THE INDIRECT TENSILE TEST A NEW APPARATUS

An Interim Report

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Prepared for:

Federal Highway Administration and
Michigan Department of Transportation

March 1987

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TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION:

During the past few years, the design of flexible pavement has rapidly evolved from empirical and semi-empirical methods to pavement design systems based on elastic and/or viscoelastic theories. Today, many agencies use such systems in one form or another for new pavement and/or overlay designs. The use of such systems however, requires a thorough knowledge of the basic mechanical properties of the asphalt paving materials which are a function of the asphalt mix variables. A variety of tests and testing equipment have been developed and employed in the laboratories to evaluate said properties. Regardless of the complexity of the tests, testing procedures, and testing equipment, it was found that different tests yielded different results and that the repeatability of the test data is very questionable. Further, existing asphalt concrete mix design procedures are based upon empirical parameters that possess no relationship to the structural design of asphalt pavements.

To this end, an experimental program was set up. The objectives of the program include:

a) select a simple test and test procedure that will allow the highway engineer to establish the asphalt mix design parameters based upon the fundamental engineering properties required for the structural design of pavements;

b) determine the repeatability of the test results; and

c) determine the number of tests required to reliably obtain the mechanical properties (resilient modulus and Poisson's ratio, fatigue life and permanent deformation characteristics, and creep and viscoelastic properties) of the asphalt materials.

Several tests were employed in the program. These include triaxial (constant and cyclic loads), flexural beam tests, Marshall tests, indirect (constant and cyclic loads), and creep tests. The test results indicated that:

a) existing tests cannot be used to establish the mix design parameters based upon the fundamental engineering properties unless an expensive and time-consuming testing program is employed.

b) the material properties obtained from the different tests are inconsistent;

c) for the indirect tests (utilizing existing equipment), the repeatability of the test results is poor at best; and

d) results obtained from the indirect tensile test were the most promising although they were not consistent;

Further, it was found that the inconsistency of the indirect test results is mainly related to the equipment rather than the test mode. Existing indirect test apparatus possess one or more of the following problems:

a) A rocking motion of the loading piston which distorts the accuracy of the vertical deformation of the sample. This motion can be an order of magnitude larger than the sample deformation. Deformations recorded on both sides of the center of the loading head were significantly different and in some instances one was negative while the other was positive.

b) Due to equipment configuration, the test specimen may roll over the lower curved load strip. This motion will result in erroneous horizontal deformations. Indeed, in some tests, the horizontal deformation along the diameter of the test specimen was negative implying that the specimen was being subjected to compression rather than tension.

c) The position of the test specimen on the lower curved load strip is arbitrary and differs from one sample to another. Inaccurate positioning of the test specimen may result in inaccurate measurement of the radial deformation. Consequently, the calculated value of Poisson's ratio may be negative or higher than the limiting value of 0.5 (for an isotropic elastic materials).

d) During a repeated load test, the horizontal axis of the test specimen may rotate relative to the vertical axis of the loading head. Such a rotation will yield a smaller measurement of the radial deformation on one side of the diameter relative to the opposite side.

e) Existing apparatus are not equipped to measure the deformation of the test specimen in three directions.

This shortcoming means that part of the information available from the test is being lost.

2. A NEW APPARATUS

To overcome the above-stated problems, a new simple and inexpensive indirect tensile test apparatus was designed by Dr. Gilbert Baladi and fabricated by the machine shop of the Materials and Technology Division of Michigan Department of Transportation (MDOT). Relative to the existing equipment, the new apparatus possesses the following advantages:

a) The deformation of the indirect test specimen can be measured in one, two, or three directions using either one or two linear variable differential transducers (LVDT) in each direction.

b) The apparatus can be used under any existing loading frame (e.g. Marshall, a hydraulic system such as an MTS, triaxial, unconfined), see Figures 1 through 6; and it has a guiding system that consists of four frictionless posts.

c) The function of the frictionless guiding system of the apparatus is to prevent any possibe rotation and/or rocking of the upper curved load strip of the loading head.

d) The apparatus has four reference positions for easy placement under the center of the loading mechanism of a standard loading frame.

e) The apparatus has a sample stopper for easy positioning of the test specimen on the lower curved load strip of the apparatus and for a perfect alignment of the horizontal diameter (axes) of the specimen with the axes of the horizontal LVDT(s).

f) The different parts of the apparatus were made from materials available at a typical machine shop or a supply store.

g) The apparatus is simple and it can be easily fabricated at any local machine shop.

In the following sections, the design of this new apparatus is introduced. Observations concerning the new apparatus, the test results, and the analytical models (equations) to reduce the test data are also presented.

3. ENGINEERING DRAWINGS OF THE NEW INDIRECT TEST APPARATUS

As stated in the previous paragraph, the new apparatus was originally designed by Dr. Gilbert Baladi. Later, the design was slightly modified by several personnel of the Materials and Technology Division of (MDOT). The apparatus was then fabricated by the machine shop of MDOT. The engineering drawings of the new indirect tensile test apparatus are enclosed. Sheet 1 shows an elevation view of the assembled apparatus and specimen stopper, one top view and several elevation views of the lower stationary plate. The materials list is also presented on this plate. Sheet 2 shows top and elevation views of several parts of the apparatus.

As noted above, one copy of the apparatus was manufactured by the machine shop of MDOT. This copy was utilized in a research program sponsored by the United State Department of Transportation (USDOT), the Federal Highway Administration (FHWA) and directed by Dr. Gilbert Baladi. During the course of the investigation, it was noticed that **the friction between the loading piston and the upper stationary plate is minimal to nonexistant**. This is mainly due to a precision manufacturing exercised by the machine shop personnel. If the friction between these two parts of the apparatus is of concern, then **a load cell should be added between the lower curved load strip and the lower stationary plate**. The load recorded by the load cell will then be the true load applied to the test specimen.

Figure 1 depicts two general views of the apparatus taken from two different angles. Figure 2 shows the apparatus seated on a standard Marshall frame. Figure 3 shows the indirect test equipment in the test chamber under an MTS loading head. Figure 4 depicts the apparatus with the loading piston removed while figure 5 shows the loading piston seated off position on top of the apparatus. In this last figure, the four posts of the guiding system are also shown. Figure 6 shows a top view of the apparatus with the loading head removed. The four Thompson-type rollers shown in the figure are used to guide the four posts of the loading piston.

4. USE OF THE APPARATUS

The following types of test were conducted using the new indirect tensile test apparatus:

a) Indirect tensile tests utilizing the standard Marshall loading frame and stress rate: in this test mode, some of the test specimens were conditioned standard Marshall specimens. Others were tested dry at 140° F. Still others were tested dry at 77 and 40° F. The test data were then reduced to extract the tensile strength of the specimens, the deformation ratios, and the equivalent stability and flow. This information was then correlated to the stability and flow data obtained from standard Marshall tests.

b) Constant cyclic load tests utilizing an MTS hydraulic system: in this test, a sustained load of 50 pounds was first applied to the specimen. After 15 minutes, the specimen was subjected to a constant peak to peak cyclic load of 500 pounds at a frequency of 2 cycles per second (each cycle consisted of a loading period of 0.1 second and a relaxation period of 0.4 second). During the test, the elastic, total, and plastic (permanent) deformations of the test specimen were collected along the vertical, horizontal, and length of the samples. The data were then analyzed to obtain the resilient, viscoelastic, and plastic characteristics of the specimens and their fatigue lives.

c) Variable cyclic load test utilizing an MTS hydraulic system: in this test, the specimens were subjected to a constant sustained load of 50 pounds. The magnitude of the cyclic load was varied from 100 to 200 to 500 pounds. Each cyclic load was applied for 1000 cycles. The test frequency and loading and relaxation periods were the same as those of the constant cyclic load tests.

5. TEST SPECIMENS

A total of 412 indirect test specimens were fabricated and tested using the new indirect test apparatus. The specimens were made using the following materials:

a) three different types of aggregate (crushed and angular limestone, relatively rounded natural aggregate, and a mix of 50 percent by weight per sieve of the crushed limestone and natural aggregates);

b) two different aggregate gradations; and

c) three types of asphalt cement.

For each material combination, a constant percent asphalt content was utilized (the percent asphalt content at three percent air voids as determined from a standard Marshall mix design). The test specimens were made at three different percent air voids (3, 5, and 7) by varying the compaction efforts. For each material combination and percent air void, one triaxial type sample (4 inches in diameter and 8.5 inches high) was made. Later, the triaxial sample was cut into three (2.5 inches high) indirect test specimens. The three indirect specimens (triplicate) were then tested under the same conditions (test temperature, and test type) using the new indirect test apparatus.

6. TEST RESULTS

The test results will be published in a final report to be submitted to the Federal Highway Administration (FHWA) in July, 1987 unless permission to their publication is obtained prior to this date. Nevertheless, analysis of the test results have indicated that:

1) For any test specimen, the test results are consistent and very reasonable.
2) For any triplicate specimens, the maximum difference between the results of the three tests is only seven (7) percent.
3) The values of the resilient modulus obtained from these tests agree very well with those obtained from cyclic load triaxial tests.
4) Poisson's ratio was found to be a function of the mix variables. For all 412 specimens, the value of Poisson's ratio varies from 0.2 to 0.42; and for any triplicate specimens, Poisson's ratio is almost constant.
5) The fatigue lives of all 412 test specimens are more

meaningful, more reasonable, and more consistent (for a triplicate) than those obtained from flexural beam tests.

6) The cumulative permanent (plastic) deformations (from cyclic load tests) of the test specimens can be analyzed in both compression and tension modes and they are more consistent than those obtained from cyclic load triaxial tests.

7) For any combination of variables, the test results can be reproduced with a high degree of accuracy.

7 ANALYTICAL MODELS FOR THE INDIRECT TENSILE TEST

Two analytical models to reduce the test results and to calculate the resilient modulus and Poisson's ratio were developed.

The first model assumes that the applied load and the resulting stress are perfectly vertical (vertical load through the chord of the specimen). This implies that friction can be developed between the loading strip and the specimen. For this case, the resilent modulus and Poisson's ratio can be calculated using the following equations:

$$U = \frac{3.52961 - 0.269909 \times DR}{DR} \qquad (1)$$

$$M_R = \frac{3.52961 \times P}{L \times DV} \qquad (2)$$

$$M_R = \frac{0.317477 \times P \times U}{DL} \qquad (3)$$

where: the constants in the equations are integration constants;

U = Poisson's ratio;

DR = deformation ratio = DV/DH;

DV = vertical deformation of the sample along the 4" diameter (inches);

DH = horizontal deformation of the sample along the 4" diameter (inches);

M_R = resilient modulus (psi);

L = sample thickness (inches);

DL = deformation of the sample along the thickness of the sample (inches); and

P = the magnitude of the applied load (pounds).

Theoretically, the values of the resilient modulus from equations 2 and 3 should be the same provided that the materials are homogeneous and isotropic. Since this is not the case for asphalt mixes, one should expect some variations between the two values. Nevertheless, equation (2) can be utilized if the deformation in the third dimension is not measured. If the sample deformations in all three directions are measured, then the values of the resilient modulus obtained from equations 2 and 3 should be compatible (a maximum difference of 10 percent). Another alternative is to develop an equation for the resilient modulus based upon least squares analysis from equations 2 and 3. This will yield a more accurate value of the resilient modulus than that calculated using any one equation.

The second model assumes that the load is applied normal to the contact area between the specimen and the loading strip (i.e., their is no friction between the loading strip and the test specimen). For this case the resilent modulus and Poisson's ratio can be calculated using the following equations:

$$U = \frac{3.58791 - 0.269895 \times DR}{0.062745 + DR} \qquad (4)$$

$$M_R = \frac{P\ (3.58791 - 0.062745 \times U)}{L \times DV} \qquad (5)$$

$$M_R = \frac{0.319145 \times P \times U}{DL} \qquad (6)$$

where: the constants in the equations are integration constants; and all other parameters are as before.

Again, in theory, the two values of the resilient modulus of equations 5 and 6 should be exactly the same for homogeneaous and isotropic material. Asphalt mixes are heteregeneous and anisotropic. Consequently, differences between the two calculated values should be expected. Equation (5) can be utilized if the deformation in the third dimension is not measured. If the sample deformations in all three directions are measured, then the two values of the calculated resilient modulus from equations 5 and 6 should be compatible (a maximum difference of 10 percent). Substantial difference between these two values may mean that the test results are not accurate. It is also possible to write one equation for the resilient modulus and another for Poisson's ratio using least squares analysis. Such equations were developed and are presented below.

$$U = (0.225127 \times H^2 - 0.269895 \times V^2 - 0.0447676 \times A^2 + 3.570975 \times H \times V - 0.086136 \times A \times H - 1.145064 \times A \times V)/D \tag{7}$$

$$E = (0.253679 \times H + 3.9702876 \times V + 0.0142874 \times A)/D \tag{8}$$

where: $D = 1.105791(H^2 + V^2 + A^2) - (H - 0.0627461 \times V - 0.319145 \times A)^2$;

$H = DH \times L/P$;

$V = DV \times L/P$;

$A = DL/P$; and

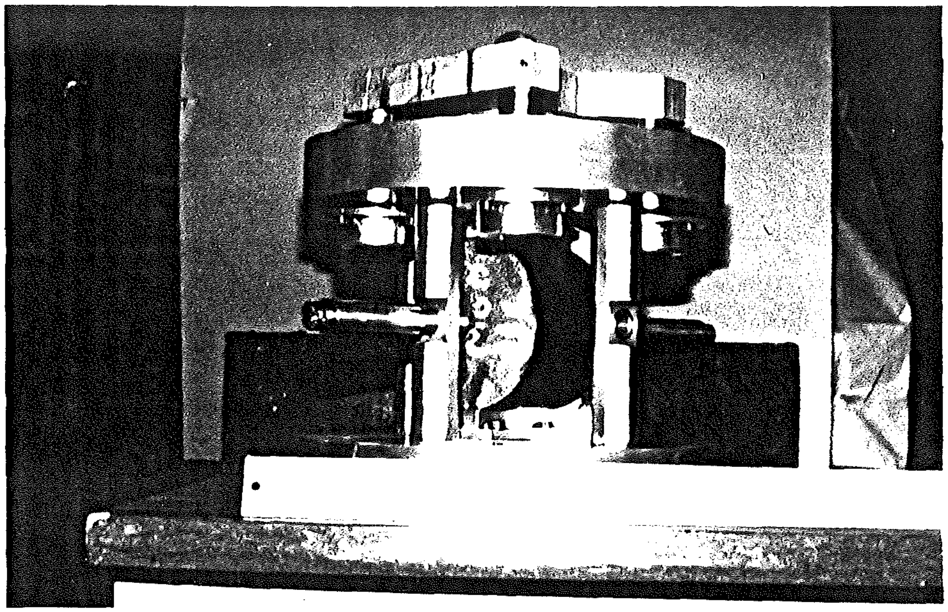
DH, DV, DL, L, and P are as before.

If the sample deformations are accurately measured in all three directions, then equations 7 and 8 yield the best estimates of the resilient modulus and Poisson's ratio. If one of these three deformations however is not correct or not available then equations 4 and 5 or 4 and 6 should be used.

8. SUMMARY

A knowledge of the fundamental mechanical properties of flexible pavement materials is essential for the structural design of pavements. This basic knowledge becomes increasingly important as more highway engineers use pavement design systems based upon elastic and/or viscoelastic theories which require estimates of these properties. Further, a proper asphalt concrete mix design procedure should be based upon these fundamental properties. There are several different tests and testing apparatus available to obtain these properties. Some tests are very complex, time consuming, and require expensive and sophisticated equipment. Others require several assumptions prior to data reduction. Some yield inconsistent results due mainly to ill-designed testing apparatus.

The indirect tensile device developed in this project and described above alleviates these problems. The test results were found to be consistent and reproducable. The apparatus can be used under any existing loading frame to conduct one or several types of test (indirect tensile tests, indirect tensile cyclic load tests, and fatigue tests). If the indirect tensile cyclic load test is selected, and the test specimen is subjected to an adequate number of load repetitions, then the test results can be analysed for resilient and viscoelastic characteristics, and for permanent deformations and fatigue life.



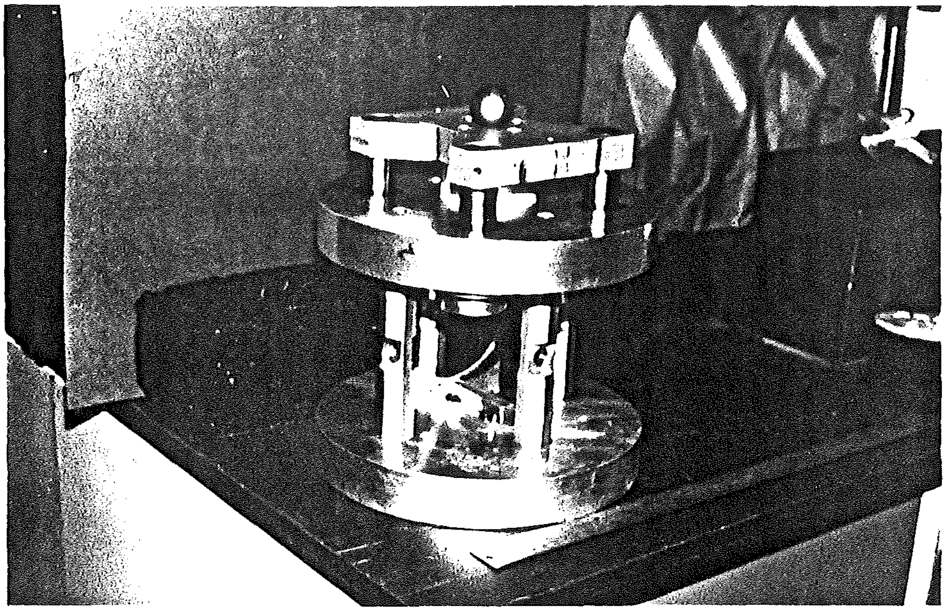


FIGURE 1. GENERAL VIEWS OF THE NEW INDIRECT TENSILE TEST DEVICE.

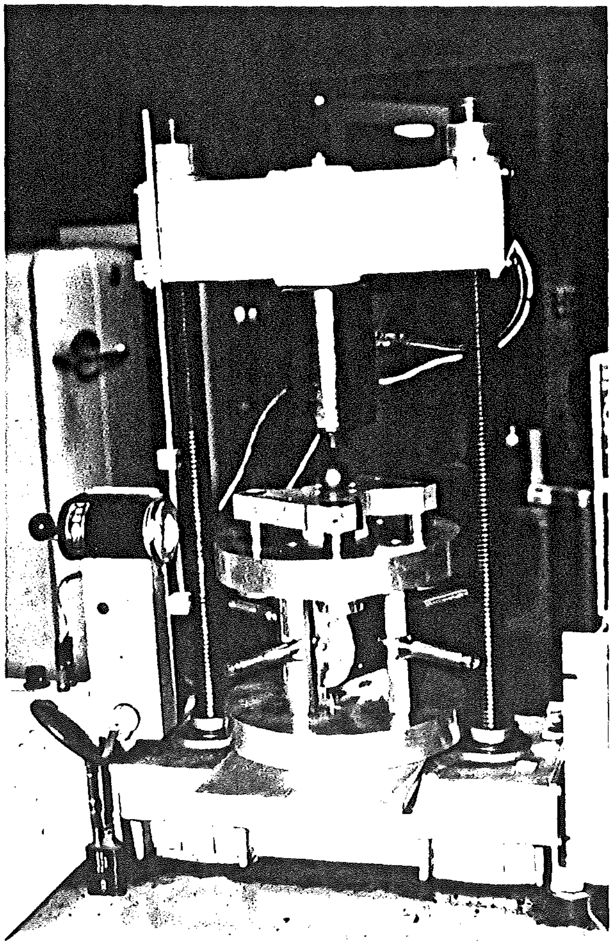


FIGURE 2. THE APPARATUS ON A STANDARD MARSHALL TEST FRAME.

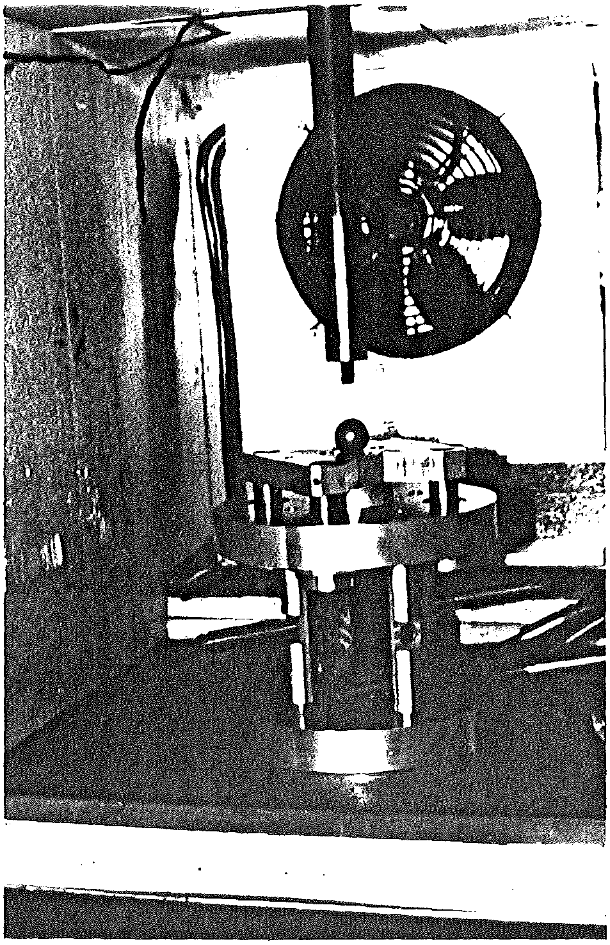


FIGURE 3. THE APPARATUS IN A TEMPERATURE CHAMBER UNDER AN MTS LOADING RAMP.

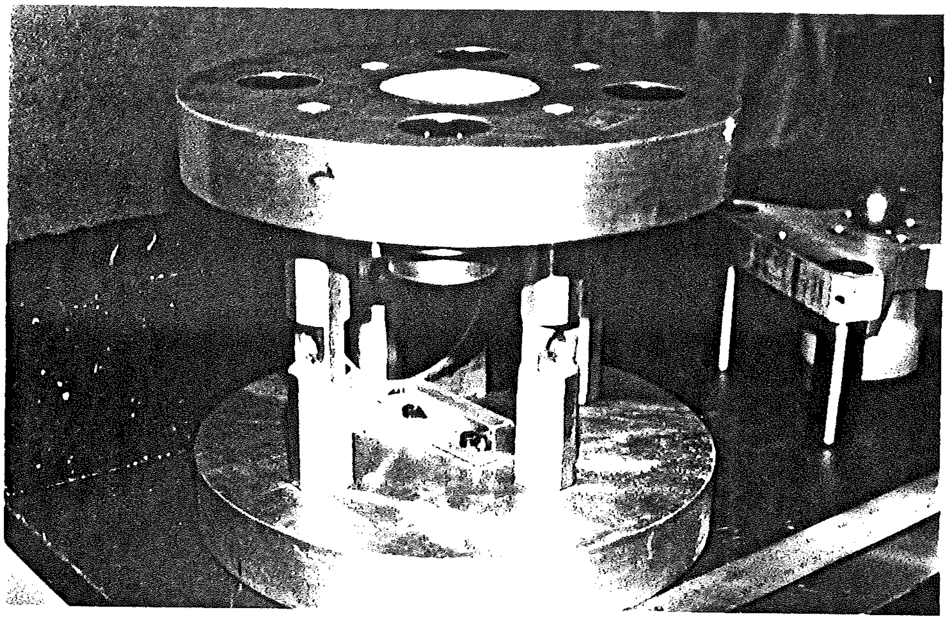


FIGURE 4. THE APPARATUS WITH THE LOADING PISTON REMOVED.

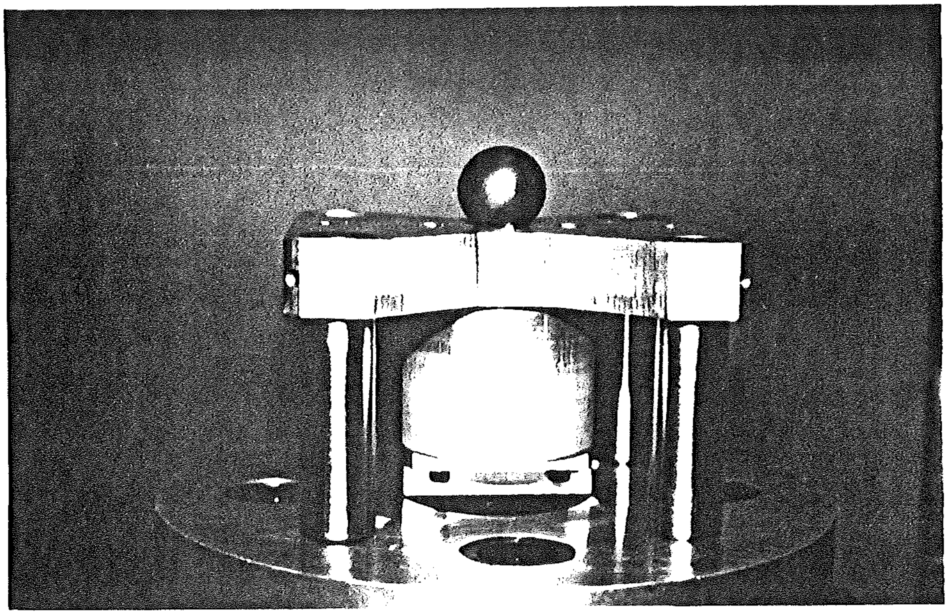


FIGURE 5. THE APPARATUS WITH ITS LOADING PISTON OFF POSITION.

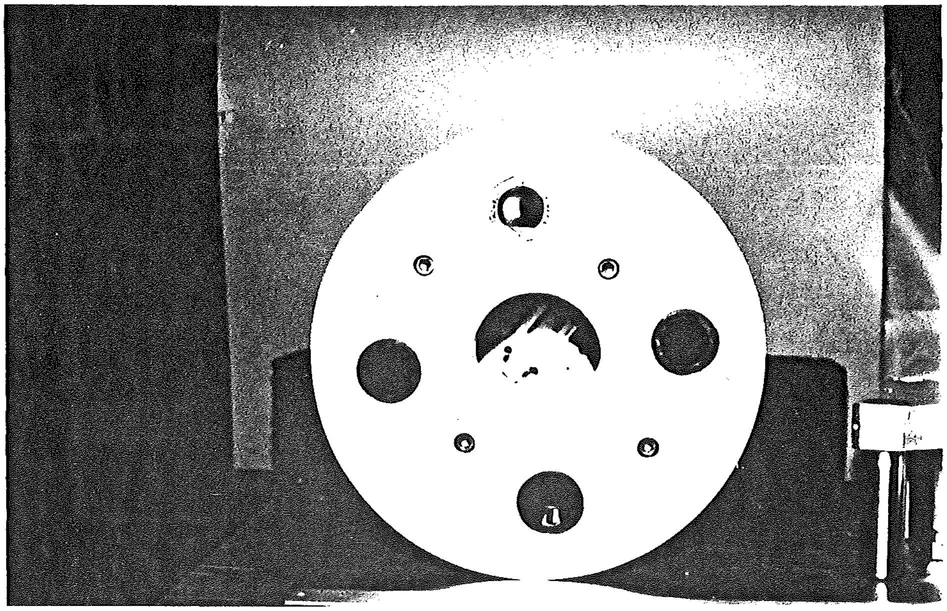
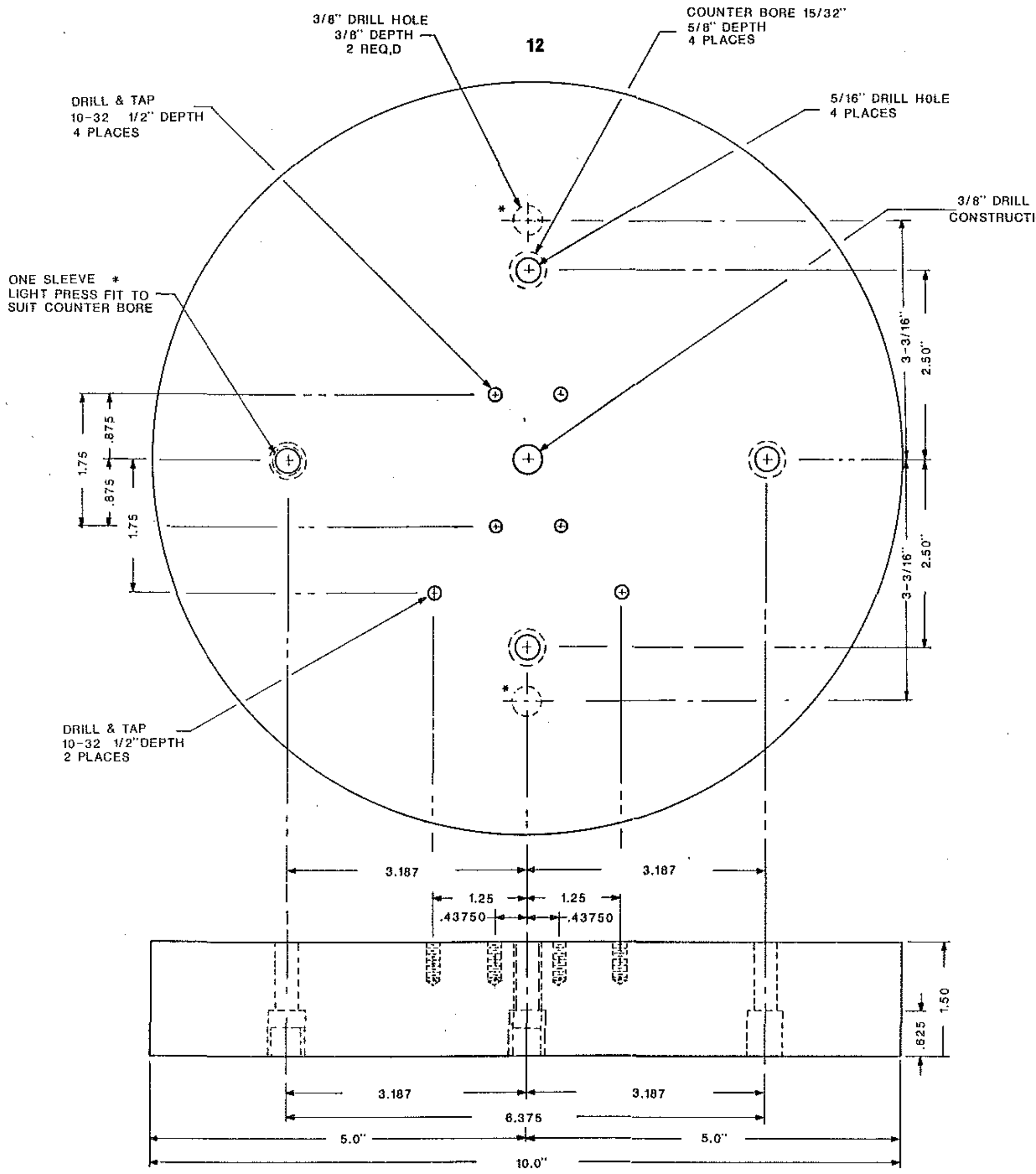
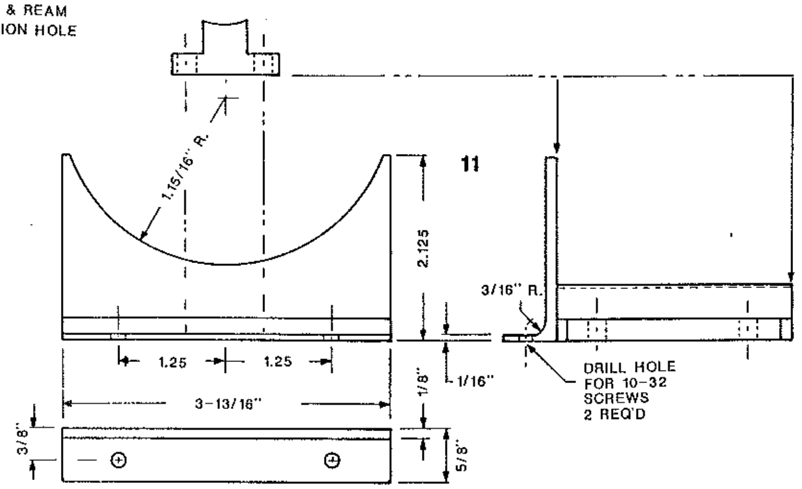


FIGURE 6. TOP VIEW OF THE APPARATUS WITH THE LOADING PISTON REMOVED.

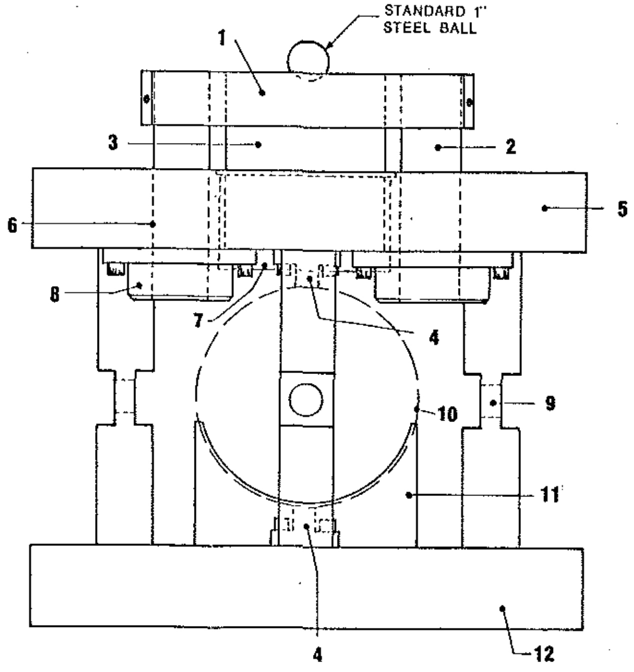


* LOCATION HOLES FOR MARSHALL BASE PLATE



PART NO.	MATERIALS LIST
1	LOADING PISTON GUIDE PLATE, 1 REQ'D. ALUM. 6061T651
2	GUIDE POST, 4 REQ'D. STD. 1" DIA. STEEL DRILL ROD
3	LOADING PISTON, 1 REQ'D. ALUM. 6061T651
4	LOAD STRIP, 2 REQ'D. ALUM. 6061T651
5	UPPER STATIONARY PLATE, 1 REQ'D. ALUM. 6061T651
6	SUPER NO. 16 THOMSON LINEAR MOTION BUSHING, 4 REQ'D.
7	BUNTING BEARING, BRONZE #B.C. 2428, 1 REQ'D.
8	BEARING RETAINER CAP, 4 REQ'D. ALUM. 6061T651
9	POST, LVDT HOLDER, 4 REQ'D. ALUM. 6061T651
10	TEST SPECIMEN
11	SPECIMEN STOP
12	LOWER STATIONARY PLATE, 1 REQ'D. ALUM. 6061T651

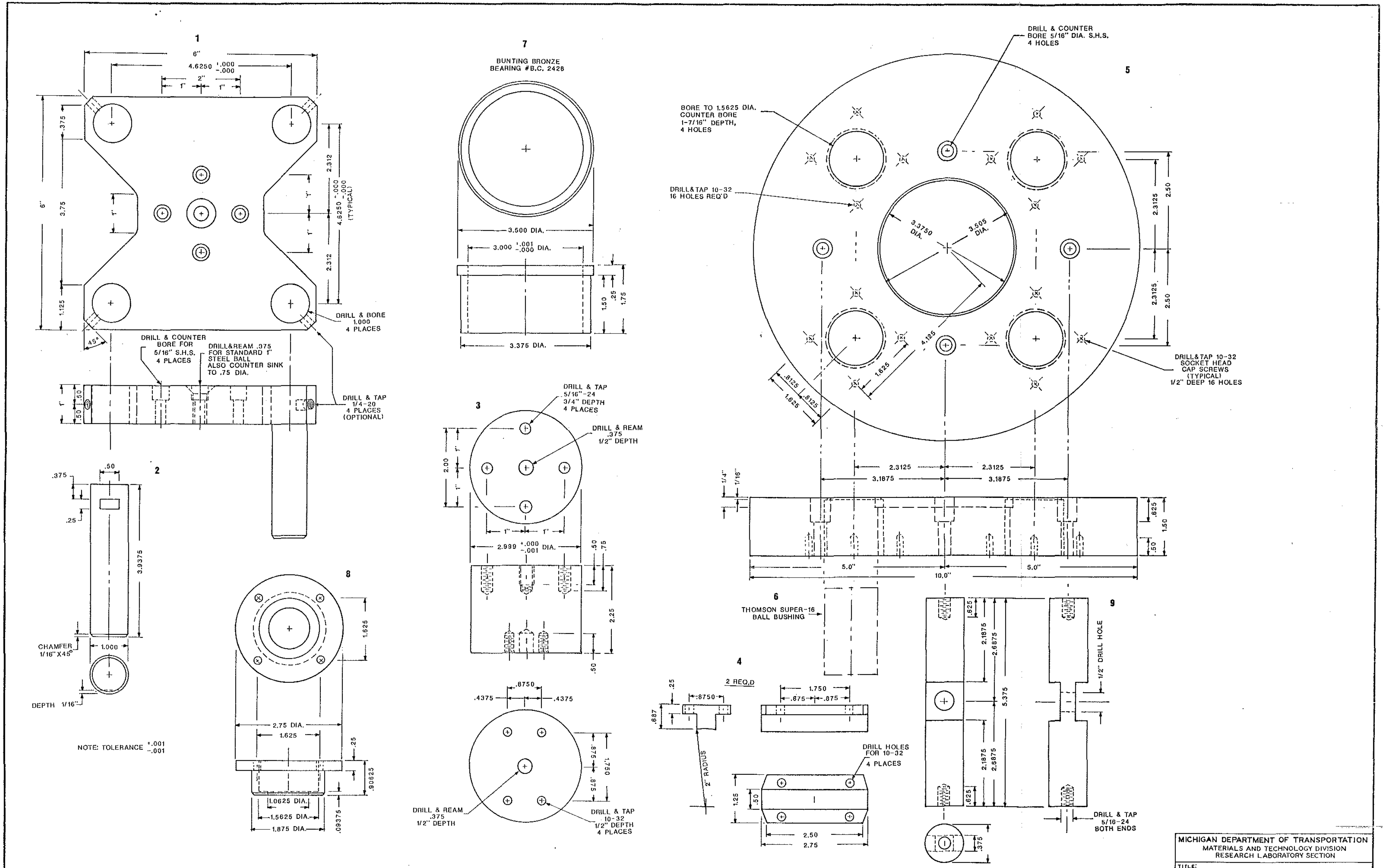
NOTE: TOLERANCE $^{+.001}_{-.001}$



GENERAL VIEW

MICHIGAN DEPARTMENT OF TRANSPORTATION
MATERIALS AND TECHNOLOGY DIVISION
RESEARCH LABORATORY SECTION

TITLE: INDIRECT TENSILE DEVICE	
DRAWN BY: R.G. MOREHOUSE	DATE: 2 - 9 - 87
CHECKED BY: D. CAUDELL	DATE: 3 - 3 - 87
REVISIONS:	SHEET 1 OF 2



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TITLE: INDIRECT TENSILE DEVICE	
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CHECKED BY: D. CAUDELL	DATE: 3-3-87
REVISIONS:	SHEET 2 OF 2