shrinkage, temperature and moisture changes in the concrete and therefore require very careful evaluation. This point is important in all cases of long-term observation without controlled loading of the structure.

Description of Extensometer

An extensometer, in principle, is a mechanical device for measuring the change in distance between two gauge marks which usually consist of small holes drilled into steel. The extensometer itself consists of two conical steel points mounted on a metal frame which carries a dial gauge actuated by a lever. One of the conical points is fixed, the other movable (over a range of 3/100 inch). This movable point is part of the lever which actuates the dial gauge with a lever ratio of 1:10. Therefore each unit on the dial gauge which is graduated in 1/1000 inch, represents a movement of the movable point of 1/10000 inch. With a gauge length of 8 inches this is a strain of 12.5 micro inches per inch.

A gauge length of 8 inches is frequently used; other extensometers with gauge lengths from 2 to 24 inches are commercially available. The choice of a particular gauge length results from a compromise between a desire for the higher accuracy of a longer gauge and a desire for a more accurate measurement of local stresses in areas of varying stresses.

Installation of Stainless Steel Plugs in Flat Concrete Surfaces

With this type of extensometer no measurements can be made directly on concrete, as the measuring holes or marks must necessarily be of a permanent nature. Steel plugs or plates, in which the gauge holes are drilled, are required. Stainless steel is preferable to ordinary steel.

For the accuracy of the readings, it is necessary that the top surfaces of the two plugs lie in the same plane and that the holes be exactly perpendicular to these surfaces. If the plugs are to be embedded in the concrete they must be held in this position by a jig until the concrete has set. The holes for the extensometer readings are drilled into the plugs in advance and, owing to the small range of measurable movement, have to be held at exactly the right distance by a jig fitted with small dowel pins. This distance should be such that there is approximately an equal measuring range in both directions to permit both compressive and tensile strains or stresses to be detected.

At points of a structure where the directions of the principal stresses are not known, it is necessary to take readings in three directions in order to establish them. This note describes the latter case, in which each jig holds the plugs required for measurements in three directions. It is easy to alter the jig for measurements of strains in one direction only.

Fig. 2 shows a plan of the jig plates, the plugs and a template for drilling gauge holes at the correct distance perpendicular to a plane surface. The procedure in making the jig plates and installing the plugs is as follows:

1. The template bar and the plugs should be made by a machine shop. Then the 10 by 10-inch jig plates, which must be truly flat, are drilled in the following manner. The small gauge holes are drilled first using a #54 drill and the template bar to ensure perpendicular drilling. The hole which is common to the three directions of measurement is drilled first,

then the three others after inserting the shank of a #54 drill through one end of the template bar into the first hole. These holes need only be 1/8-inch deep to hold short dowel pins. If desired, the length of each gauge line can be checked with the extensometer;

2. Beside each small hole a larger "through" hole should be drilled with a #14 drill for an 8 NC 32 brass screw which will later hold the plug in place, as shown in the assembly section on Fig. 2. Dowel pins are made by cutting short pieces of drill rod. Before the plugs are fastened to the jig plate, however, two handles similar to metal drawer handles should be attached to the top side of the plate; the underside and the edges of the plate should be covered with a thin coat of grease to allow easy removal of the plate from the concrete. Care should be taken to keep the plugs free from grease when fastening them;

3. The jig plate is installed immediately after the top surface of the concrete has been trowelled. The plate should be moved back and forth slightly until its underside is flush with the concrete surface so that the plugs may be well surrounded by concrete. Sometimes air pockets form under the plate around the plugs. In order to reduce this danger, two small grooves should be drilled into the jig plates adjacent to each #14 drill hole, as shown by dotted lines in the assembly section, to allow the air to escape. It is possible that by making the jig plates of transparent material, for example Lucite, air pockets could be seen.

When the strain measurements are to be made on vertical or overhead concrete surfaces, the jig plates must be made an integral part of the form work by cutting a corresponding hole in the form boards. As an alternative, suitable plugs could be installed, after the forms are removed, by drilling holes into the concrete and grouting the plugs, into which the gauge holes could subsequently be drilled. One difficulty, however, would be to obtain plug surfaces lying in the same plane which, as already mentioned, is essential for the accuracy of the measurements;

4. After the concrete has set sufficiently, the brass screws are removed and the jig plate lifted off. The jig plates, screws and dowel pins can then be used again for other places of measurement. Any holes from air pockets around the plugs should be grouted with cement paste;

5. The first set of strain readings can now be taken with the extensometer. They are the so-called "zero readings" which, depending on conditions, might already include some small strains due to shrinkage, temperature changes, etc.;

6. After every reading the plugs are protected by covering them with ½-inch hard rubber faucet washers, using 8 NC 32, 3/8-inch brass screws to hold them.

Technique of Extensometer Readings

Before taking the first reading, the edges of the gauge holes should be lapped with a centre punch having a cone with an angle of 60 to 90 degrees. A pierced wooden block to hold the centre punch perpendicular to the surface of the plugs during this operation is helpful. By reaming a drill hole in this way, the sharp edge of the hole is cut and a better

bearing is provided for the conical points (angle of 45 degrees) of the extensometer and the danger of a possible change of reading by wear of the hole is reduced.

For the readings, the gauge holes must be clean, especially for the important zero reading. Metal chips and dirt can best be removed by using a round wooden tooth-pick or the sharpened end of a wooden match. When taking a reading the movable point of the extensometer should be set first in one of the gauge holes, then the fixed point in the other gauge hole. Apply a firm pressure (roughly 10 lb.) on the extensometer, using one hand at each end. This pressure must be applied perpendicularly to the structure, without a component parallel to the extensometer. By slightly rocking the instrument back and forth at right angles to its axis, no change of reading should occur if the gauge holes are perfect. If this is not the case, special attention should be paid to taking the reading only when the extensometer is perpendicular to the surfaces of the plugs.

It is good practice to repeat every reading by removing and replacing the extensometer. Even to remove only the fixed point part way is helpful. The accuracy of strain measurements depends to a great extent on a person's ability to obtain consistent readings, that is, to obtain always the same value when the readings are repeated.

Temperature Effects

When making strain measurements the strains due to temperature changes of the structure as well as the effect of the temperature expansion of the extensometer itself are included in the readings. The Metzger gauge is made of steel (not invar) and therefore is quite sensitive to temperature changes. In cold weather the heat of the operator's hands is quite sufficient to change the readings noticeably and the operator's breath when directed against the gauge can also have a marked effect.

If the assumption is made that the extensometer has the same coefficient of expansion as the structure, no correction of the readings is necessary for temperature effects, provided the extensometer is at all times at the same temperature as the structure. As the coefficients of expansion of different steels do not vary appreciably and in addition are fairly close to those of concrete, this assumption can be justified in many cases. A "standard bar" for reference readings should be used in all cases. The standard bar, to permit complete temperature compensation, must have the same coefficient of expansion and must be at the same temperature as the structure at each point of measurement. These are sometimes difficult to obtain in a strict sense.

It is also important to use a standard bar to be able to correct for any changes in the effective length of the extensometer which might be caused by accidental bending of the conical points, or by unavoidable adjustments, or by repairs to the gauge.

The punch bar which is supplied with each extensometer can be used as the standard bar by taking readings on the holes drilled for this

purpose near the set-screws. The bar should be laid on the structure near the measuring points some time in advance of the readings to allow sufficient time for it to assume the temperature of the structure. If the air temperature is different from that of the structure it may be advisable to cover the standard bar with a felt pad.

Under normal conditions (fairly constant and uniform temperature of both structure and air), it is sufficient to take a reading of the standard bar at the beginning and at the end of a series of readings, provided, of course, that the extensometer and standard bar remain at the same temperature as the structure. It is necessary therefore to prevent the extensometer from being warmed up by the operator's hands. For this purpose ¼-inch sponge rubber pads can be glued on both ends of the extensometer to avoid direct contact between the fingers and the instrument. A record of the air temperature at the time of measurement should be kept.

The correction of a strain reading for a standard bar reading differing from the zero reading, is done by adding or subtracting the same amount as is required to change the standard bar reading to its original value.

Evaluation

After the change in gauge length from the time of the zero reading has been established, the unit strain is computed by dividing the change by the gauge length.

The apparent stress is then determined by multiplying the unit strain by the modulus of elasticity of the material on which the measurements are made. For concrete, the modulus of elasticity should be measured on test cylinders at various ages corresponding to those of the structure at the times readings are taken.

Closing Remarks

In this Note the technique of measuring two-dimensional (surface) strains on concrete by one method only, namely, by means of an 8-inch Metzger extensometer, has been described. Each problem of strain measurement requires individual consideration and the method best suited in a particular case should only be decided after a careful study of the several possible approaches.

Further Technical Notes on the measurement of strain will be prepared when occasion arises.

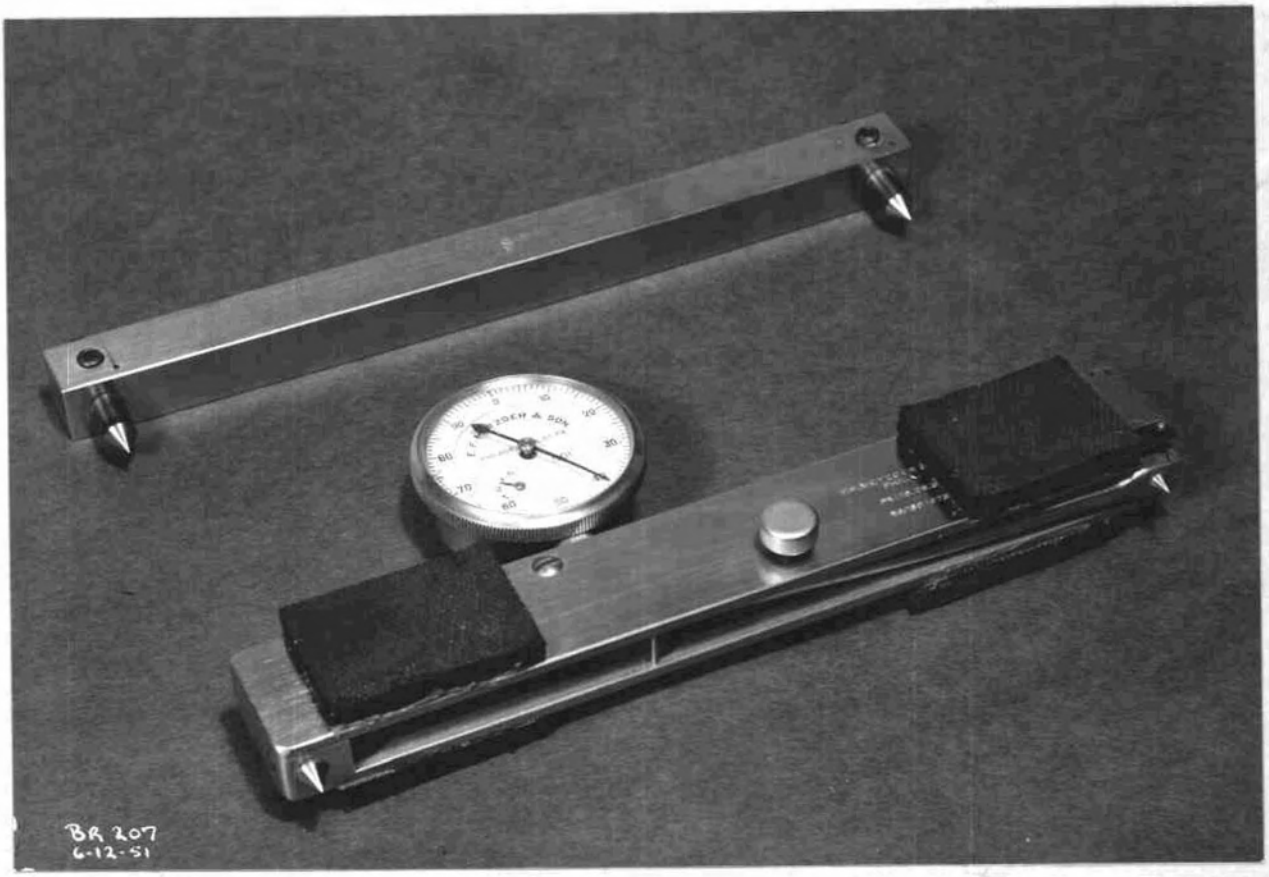


Fig. 1

8-Inch Extensometer for Strain Measurements,
with Punch Bar Used as Standard Bar.



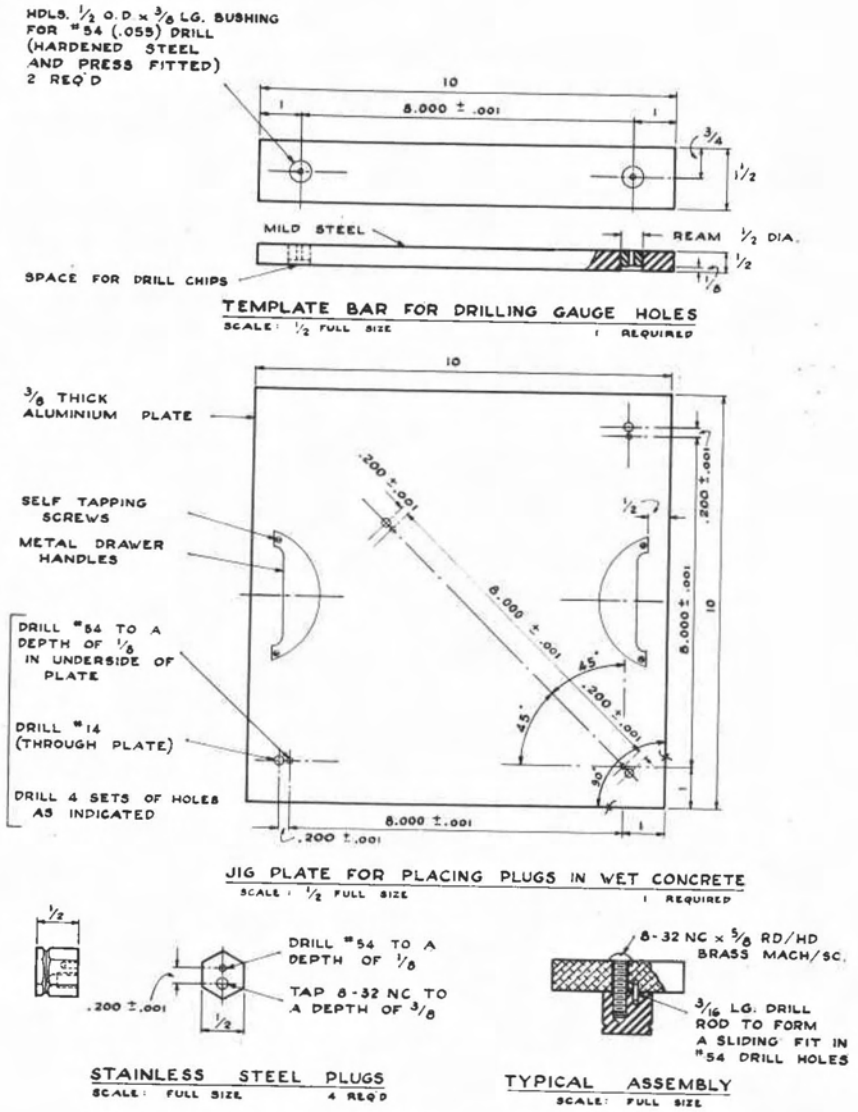
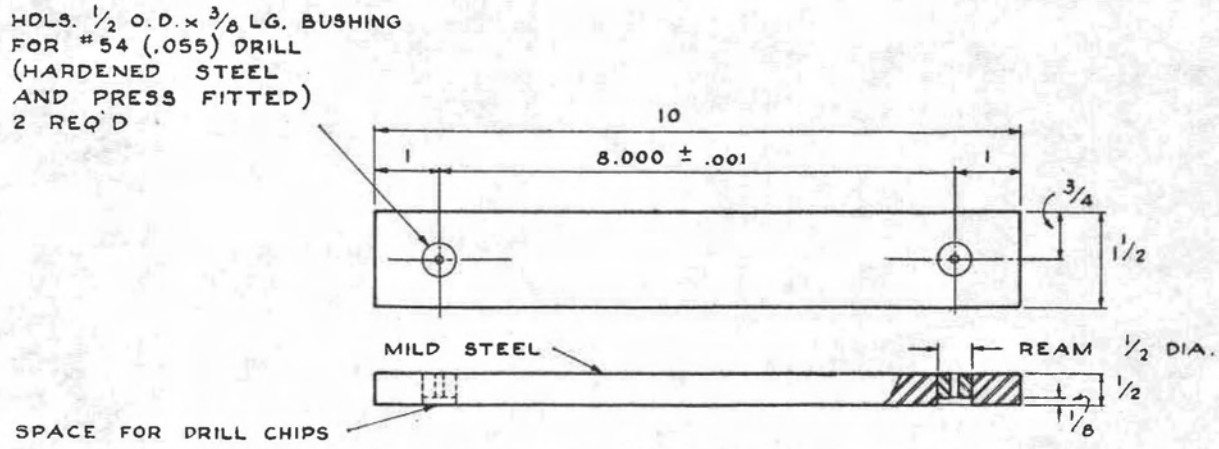
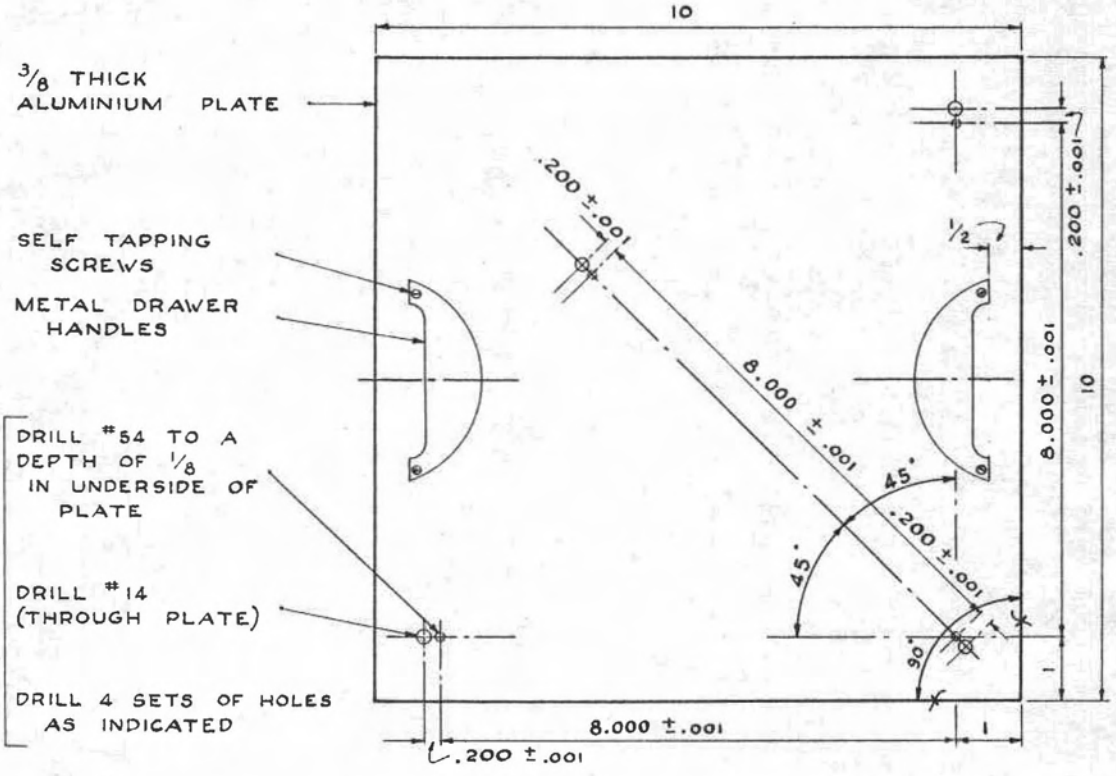

HDLS. 1/2 O.D x 3/8 LG. BUSHING FOR #54 (.055) DRILL (HARDENED STEEL AND PRESS FITTED) 2 REQ'D
10
1
8.000 ± .001
1
3/4
1 1/2
MILD STEEL
REAM 1/2 DIA.
1/2
1/8
SPACE FOR DRILL CHIPS
TEMPLATE BAR FOR DRILLING GAUGE HOLES
SCALE: 1/2 FULL SIZE
1 REQUIRED
10
3/8 THICK ALUMINIUM PLATE
SELF TAPPING SCREWS
METAL DRAWER HANDLES
DRILL #54 TO A DEPTH OF 1/8 IN UNDERSIDE OF PLATE
DRILL #14 (THROUGH PLATE)
DRILL 4 SETS OF HOLES AS INDICATED
.200 ±.001
1/2
8.000 ±.001
45°
.200 ±.001
8.000 ±.001
10
.200 ±.001
8.000 ±.001
.200 ±.001
JIG PLATE FOR PLACING PLUGS IN WET CONCRETE
SCALE: 1/2 FULL SIZE
1 REQUIRED
1/2
.200 ±.001
1/2
DRILL #54 TO A DEPTH OF 1/8
TAP 8-32 NC TO A DEPTH OF 3/8
STAINLESS STEEL PLUGS
SCALE: FULL SIZE
4 REQ'D
8-32 NC x 5/8 RD/HD BRASS MACH/SC.
3/16 LG. DRILL ROD TO FORM A SLIDING FIT IN #54 DRILL HOLES
TYPICAL ASSEMBLY
SCALE: FULL SIZE
ALL DIMENSIONS IN INCHES

FIGURE 2



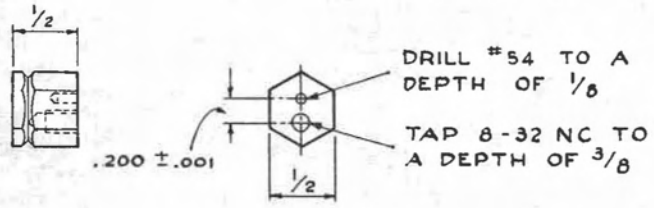
TEMPLATE BAR FOR DRILLING GAUGE HOLES

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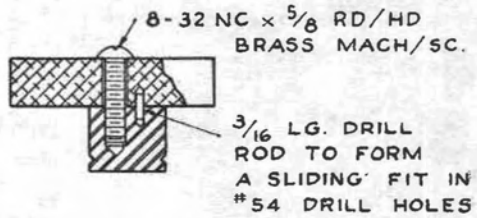
JIG PLATE FOR PLACING PLUGS IN WET CONCRETE

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STAINLESS STEEL PLUGS

SCALE: FULL SIZE — 4 REQ'D

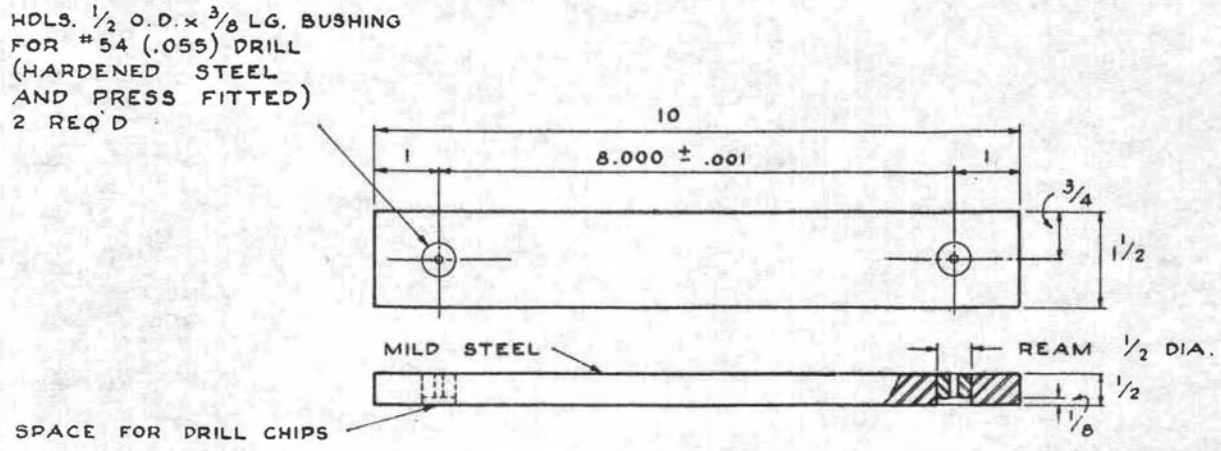


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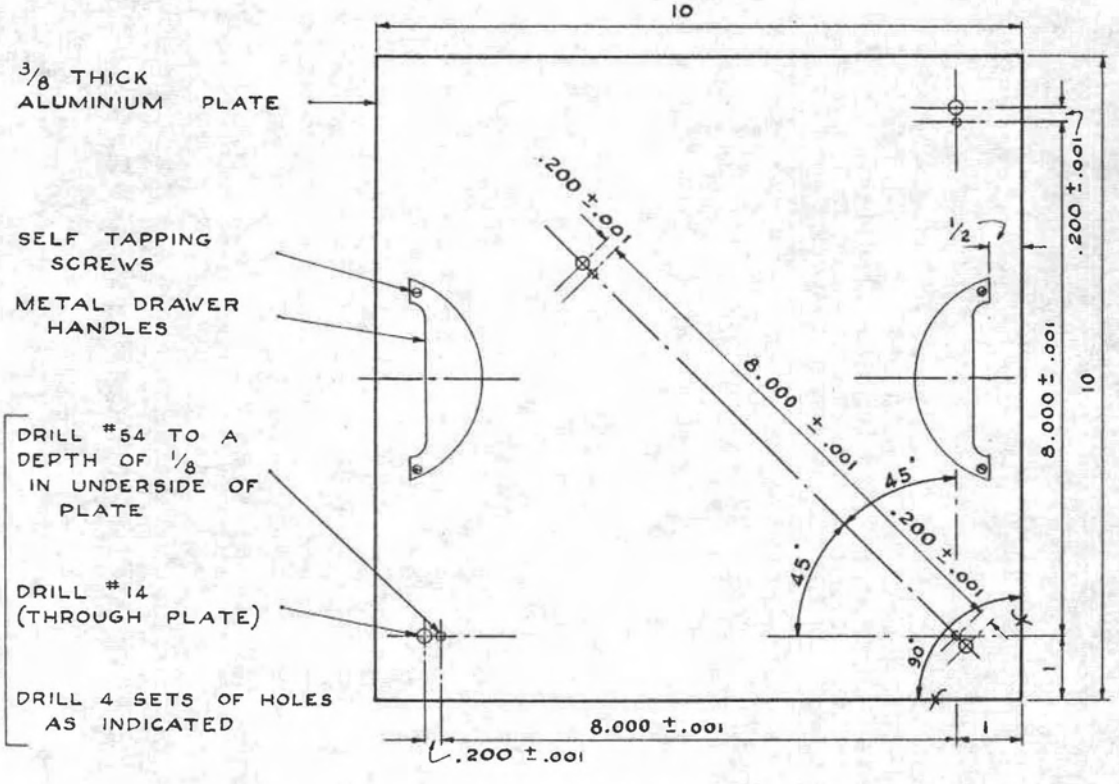
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FIGURE 2



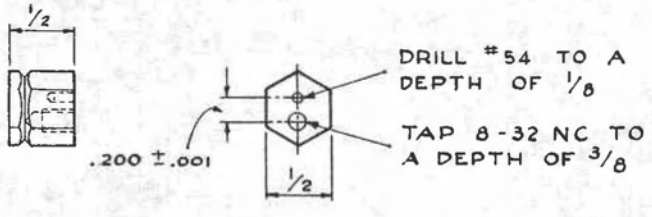
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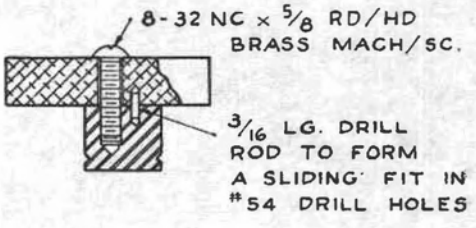
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STAINLESS STEEL PLUGS

SCALE: FULL SIZE — 4 REQ'D

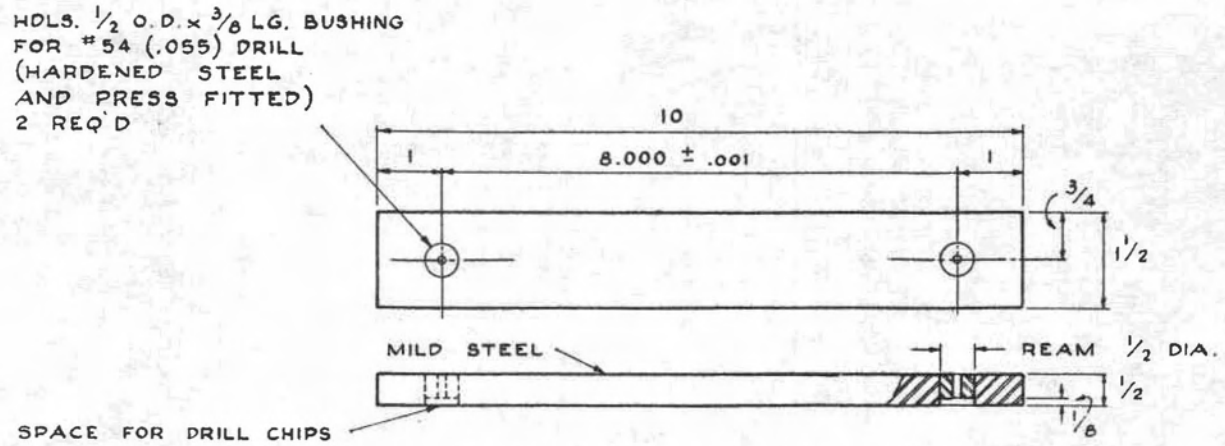


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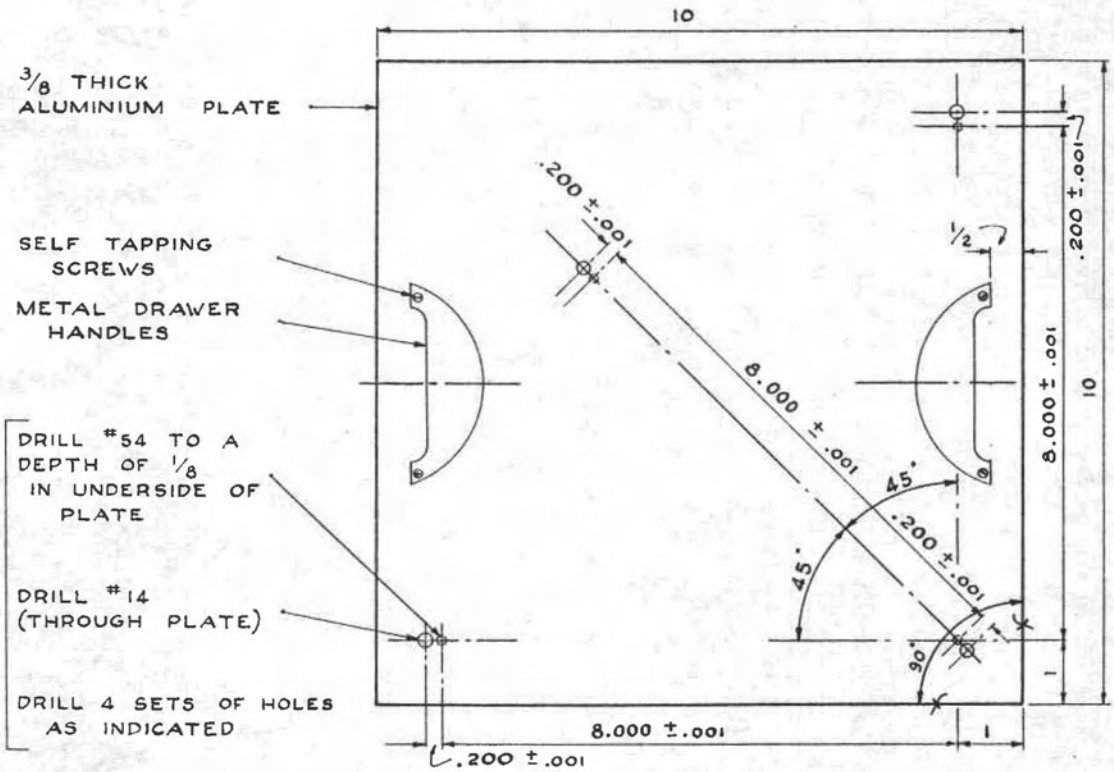
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FIGURE 2



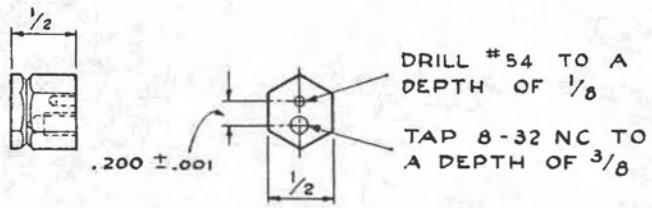
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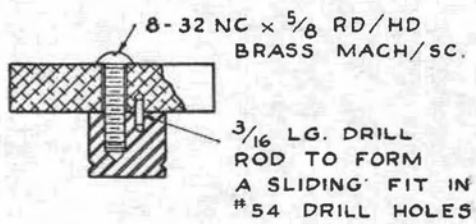
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STAINLESS STEEL PLUGS

SCALE: FULL SIZE — 4 REQ'D

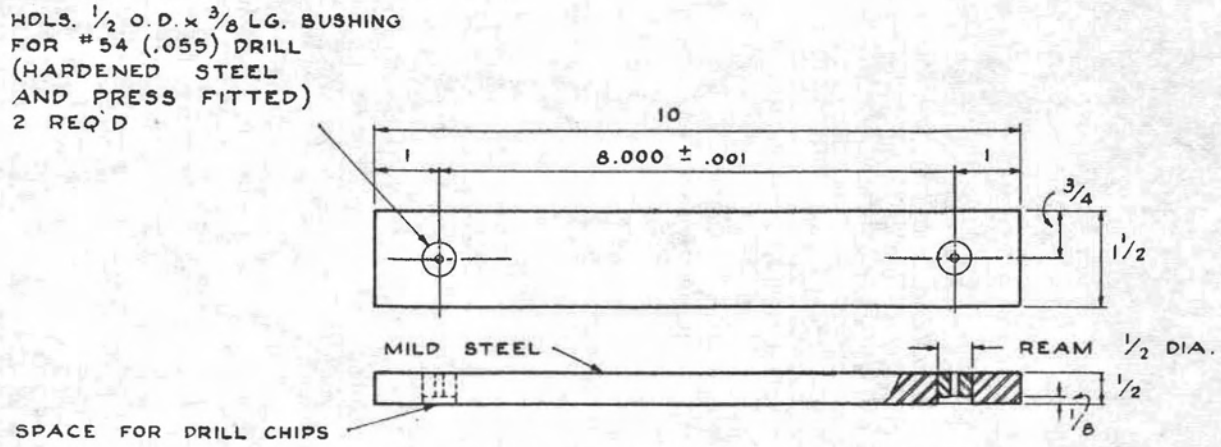


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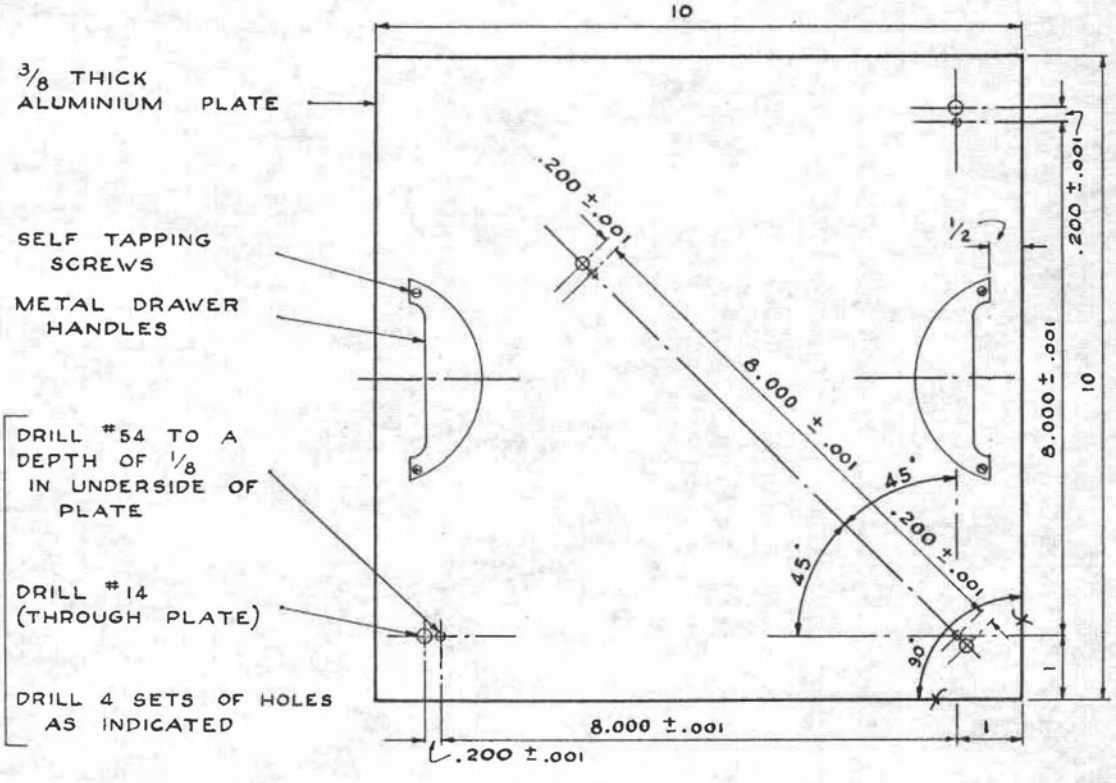
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FIGURE 2



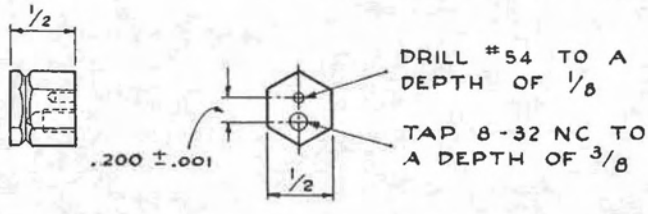
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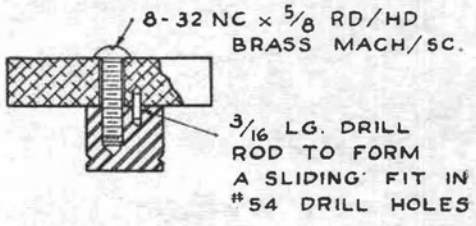
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STAINLESS STEEL PLUGS

SCALE: FULL SIZE — 4 REQ'D

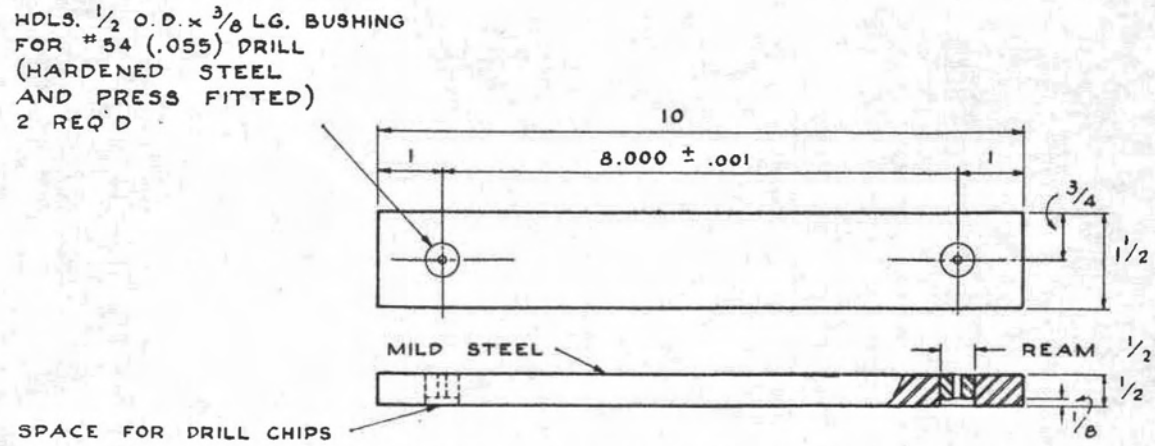


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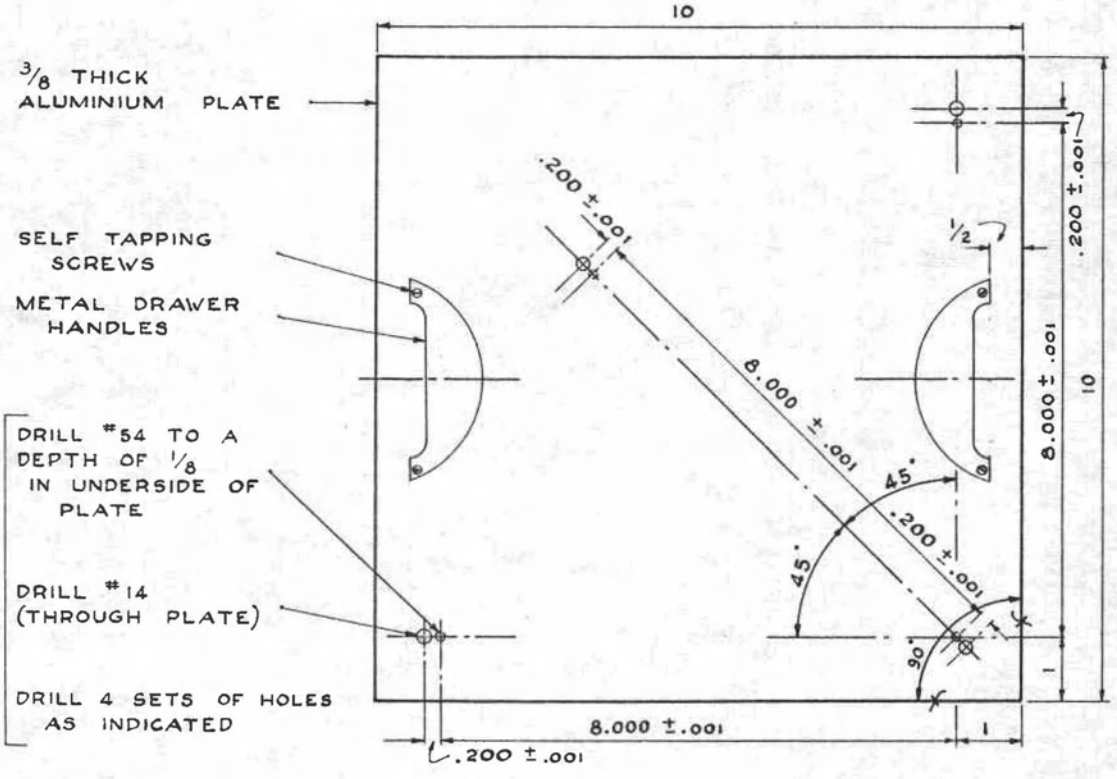
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FIGURE 2



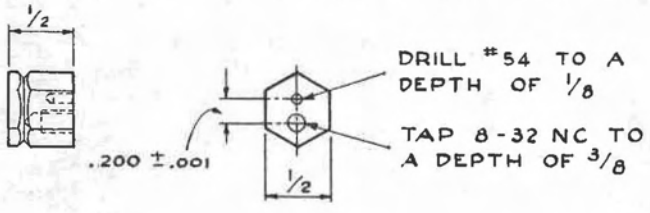
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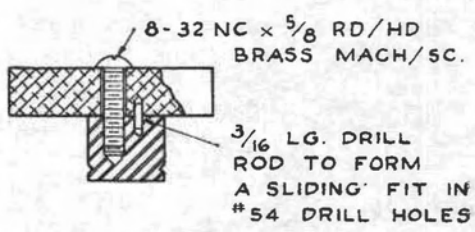
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STAINLESS STEEL PLUGS

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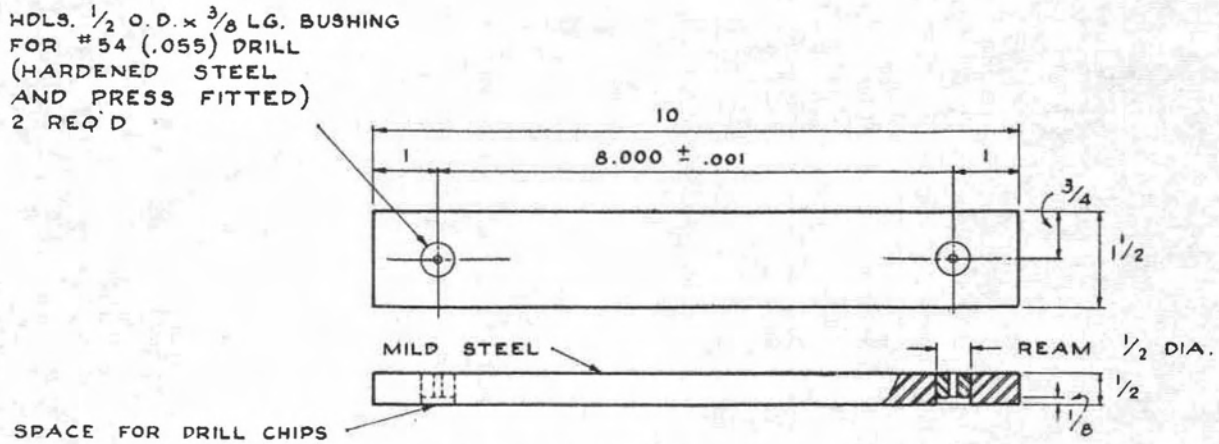


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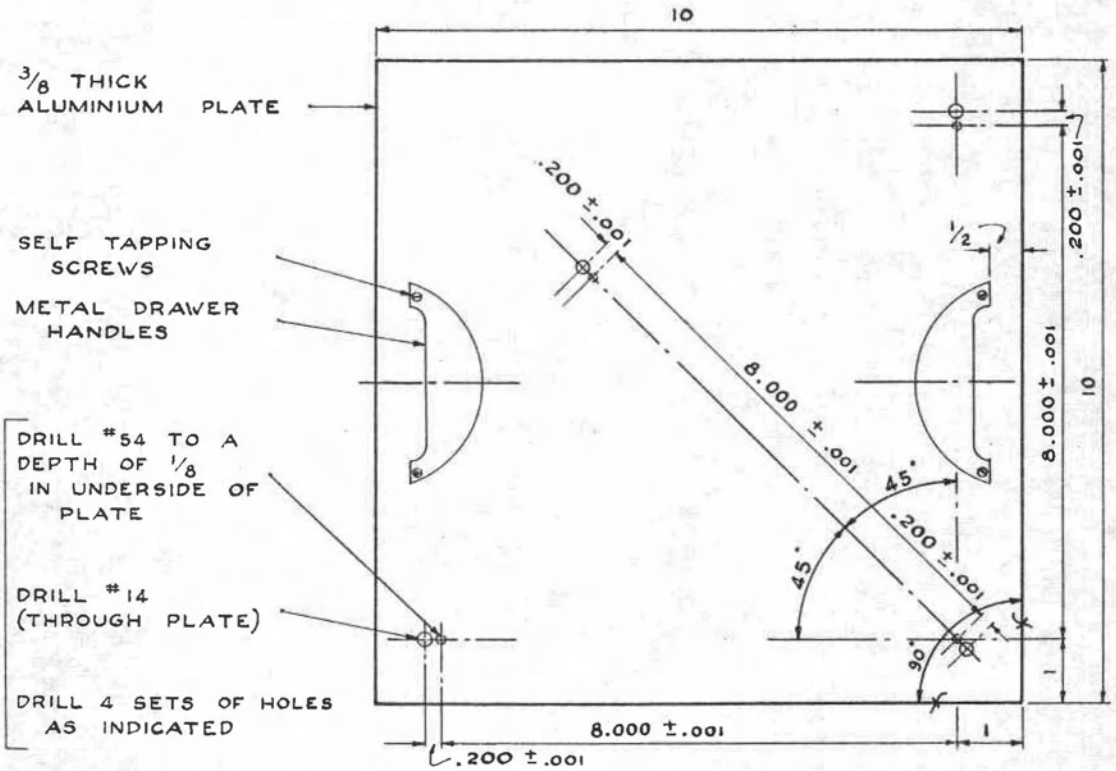
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FIGURE 2



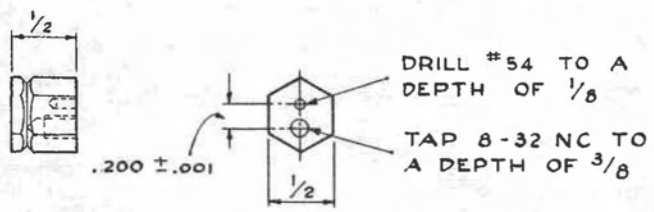
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SCALE: 1/2 FULL SIZE — 1 REQUIRED



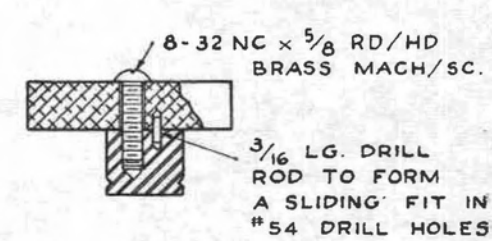
JIG PLATE FOR PLACING PLUGS IN WET CONCRETE

SCALE: 1/2 FULL SIZE — 1 REQUIRED



STAINLESS STEEL PLUGS

SCALE: FULL SIZE — 4 REQ'D

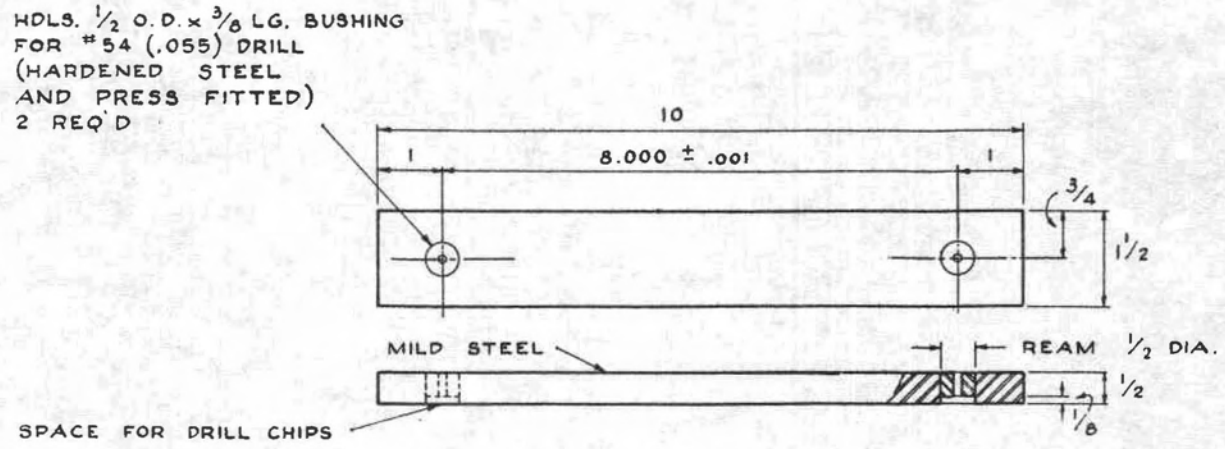


TYPICAL ASSEMBLY

SCALE: FULL SIZE

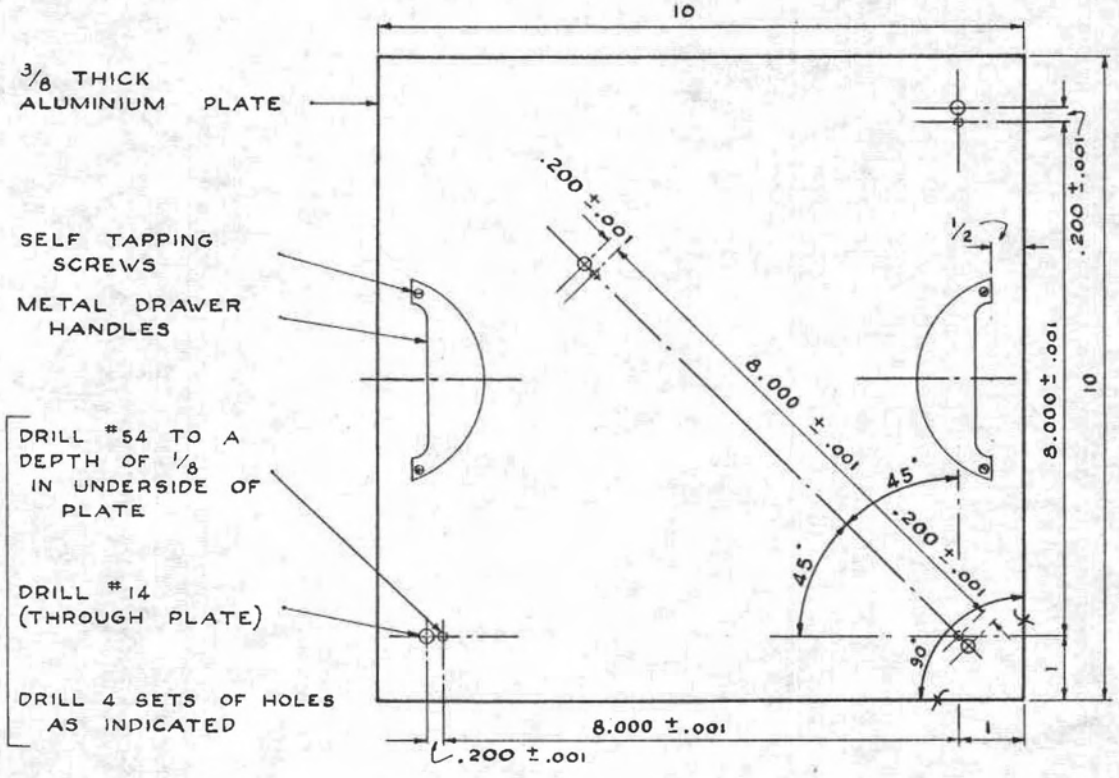
ALL DIMENSIONS IN INCHES

FIGURE 2



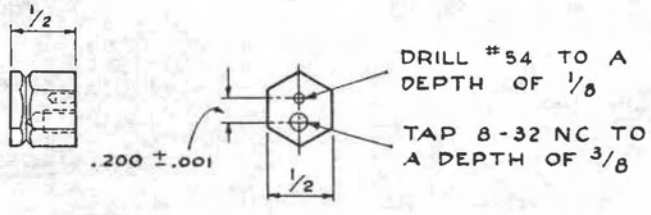
TEMPLATE BAR FOR DRILLING GAUGE HOLES

SCALE: 1/2 FULL SIZE — 1 REQUIRED



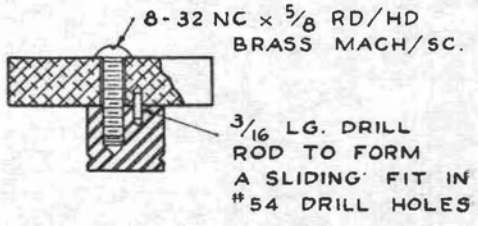
JIG PLATE FOR PLACING PLUGS IN WET CONCRETE

SCALE: 1/2 FULL SIZE — 1 REQUIRED



STAINLESS STEEL PLUGS

SCALE: FULL SIZE — 4 REQ'D

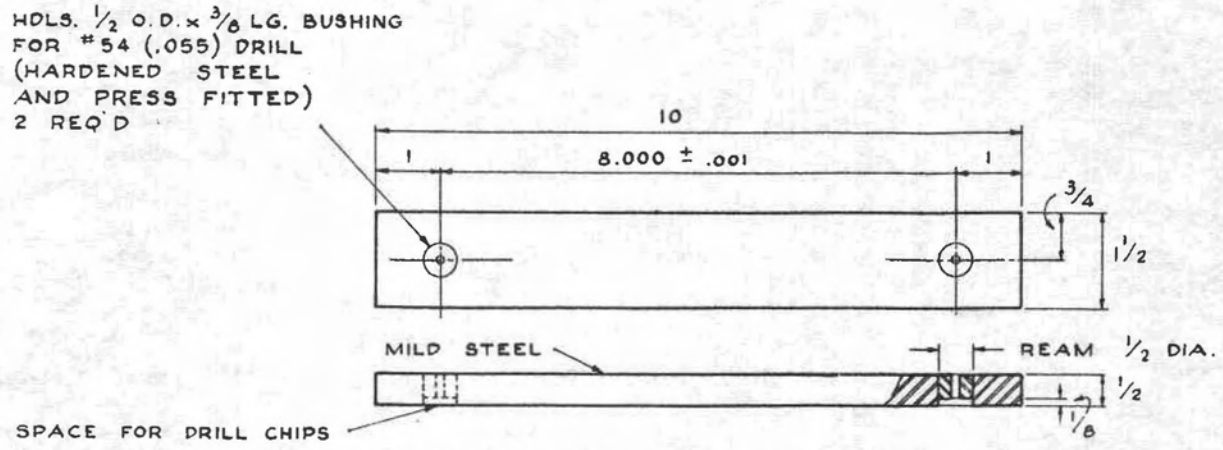


TYPICAL ASSEMBLY

SCALE: FULL SIZE

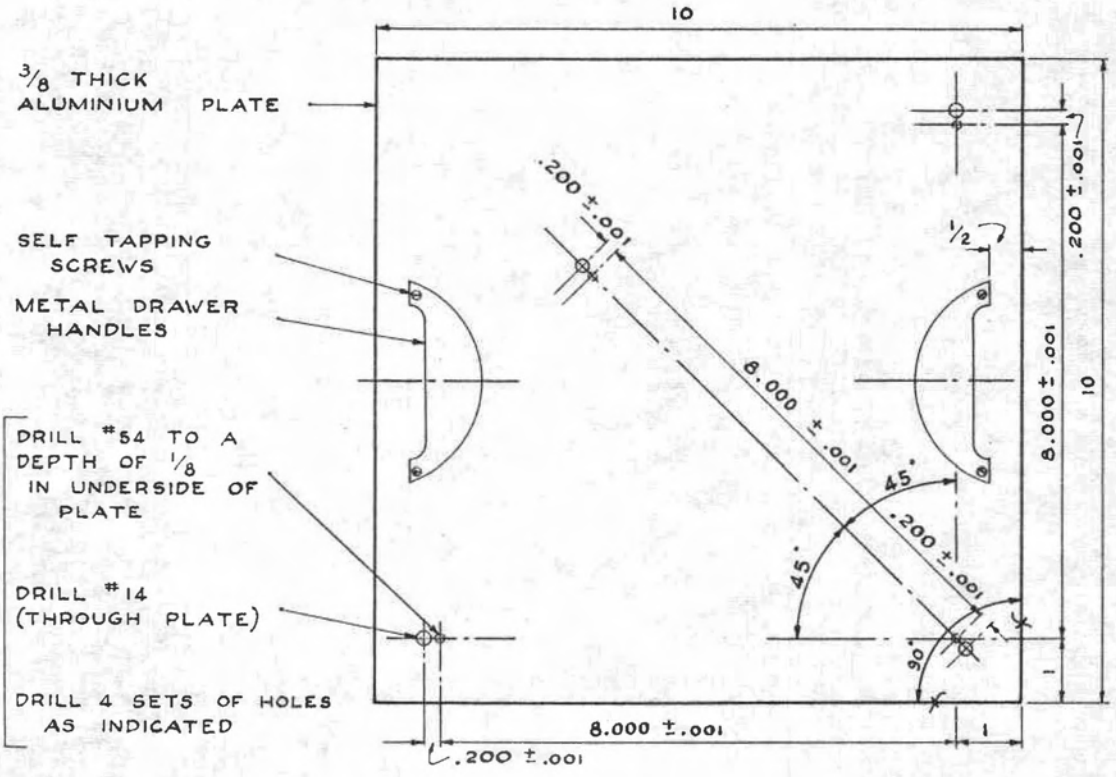
ALL DIMENSIONS IN INCHES

FIGURE 2



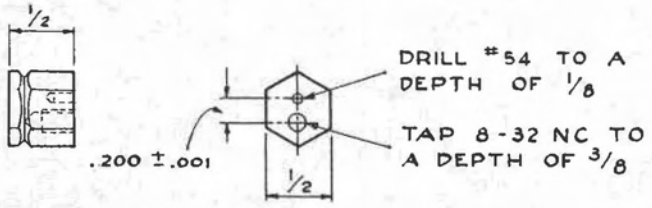
TEMPLATE BAR FOR DRILLING GAUGE HOLES

SCALE: 1/2 FULL SIZE — 1 REQUIRED



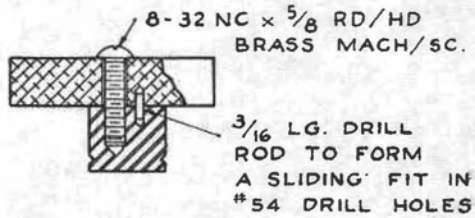
JIG PLATE FOR PLACING PLUGS IN WET CONCRETE

SCALE: 1/2 FULL SIZE — 1 REQUIRED



STAINLESS STEEL PLUGS

SCALE: FULL SIZE — 4 REQ'D



TYPICAL ASSEMBLY

SCALE: FULL SIZE

ALL DIMENSIONS IN INCHES

FIGURE 2