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A Comparison of Test Fixtures For Drop-Ball Impact Testing of Safety Spectacles

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE / Public Health Service
Center For Disease Control / National Institute For Occupational Safety And Health

A COMPARISON OF TEST FIXTURES FOR DROP-BALL IMPACT TESTING OF SAFETY SPECTACLES

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ABSTRACT

This report describes the results of drop-ball impact tests which were conducted for the purpose of evaluating five different safety spectacle mounting fixtures. The present ANSI Z87.1-1968 lens-only test block was found to be an adequate method for testing lens breakage. However, additional fixtures are needed to test the entire lens-frame unit. Both the present Z87.1-1968 lens-in-frame test block and the proposed Z87.1 test fixture were found to be inadequate due to their limited application and mechanical problems. The remaining two test fixtures examined in this study were designed by NIOSH for the purpose of eliminating the problems associated with the above mentioned test fixtures. It was found that these two test stands accommodated all styles of spectacles presently available and eliminated some problems associated with the other fixtures.

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A COMPARISON OF TEST FIXTURES FOR DROP-BALL IMPACT TESTING OF SAFETY SPECTACLES

The subject of impact testing of safety spectacles has long been one of discussion and concern in the safety field. Recently there has been controversy over whether the most effective testing method is drop-ball impact testing (high mass, low velocity) or ballistic impact testing (low mass, high velocity). Within either method, there is still the question of what impact energy level safety spectacles should be subjected to, as a requirement for passing an impact resistance test, as well as, how does this impact energy relate to that which is actually required for adequate protection of the user. There is also the question of test fixtures or methods of holding and positioning the spectacles to be tested, which range from blocks which position only the lens to the recent addition of anthropometric headforms.

The purpose of this study was to evaluate five different test fixtures that can be used to test safety spectacles using the drop-ball impact method. Two of these fixtures are test blocks presently required by the Occupational Safety and Health Administration (OSHA) under the American National Standards Institute (ANSI) Z87.1-1968. {2}[1] One is a test fixture being proposed in a revision of the ANSI Z87.1-1968 {3} and the remaining two were designed by the National Institute for Occupational Safety and Health (NIOSH). The work was conducted in the Safety Hazard Control Research Laboratory of the Engineering Branch, Division of Laboratories and Criteria Development.

Background

Present United States requirements for safety spectacles are presented in the Federal Register, Section 1910.133 {1} This section dictates the general requirements for eye and face protection and specifies that the design, construction, testing, and use of such devices shall be in accordance with the ANSI Eye and Face Protection Standard Z87.1-1968. The Z87.1-1968 Standard requires impact resistance testing for safety spectacles using the drop-ball method in Section 6.3.4.2, "Impact Resistance Test." There are three impact tests given in this section, the first is entitled "Lens in Frame Glass and Plastic." For this test the spectacle nose piece and temple hinge are removed to assure uniform support. Because of this requirement and the common design of metal spectacle frames, it is not possible to test spectacles with metal frames on this test block. Also, since only one lens side is tested at a time, the spectacles are usually cut in half through the bridge. The frame eye, with the lens object side up is then mounted on a test block as shown in Figure 1 (ANSI Z87.1-1968, Figure 5, page 25). The test block is mounted in the hole of a base plate, shown in Figure 2 (ANSI Z87.1-1968, Figure 6, page 24). The frame eye is to withstand the impact of a 1.00 inch diameter steel ball weighing approximately 2.4 ounces, dropped in free fall from a height of 50 inches. Chipping of the lens or dislodgement of the lens from the frame eye should not occur. The second test in Section 6.3.4.2.2, "Lens on Block - Glass and Plastic," is for the lens

[1]**Numbers** in brackets indicate number of reference in the reference section.

only, which is removed from the frame before testing. The lens is mounted object side up on the test block shown in Figure 3 (ANSI Z87.1-1968, Figure 7, page 25) which, in turn, is mounted in the hole of the base plate shown in Figure 2. The lens shall withstand the same impact requirements as for the lens-in-frame test without breaking. Section 6.3.4.2.3 concerns the breakage pattern of glass lenses. (Since this study is concerned with spectacle failure only, breakage pattern was not considered as an evaluation criteria for the purpose of this report.)

The ANSI Z87 Committee is presently in the process of preparing a proposed revision of the Z87.1-1968 Standard. {3} The revision again includes three different impact tests for safety spectacles. All use drop-ball impact testing, however, there are changes from the Z87.1-1968. All lenses would still be tested out of the frame on the test block shown in Figure 3 at the same impact energy requirements. The changes come in the area of lens-in-frame testing. Safety spectacles with plastic frames would still be tested by using the test block shown in Figure 1 which requires removal of the nose pad and temple hinges. The impact requirements remain at the 1.00 inch diameter ball dropped in free fall from 50 inches. The third test fixture is one that is new to the Z87.1 Standard and applies only to spectacles with metal or combination metal-plastic frames with either glass or plastic lenses. This type of spectacle would be mounted on the test fixture shown in Figure 4 (ANSI Z87 Committee proposed revision of Z87.1-1968, Figure 6A, page 32) which would slide through the base plate shown in Figure 5 (ANSI Z87 Committee proposed revision of Z87.1-1968, Figure 6, page 33). The spectacles would be supported at the bridge by the bridge support and the temples are clamped between the clamping knobs. The impact requirements for this fixture are the same as for the test blocks previously described.

Equipment

The actual testing was conducted using a drop-ball tower. The drop-ball tower has a base plate quite similar to that shown in Figure 2 permanently attached to its main base which is aligned with the electro-magnet used to hold and drop various sizes of steel balls. Also used were six sizes of solid steel balls varying in diameter from 1 inch to 2¼ inches. The drop-balls were massed on a pan balance and an analytical balance. Figure 6 shows the masses of the drop-balls used and their calculated densities which were calculated to insure that each ball's composition was consistent with each of the other drop-balls to be used.

Also used were the five test fixtures which were to be compared. The first was the ANSI Z87.1-1968 lens-only test block as previously described and shown in Figure 3. The second was the ANSI Z87.1-1968 lens-in-frame test block as shown in Figure 1. The third was the test fixture shown in Figure 4 which is being proposed by the ANSI Z87 Committee in the revision to the ANSI Z87.1-1968 Standard. Since Figures 4 and 5 are basic sketches, it was necessary to prepare Figure 7 (three pages). The base plate in Figure 7, page 3 differs from Figure 5 in that it does not include the mounting hole which would be used for the test blocks in Figures 1 and 3. It was not included since the drop tower includes this feature already. Also the dovetail on the block and the dovetail groove in the base plate were modified slightly. Two other test fixtures were designed by NIOSH for the purpose of correcting some of the problems encountered when using the proposed ANSI test stand. These problems will be discussed in a following section of this paper. The two test stands, designed by NIOSH, are shown in Figure 8. NIOSH Test Stand No. 1 is shown in Figure 8, pages 1, 3, and 4, while NIOSH Test Stand No. 2 is shown in Figure 8, pages 2, 3, and 5. The base plate used with both stands is the same as that used with the proposed ANSI Z87 test stand as shown in Figure 7, page 3.

The safety spectacles used in this study were all clear 6.00 D plano lenses of toughened glass, CR-39, or polycarbonate mounted in safety frames. These spectacles were obtained directly from the manufacturers and are representative of what is available on the consumer market today.

Procedure

Since the purpose of this study was to compare the five different test fixtures, the safety glasses were tested to failure thus allowing comparison of the relative failure points. The variable used for comparing failure points of the samples was the kinetic energy of the drop-ball at impact with the spectacle lens. This parameter was chosen so as to allow comparison with data found in the literature. The impact kinetic energy of the drop-ball was calculated from the following formula:

$$KE = 1/2\ MV^2 = \text{kinetic energy}$$

where: M = Mass

V = Velocity

Since all testing was conducted using the drop-ball method which is free fall and assuming a gravitational constant of 32.16 ft/sec^2, the impact velocity was calculated from the formula:

$$V = (64.32h)^{1/2}\ \text{ft/sec}$$

where: V = Velocity

h = Height that ball is dropped (in feet)

The mass used in calculating the kinetic energy was the actual mass obtained from the balances as shown in Table 6. An impact energy table was prepared for easy reference and is shown in Table 9. The corresponding impact energy for all of the drop heights and sizes of balls that were used in this study are shown in this figure.

It was decided that the initial impact should be that as required in the ANSI Z87.1-1968 Standard, this being a 1 inch diameter steel ball dropped from 50 inches. If the spectacles passed this impact, the height would be increased by 10 inches at a time up to 100 inches. The sample would be impacted at each of the points and be checked for failure. If failure did not occur at 100 inches with the 1 inch ball, the impact energy would be increased by going to the 1-1/4 inch diameter ball. The initial height for going to the next larger ball was selected by calculating the height in multiples of ten inches such that the value would give an impact energy slightly higher than the energy at 100 inches with the previous size ball. The impact energy was increased until failure occurred and this height and ball size was recorded as that specific sample's failure point. The same pattern for increasing the impact energy until failure was used for every sample tested in this study. The pattern for increasing the energy is shown in Table 10. The initial impact is shown at the top of the figure. If the sample passed this impact, the next impact is shown directly below. The table was followed down the page until failure occurred and this point was recorded as the specimen's failure point.

Results

Each batch of spectacles tested consisted of the same model made by one manufacturer. After testing was completed for each batch, the mean impact failure energy and standard deviation from the mean (assuming a normal curve for failure) were calculated using the following formulas:

$$\overline{X} = \Sigma\ \chi_i/n$$

$$\sigma = \{\Sigma(\chi_i-\overline{X})^2/n-1)\}^{1/2}$$

where: Σ = summation

$\overline{X}$ = mean

χ_i = each data point $i = 1....n$

σ = standard deviation

n = number of samples tested

Results - Z87.1-1968 Lens-Only Test Block

The first test fixture used was the present Z87.1-1968 lens-only test block as shown in Figure 3. The results obtained using this test block are shown in Table 11. For this method all lenses were removed from the frame before testing. The lenses were positioned on the rubber gasket which was attached to the test block. To prevent the lenses from flying off the test block after impact and possibly being damaged in this manner, a holder was positioned over the lens. Recentering the lens on the gasket was done as necessary. This type of testing concerns itself only with one mode of failure, that being breakage of the lens (chipping or cracking of the lens will be considered as breakage). This is a test for safety lenses only and not a test of the whole safety spectacle system. Table 11 shows that toughened glass lenses easily passed the present ANSI impact requirement (i.e., 0.61 ft-lb_f); however, wide ranges in impact failure energies were observed. The one set of 20 CR-39 lenses all passed the 0.61 ft-lb_f impact; however, the mean failure energy was much lower than that for any of the toughened glass lenses. Also, two different manufacturers' polycarbonate lenses were tested. These lenses were not borken even with the 2-1/4 inch ball at 100 inches; however, "bottoming out" of the rubber gasket on the test block began to occur with the 1-3/4 inch ball thus allowing the metal test block to dent the rear side of the lens indicating that modification may be necessary in order to test at the higher energies. Another potential problem associated with this stand is the inaccuracies in repositioning the lens after each impact. A recent NBS study indicated that substantial flaws in the lens can initiate fracture if located near the point of impact. Therefore, slight variations in positioning can become critical. This may account for the large standard deviations shown in Table 11.

Results - Z87.1-1968 Lens-In-Frame Test Block

The next test fixture employed was the ANSI Z87.1-1968 lens-in-frame test block shown in Figure 1. The results for testing with this block are shown in Figure 12. The safety spectacles must be prepared before being used on this stand and only plastic frames (spectacles with metal temples and plastic front of the frame, also) may be tested on this block. Preparation involved removing the temples, temple hinges, and nose pads as well as cutting the lens eyes into two separate pieces. Because of their construction where the temple hinge is part of the front frame, metal frames cannot be tested on this test block although this is not mentioned in the ANSI Z87.1-1968 Standard.

Figure 12 indicates that for glass and polycarbonate lenses in plastic frames impacted using this method failure depended upon how large an impact the frame could withstand before dislodgement of the lens occurred for most of the samples tested. Only occasionally was failure due to lens or frame breakage. However, for the CR-39 lenses failure was attributed to lens breakage in the majority of cases.

Problems that occurred with this test block were: after an impact the lens and frame flew off the test block requiring repositioning for additional testing and repositioning the lens in approximately the same location as the previous lens was quite difficult due to the need to see through the frame to "center" the speciment on the block.

Results - Proposed Z87.1 Test Stand

The next fixture to be used was the one proposed by the Z87 Committee as shown in Figures 4 and 7. The revised Z87.1 Standard draft calls for this test fixture to be used for testing safety spectacles with metal frames or with a combination metal-plastic frame. However, during this study spectacles with metal, plastic, or combination frames were tested since it was felt that the same test fixture should be used to test all safety spectacles regardless of their construction.

This is the first test fixture used that tested safety spectacles as a complete unit. They were mounted as received in the box. The failure modes were the same as for the Z87.1-1968 lens-in-frame test block; however, parts of the safety spectacles were not removed. Whiel the Z87.1-1968 lens-only test block tested only for lens breakage, the test stand resulted in failure by one of these modes: lens breakage, frame breakage, or lens dislodgement from the frame (partial or total dislodgement).

This test fixture was considered to be a step in the right direction; however, quite a few problems were encountered. Referring to Figure 7, page 1, it is seen that the safety spectacles would be supported at the bridge by the bridge support and that the temples would be clamped between clamping knobs A and B with the temple resting on the "ledge" of the inner clamping knob. It was observed during testing that the temples were slipping with respect to the clamping knobs at impact of the drop ball. In general it was observed that the plastic temples did not slip as much as the metal temples did. It was observed that the plastic temples tended to rotate wih respect to the locking knobs about a point where the clamping pressure may be assumed as maximum. Most of the plastic temples were slightly tapered in thickness with the largest section at the hinge end; therefore, uniform pressure was not obtained alsong the surface of the temple within the contact area of the clamping knobs. There was no apparent vertical sliding (parallel with impact force due to free fall of the ball) observed with the plastic temples as was the case with metal temples which also exhibited turning relative to the locking knobs in combiantion with vertical slippage. In no case was it observed that the clamping knobs moved relative to the clamp bar during impact. As exptected, more movement of the temples occurred at the higher impact energies. While using this stand it was necessary to remove the spectacles after each impact then replace them in the proper position before the next impact due to the slippage problems.

The results for testing conducted using the proposed Z87.1 test stand are shown in Table 13. Other problems were also encountered when using this stand. For the third batch of spectacles shown in Table 13 it is indicated under sample size that 20 specimens were tested; however, there were only 14 failure points. This situation arose because five of the ten pairs of spectacles broke at the bridge and another pair broke through the temple hinge thus support was not adequate to continue testing. Each of these failures was counted as a single data point. There was noticeable "digging in" observed on the bridges of plastic frames caused by the sharp cornered bridge support. It was thought that the sharp corners may have been causing stress concentrations although bridge breakage occurred only with the one manufacturer's spectacles and most of these failures occurred at comparatively low impact energies suggesting that the birdge was a weak point in this particular "make" of spectacles.

When spectacles with metal safety frames were tested, plastic deformation occurred mainly at the temple hinge junction allowing the frame to "wrap around" the lens causing dislodgement. With the first set of metal framed spectacles tested, quite a few lenses broke; however, it was impossible to tell whether the mode of failure was due to lens breakage of dislodgement. It was suspected that the lens was being dislodged then being trapped between the aluminum block and drop ball thus being broken. It was decided to place small rubber pads on the top of the block to prevent the lens from breaking. The rubber pads were used thereafter and the number of lens bre-kage significantly decreased. Regardless of failure mode the failure energy would not change due to use of the rubber pads. Except for the two groups discussed, all other batches exhibited lens dislodgement; by far the most frequent mode of failure as seen from Table 13.

Results - NIOSH Test Fixtures

It was felt that the slippage problems encountered with the proposed Z87.1 test stand created non-standard test conditions. In other words, some "makes" of spectacles slipped more than others and even the amount of slippage was different for the specimens within a particulate group. Therefore, it was decided that NIOSH should attempt to design a test fixture (or fixtures) that would function similarly to the proposed Z87.1 test stand but would eliminate the problems observed when using the proposed Z87.1 test stand.

This attempt resulted in the two test stands shown in Figure 8 (5 pages). NIOSH Test Fixture No. 1 is shown on pages 1, 3, and 4 and NIOSH Test Fxiture No. 2 is shown on pages 2, 3, and 5. Both assemblies use the same block and birdge support as shown in Figure 8, page 3. The differences occur in the method used to clamp the temples. The bridge support was modified from the proposed Z87.1 test stand to have a 1/16 inch radius on each side in an attempt to minimize any stress concentration and to more closely resemble the curvature of the human nose.

The clampling method for NIOSH Test Fixture No. 1 was modified from the proposed Z87.1 stand as follows: the clamp bar was made larger and was moved toward the center of the block. It also had a 1/2 inch wide cutout through each end for the purpose of placing the temples through the cutout in an attempt to eliminate any rotational movement of the spectacles. The length of the cutout along the clamp bar will accommodate any size spectacles presently made. The clamping knobs were designed to have circular grooves on the surfaces that would contact the temples for the purpose of eliminating any vertical slippage. Also, the knobs have a raised diamond knurl on their outer diameter to allow easier gripping with the human hand. It was originally planned to use the washers shown in Figure 8, page 4 between the clampling knobs if necessary; however, they were not used in this study.

The purpose of NIOSH Test Fixture No. 2 was to provide a clamping method that was more positive than that available by tightening knobs by hand. The inner clamp plate's position relative to the block is adjustable and is secured by the use of a set screw. The temple is placed between the inner and outer clamp plates. Positive clamping is achieved by the use of two cap screws on each side. The inner plate is threaded while the outer plate incorporates clearance holes which also allow tilting of this plate to conform to the shape of the temple being held. The hexagon socket head cap screws are easily tightened by the use of an Allen wrench.

The results for NIOSH Test Fixtures No. 1 and 2 are shown in Tables 14 and 15 respectively. The rubber pads were placed on the top of the stands on both sides of the bridge support during all testing conducted suing these stands. Slippage was not noted for either stand for any of the specimens tested. The contoured bridge support did not "dig into" the plastic bridges nearly as much as the sharp edged support used on the proposed Z87.1 test stand. Of the ten pair of Watchemoket spectacles tested on Test Fixture No. 1, only two broke at the bridge (resulting in a sample size of 18 as shown in Table 14). Also, two of the ten pair broke at the birdge when tested on Test Fixture No. 2. (This occurred after one side had already failed thus resulting in a sample size of 20 as shown in Table 15.) These figures compare with the five out of ten pair that broke at the birdge when tested on the proposed ANSI Z87.1 test stand. Although it appears that the bridge is a weak spot for this particular "make" of spectacles, it seems that the contoured bridge support did reduce any stress concentrations caused by the sharp cornered bridge support.

Problems can arise while using NIOSH Fixture No. 1. If the temple is discontinuous or has an added piece, clamping would not be uniform since there is no allowance for tilting of the clamping knobs. In one case with metal frames there was a small cylinder of metal added to the temple for the purpose of holding a rubber coating on the "ear end" of the temple. With this attached support was not adequate for testing purposes. However, it was found that this piece could easily be removed which was done. Due to the use of a wrench with Test Fixture No. 2 it was not required to remove the piece as it was easily crushed.

Care must be taken to tighten the clamping knobs or plates as much as possible when testing metal frames on either stand. It was also found that tightening of the cap screws on Stand No. 2 must be done with the Allen wrench to provide adequate clamping force and prevent slippage. It was also found that wearing gloves while tightening the clamping knobs on Fixture No. 2 greatly increased one's grip on the knobs especially when testing metal framed safety spectacles.

Test Fixture No. 1 seemed to be much simpler and less time consuming to use than Test Fixture No. 2 and it appread that both eliminated the problems encountered when using the proposed Z87.1 test stand.

Discussion of Results

The purpose of this study was to compare the usage of different test fixtures to be used in drop-ball impacting of safety spectacles; therefore, the comparison of results as shown in Table 16 has been prepared. Table 16 allows comparison of the calculated mean and standard deviation of th- failure energy for each "make" of glasses tested on the various fixtures. Sample size is also shown in this figure for each batch of samples tested.

The Z87.1-1968 lens-only test block tests for only one failure mode as previously mentioned. It is apparent that when lens breakage is the only failure criteria failure occurs at much higher impact energy levels than when other failure modes are considered for toughened glass lenses and polycarbonate lenses. In fact all glass lenses passed the present Z87.1-1968 impact requirement with a significant margin to spare even though testing was conducted using multiple impacts. Also, polycarbonate lenses tested for breakage could not be broken with the available equipment. However, for CR-39 lenses it is seen that the situation reverses (based on the small amount of CR-39 lenses tested) such that failure by the lens-only criteria occurs at lower levels than when testing is conducted under the multiple failure mode systems.

The Z87.1-1968 lens-in-frame test block is only applicable to safety spectacles with plastic frames as indicated in Table 16. There also seems to be no established pa-tern when comparing the mean failure energies obtained using the Z87.1-1968 lens-in-frame test block and the proposed stand and in others it is lower. Again, comparisons cannot be made for metal frames. That a pattern was not evident when comparing the Z87.1-1968 lens-in-frame test block results with any of the other test fixtures was not surprising due to the amount of preparation needed to test samples on this block. It is necessary to use a high speed cutter to remove the plastic nose pads as well as grind down the temple hinges so they can be removed. It was found that not only is this a time consuming process but it is nearly impossible to remove exactly the same amount of nose pad on one lens eye as on another. Of course, with a little practice one can become quite proficient at grinding off approximately the same amount. However, only slight variations will have an effect on the way that the frame eye rests on the block thus causing differences in support as well as in results. Also, it was found that some spectacles have a "weak spot" at the bridge but cutting the spectacles in half through the bridge eliminates this possible failure point.

When testing was conducted using the proposed Z87.1 test stand, there was considerable slippage of the temples observed between the clamping knobs. When comparing the mean failure energy obtained for the proposed Z87.1 test stand to the mean failure enrgies obtained for either NIOSH Test Fixture No. 1 or No. 2, it is observed that the failure energy is much higher for the proposed Z87.1 stand in all cases except one. Also, the standard deviations are larger except in the one case. It is believed that the one case not following this pattern was due to the large nubmer (50%) of failures at the bridge which occurred at relatively low failure energies. This significantly lowered the mean failure energy for the proposed Z87.1 stand. In fact, the mean failure energy for the five bridge failures was calculated as 1.35 ft-lb_f compared to the overall mean failure energy of 1.56 ft-lb_f. Therefore, it was thought that if as many bridge failures had occurred when using the NIOSH stands this "make" of spectacles would have followed the pattern of higher failure energies for the proposed Z87.1 stand than for the NIOSH Test Fixtures.

Slippage was not observed for either of the NIOSH Test Fixtures during testing. Comparison of the failure energies for the two NIOSH Test Fixtures showed very slight deviation which would be expected with sample sizes of 20. For all practical purposes the results can be considered as being equivalent.

Conclusions

Prior to reviewing the aforementioned NBS report, it was felt that the ANSI Z87.1-1968 lens-only test block was adequate to test for lens breakage as the single failure mode. However, in light of the problems previously mentioned and their consequences, it is now considered that modification of this test block is necessary. In general, however, it may be advisable to retain such an impact test fixture in any future standards to insure that lens breakage will occur at higher energy levels than failure would occur when testing on a total system. In other words, it is thought that failure of safety spectacles by lens breakage is more dangerous than failure by lens dislodgement (due to actual dislodgement or due to frame breakage) and the lens breakage failure mode should be avoided if at all possible.

It was found that the present ANSI Z87.1-1968 lens-in-frame test block data was inconsistent when compared to the mean failure energies obtained with the other fixtures which mounted the entire safety spectacle. This test block tests only part of the system and requires considerable preparation. Also, metal framed safety spectacles cannot be tested on this block. Therefore, it was concluded that testing using this block should be abandoned.

It was felt that the proposed ANSI Z87.1 test stand was a step in the right direction which allowed testing to be conducted on the complete system. However, problems were encountered when testing was conducted on this stand. Slippage of the temples between the clamping knobs resulted in varying test conditions as some temples slipped more than others. This slippage caused higher impact failure energies than those obtained when no slippage was observed. Therefore, if this type of testing is to be continued where the temples are rigidly held and prevented from moving during testing, it is recommended that a redesigned version of the proposed Z87.1 test stand be used to insure that the test conditions are identical for every specimen tested.

The NIOSH test fixtures were designed to eliminate the problems that occurred with the proposed Z87.1 test stand. No slippage was observed with either test fixture. For the type of impact test where the spectacles are rigidly supported at the bridge and temples either NIOSH Test Fixture No. 1 or No. 2 is adequate. Test Fixture No. 2 appeared to provide more positive clamping of the temples due to the use of Allen wrenches; however, Test Stand No. 1 was more convenient and much quicker to use.

During the course of this study it has been seen that test stands can be designed to test all the various styles and types of safety glasses made at the present time. Therefore, it was concluded that all safety spectacles, regardless of differences in their construction or material used for the frame, should be subject to testing on the same test fixtures.

Future NIOSH Project Plans

Before NIOSH can propose impact criteria levels, test procedures, and test equipment for a new eye and face protection standard, further research work must be conducted in the area of impacting safety spectacles. Future work will be done in drop-ball testing, employing an anthropometric headform as the holding fixture to compare the results with those obtained while using the test fixtures reported on in this study. A complete project in the area of ballistic (low mass, high velocity) impact testing of safety eyewear is presently contemplated thus allowing comparison of impact failure energy for the ballistic testing method versus the drop-ball testing method.

Another project in the impact area of penetration by various shapes of pointed projectiles is planned for the near future.

After completion of all the projects in the area of impact testing of safety spectacles, it is contemplated that the results and conclusions will be incorporated in any future testing and performance requirements for eye and face protective devices that may be recommended to the Occupational Safety and Health Administration.

References

{1} Federal Register, Volume 39, Number 125, Part II, Subpart I, Section 1910.133, page 23670, June 27, 1974.

{2} American National Standards Institute, Inc., Practice for Occupational and Educational Eye and Face Protection, Z87.1-1968.

{3} American National Standards, Institute, Inc., Z87 Committee, Proposed Revision of USAS Z87.1-1968 USA Standard, Practice for Occupational and Educational Eye and Face Protection.

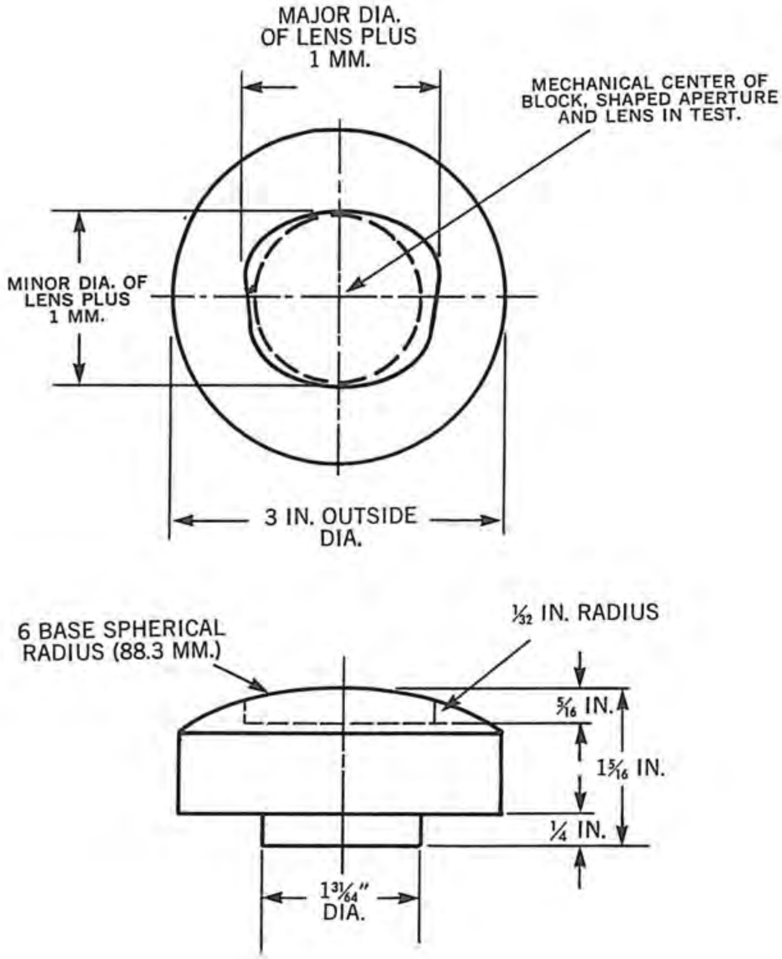


Figure 1
"Lens in Frame" Test Block
ANSI Z87.1-1968

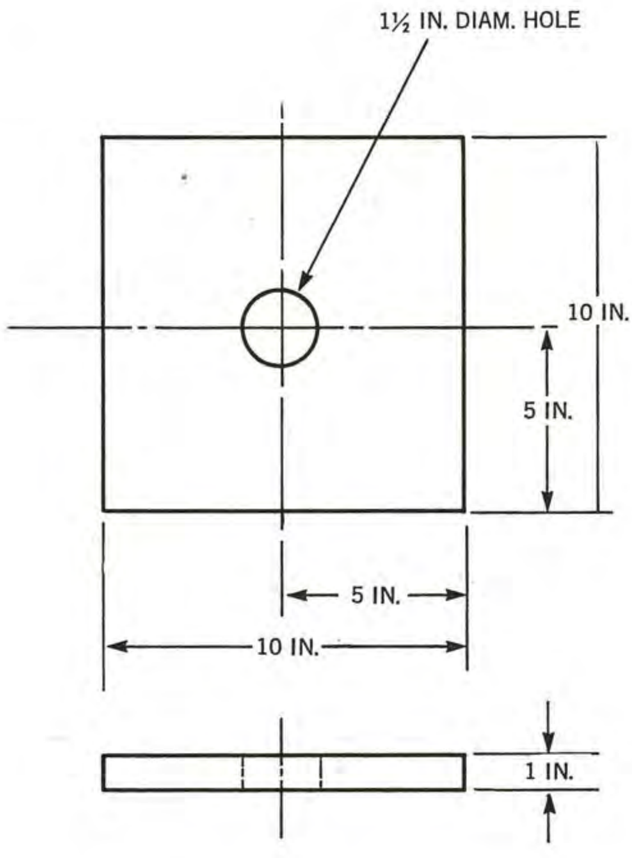


Figure 2
Base Plate
ANSI Z87.1-1968

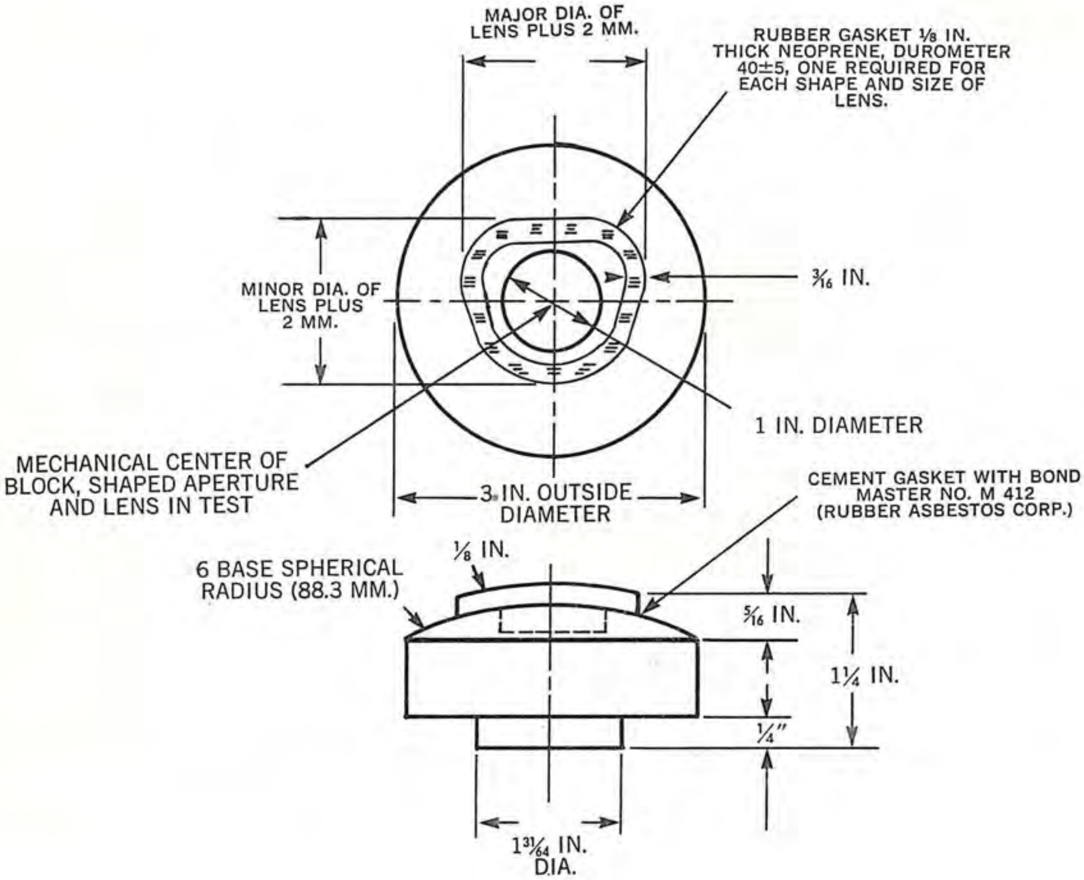


Figure 3
"Lens Only" Test Block
ANSI Z87.1-1968

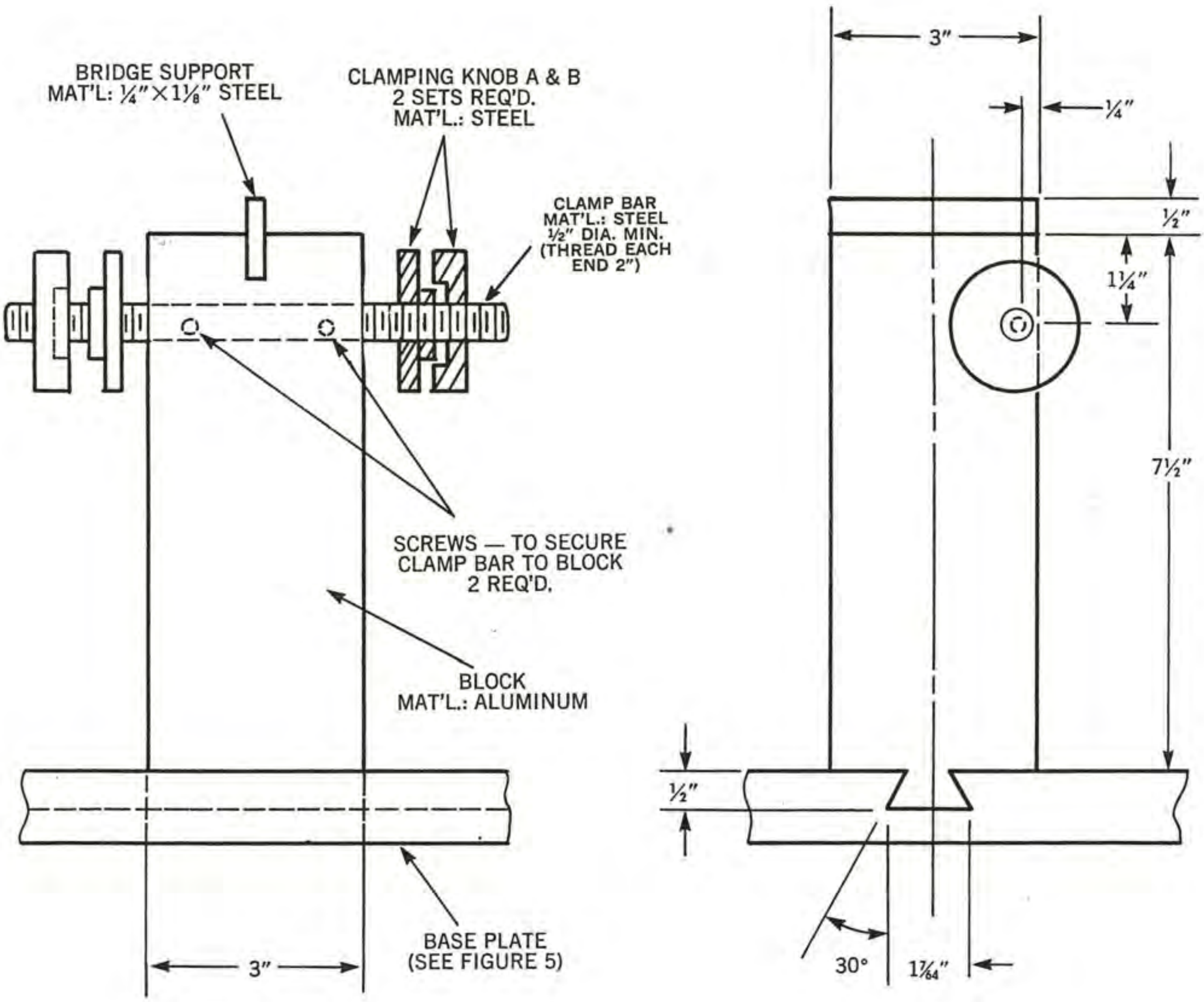


Figure 4
Test Head for Metal Safety Frames
ANSI Z87 Committee Proposed
Revision of Z87.1-1968

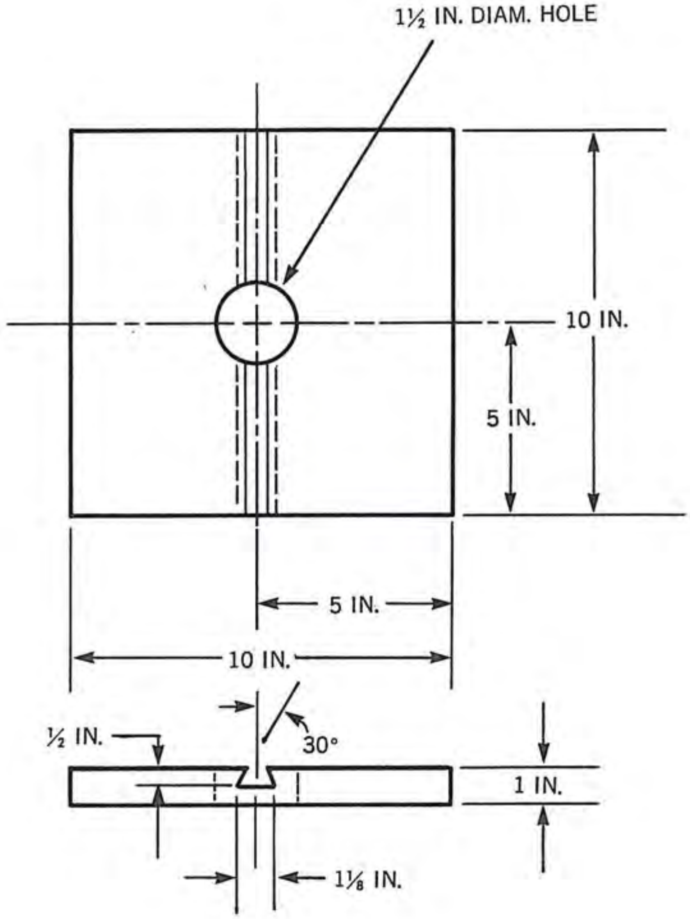


Figure 5
Base Plate
ANSI Z87 Committee Proposed
Revision of Z87.1-1968

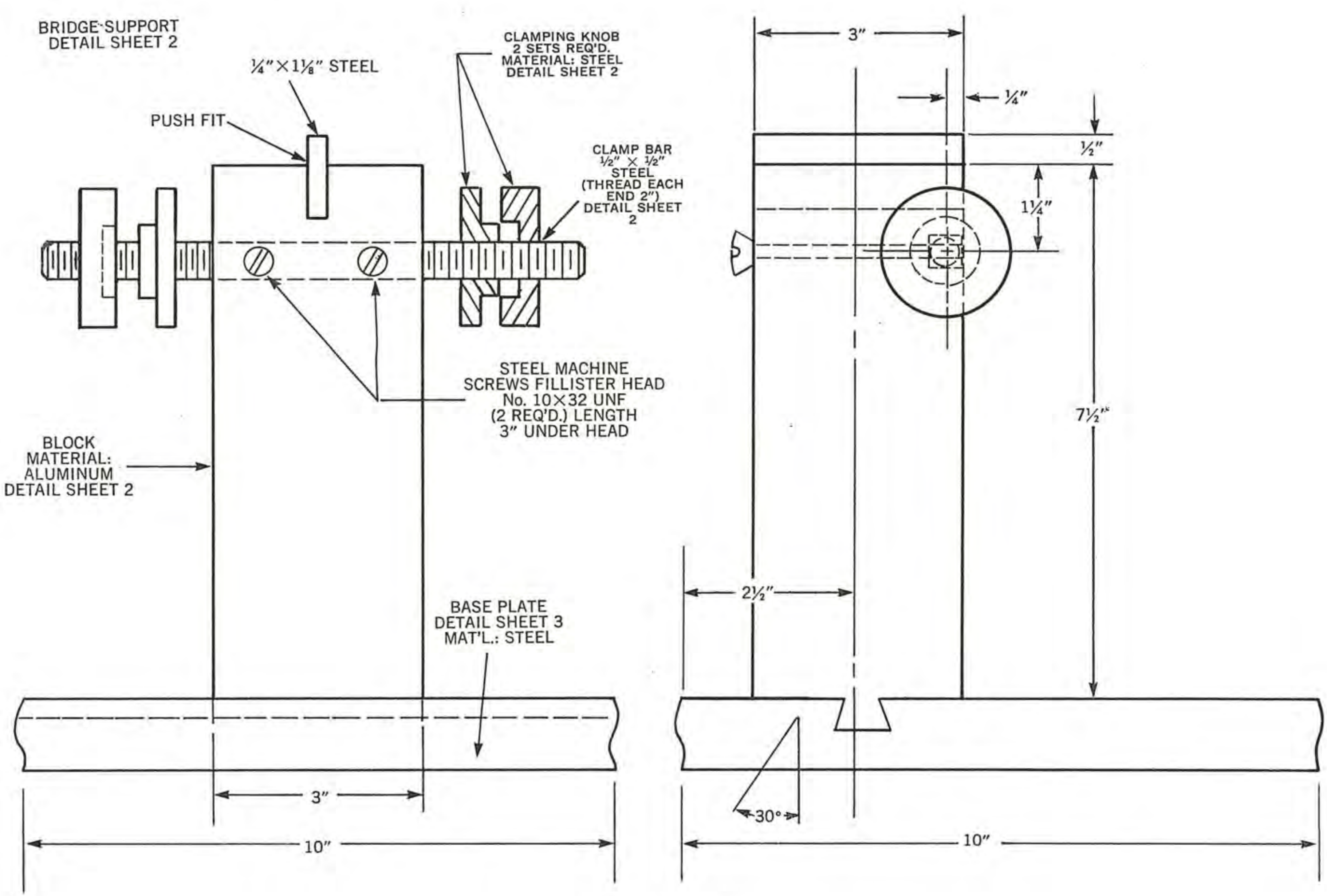


Figure 7
Test Head Assembly
Page 1

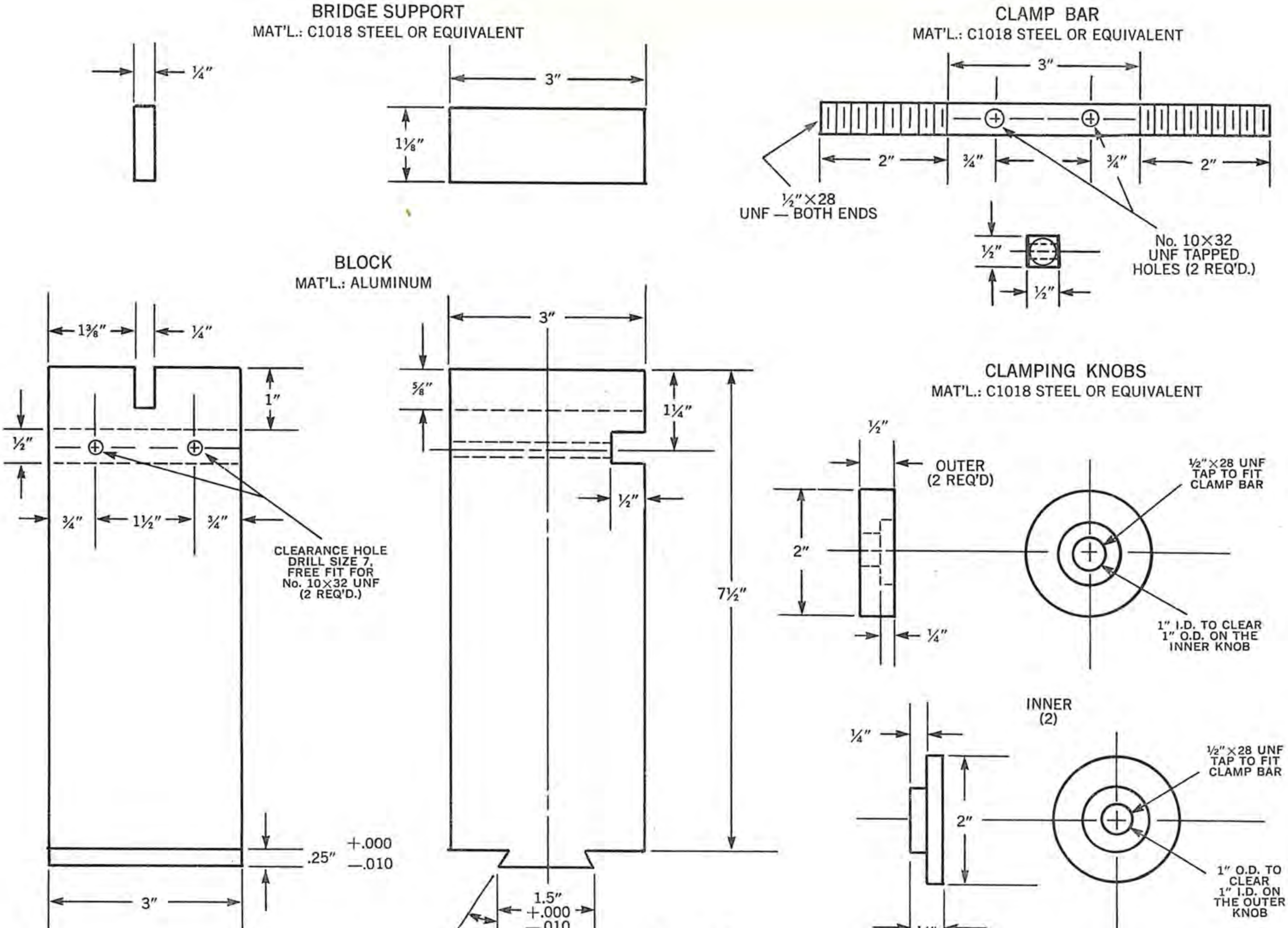
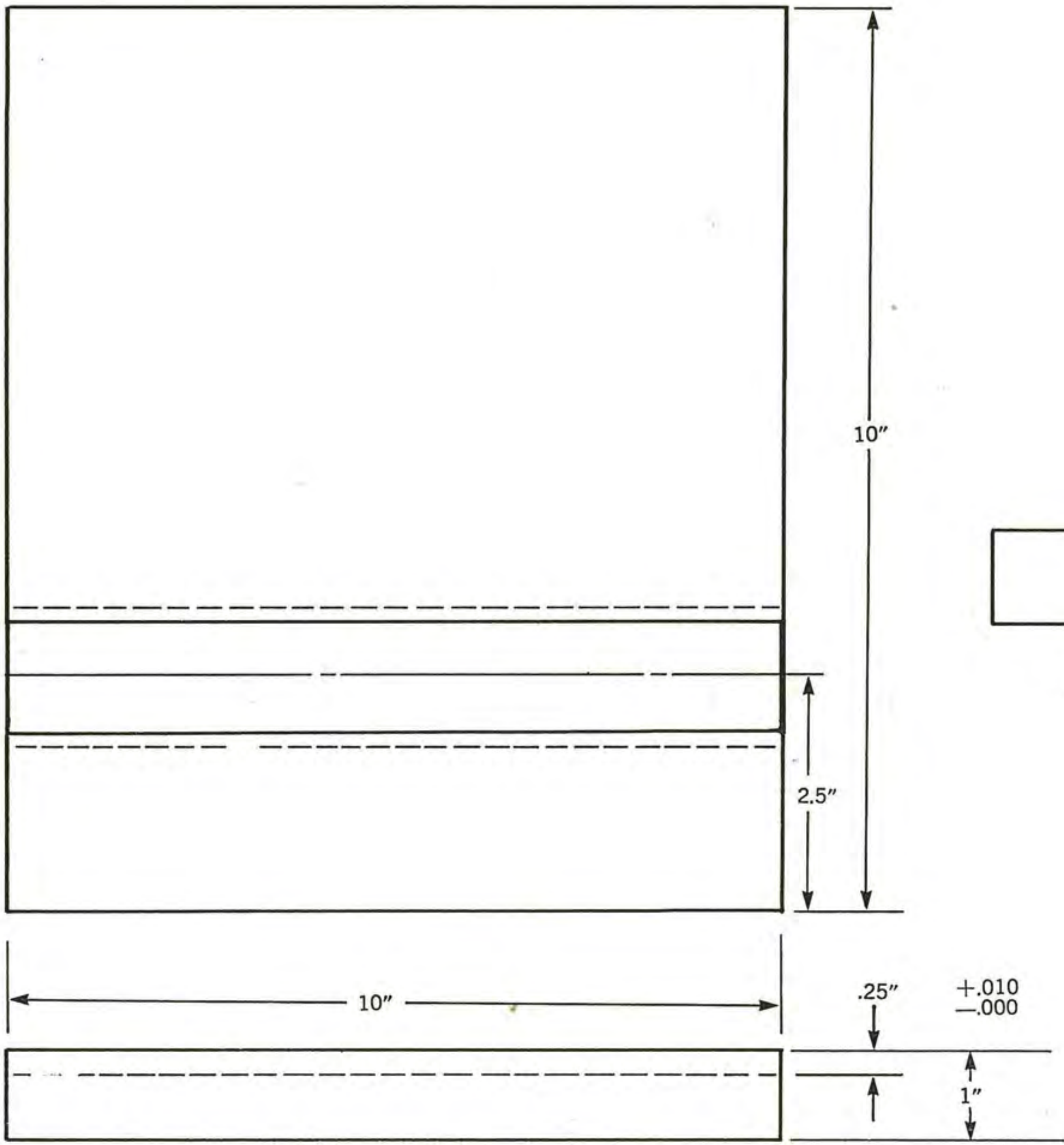
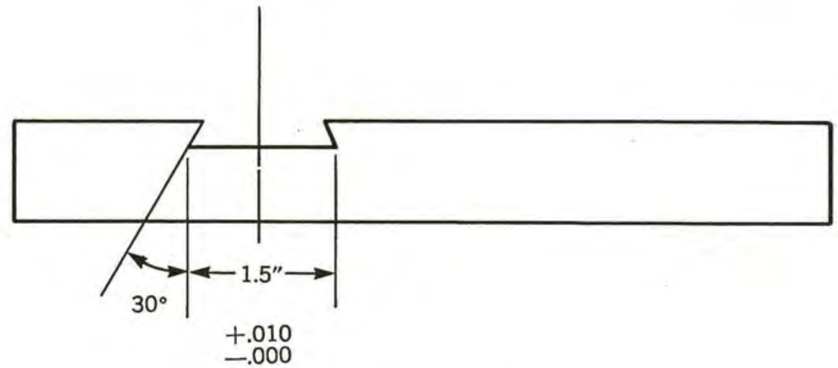


Figure 7
Page 2



BASE PLATE

Figure 7
Page 3



MATERIAL: C1018 STEEL
OR EQUIVALENT

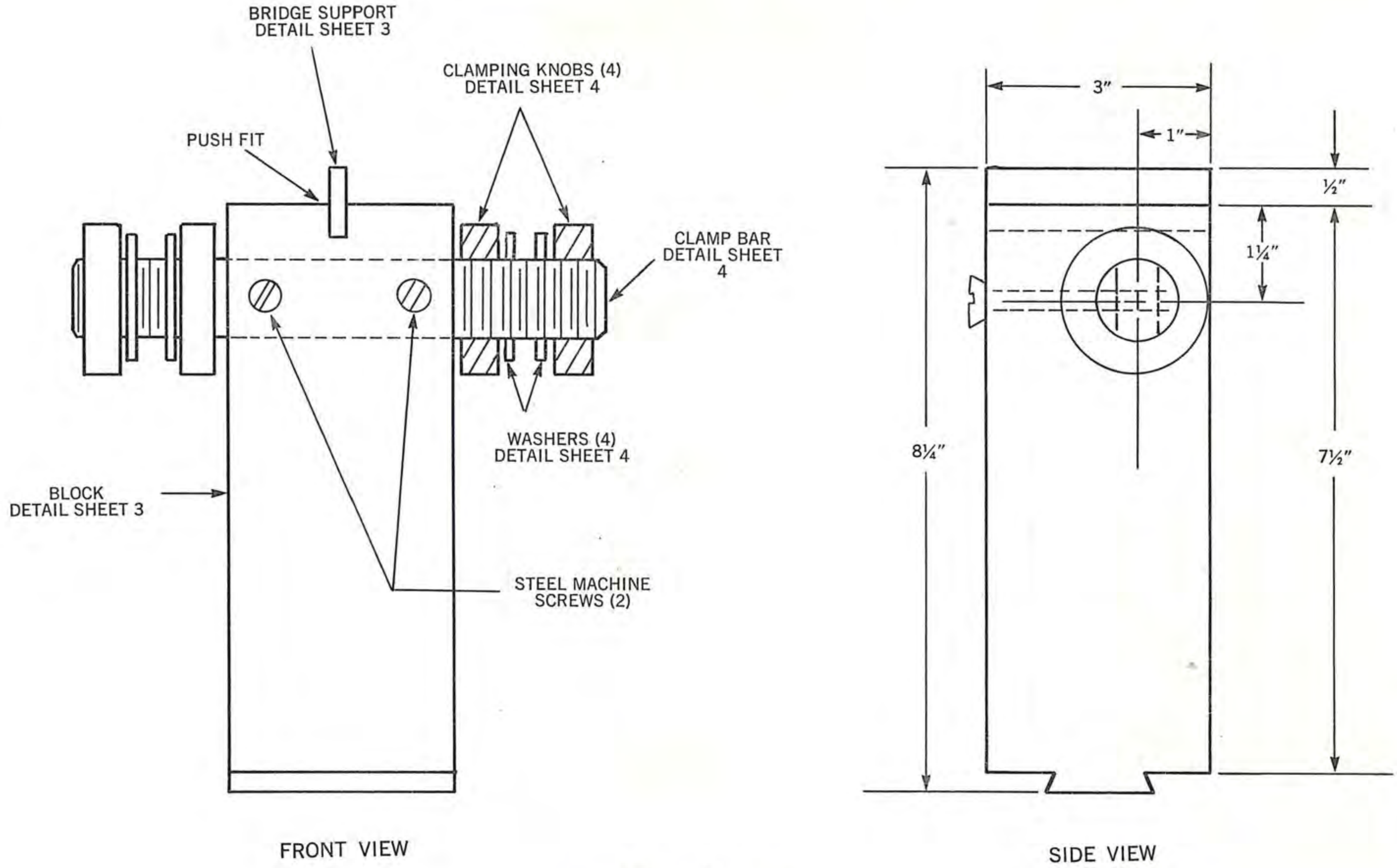


Figure 8
NIOSH Test Stand No. 1
Page 1

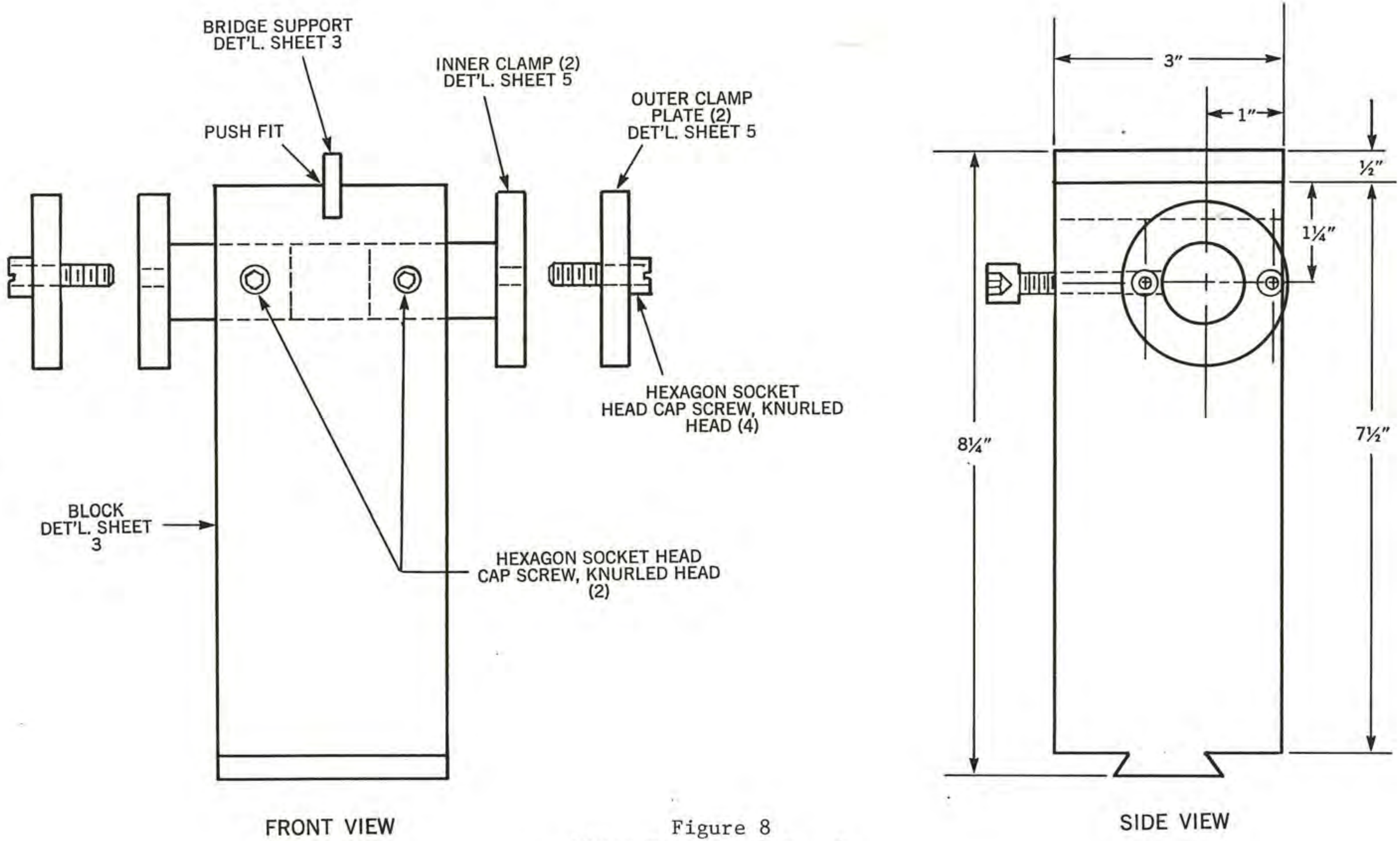


Figure 8
NIOSH Test Stand No. 2
Page 2

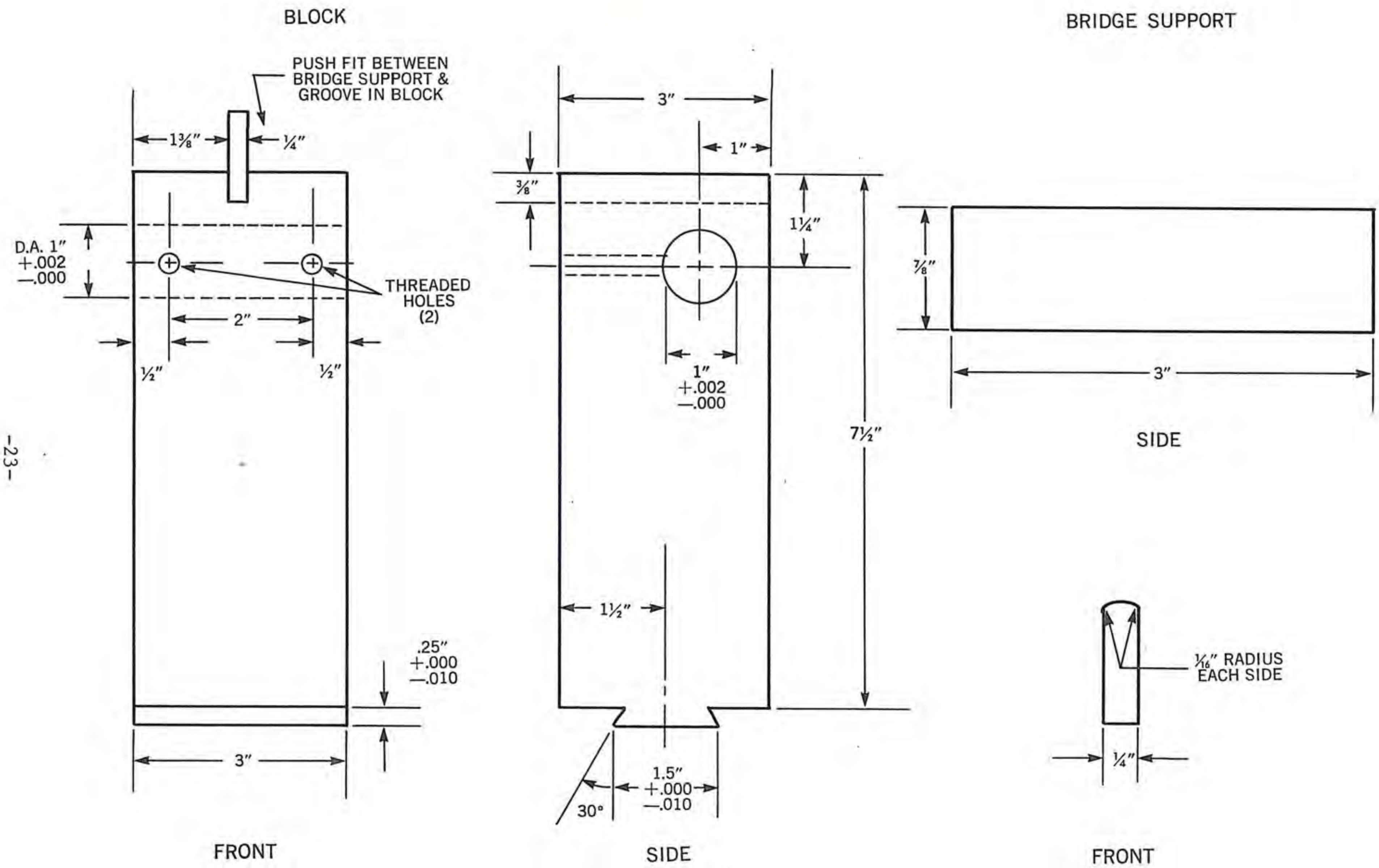


Figure 8
NIOSH Test Stands Nos. 1 and 2
Page 3

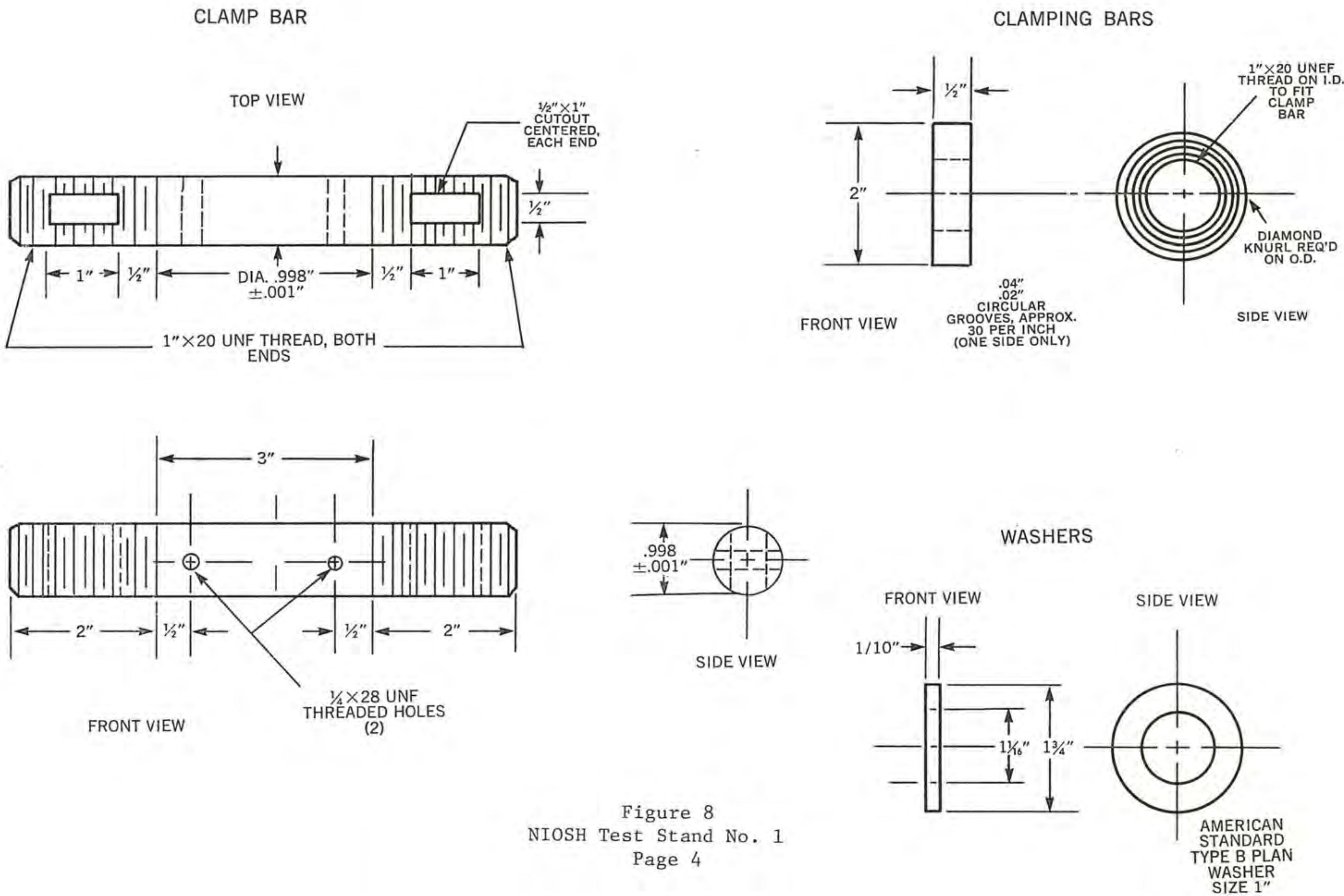


Figure 8
NIOSH Test Stand No. 1
Page 4

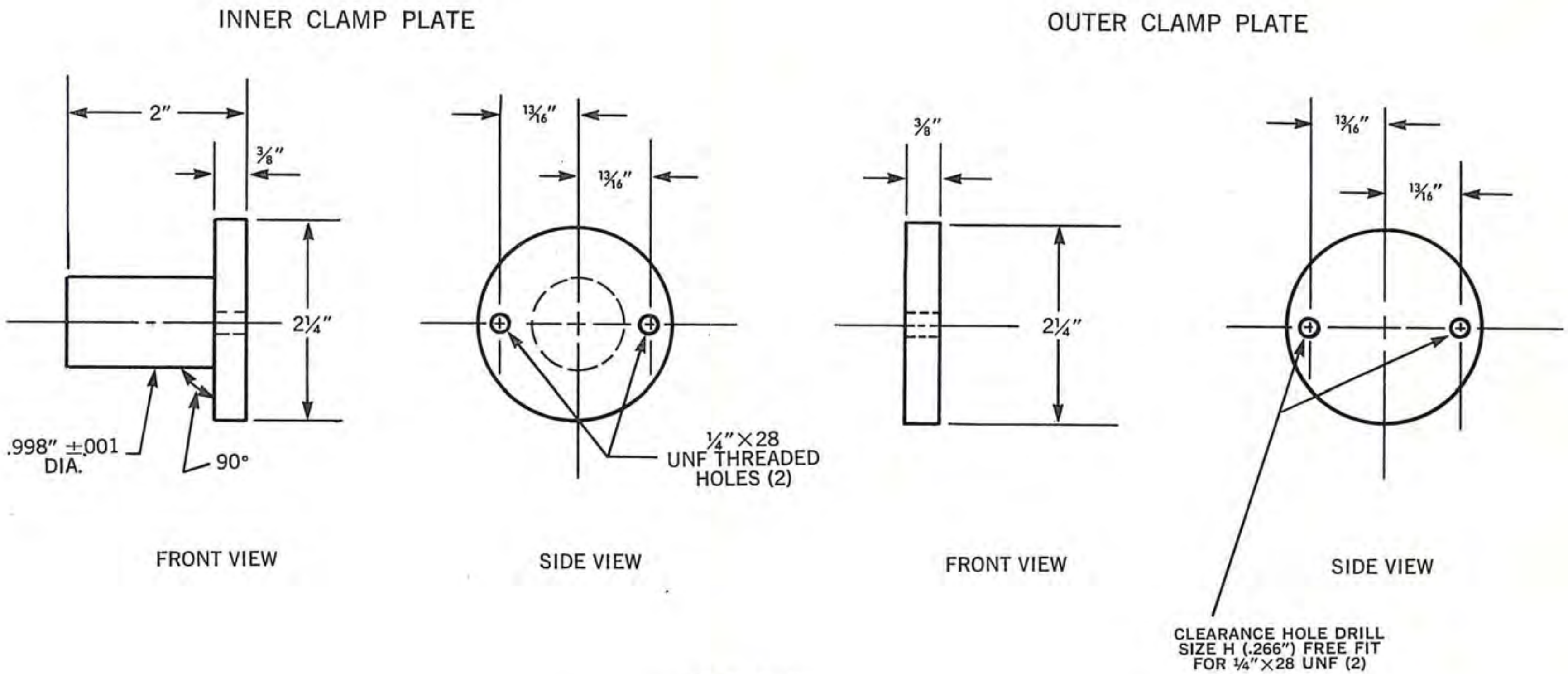


Figure 8
NIOSH Test Stand No. 2
Page 5

Table 1

Drop-ball Masses and Densities

DIAMETER (inches)	MASS (g)	DENSITY (g/cm^3)
1	66.7	7.77
1-1/4	130.4	7.78
1-1/2	225.4	7.78
1-3/4	358.1	7.79
2	527.3	7.68
2-3/4	760.9	7.79

Table 2

Impact Velocities and Energies for Various Drop Heights and Ball Sizes

DROP	HEIGHT	IMPACT VELOCITY		IMPACT ENERGY*											
				1" Dia.		1-1/4" Dia.		1-1/2" Dia.		1-3/4" Dia.		2" Dia.		2-1/4" Dia.	
inches	meters	ft/sec	m/sec	ft-lbs	joules	ft-lbs	joules	ft-lbs	joules	ft-lbs	joules	ft-lbs	joules	ft-lbs	joules
50	1.27	16.37	4.99	.61	.83	1.20	1.62	2.07	2.81	3.29	4.46	4.84	6.56	6.99	9.47
60	1.52	17.93	5.47	.74	1.00	1.44	1.95	2.48	3.37	3.95	5.35	5.81	7.88	8.39	11.36
70	1.78	19.37	5.90	.86	1.16	1.68	2.27	2.90	3.93	4.60	6.24	6.78	9.19	9.78	13.26
80	2.03	20.71	6.31	.98	1.33	1.92	2.60	3.31	4.49	5.26	7.13	7.75	10.50	11.18	15.15
90	2.29	21.96	6.69	1.10	1.49	2.16	2.92	3.73	5.05	5.92	8.02	8.72	11.81	12.58	17.05
100	2.54	23.15	7.06	≈1.23	1.66	2.40	3.25	4.14	5.61	6.57	8.91	9.68	13.13	13.98	18.94
110	2.79	24.28	7.40	1.35	1.83	2.63	3.57	4.55	6.17	7.23	9.81	10.65	14.44	15.37	20.83

*Energy calculated using actual masses of the drop balls

Table 3

Impact Energies for Various
Drop Heights and Ball Diameters

	DROP BALL DIAMETER	DROP HEIGHT (inches)	IMPACT ENERGY (ft-lb)	IMPACT ENERGY (joules)
		50	.61	.83
Initial	1"	60	.74	1.00
Impact →	Diameter	70	.86	1.16
		80	.98	1.33
		90	1.10	1.49
		100	1.23	1.66
		60	1.44	1.95
	1-1/4"	70	1.68	2.27
	Diameter	80	1.92	2.60
		90	2.16	2.92
		100	2.40	3.25
		60	2.48	3.37
Increase	1-1/2"	70	2.90	3.93
Impact	Diameter	80	3.31	4.49
Energy		90	3.73	5.05
		100	4.14	5.61
		70	4.60	6.24
	1-3/4"	80	5.26	7.13
	Diameter	90	5.92	8.02
		100	6.57	8.91
		70	6.78	9.19
	2"	80	7.75	10.50
	Diameter	90	8.72	11.81
		100	9.68	13.13
		80	11.18	15.15
Maximum	2-1/4"	90	12.58	17.05
Impact →	Diameter	100	13.98	18.94

Table 4

Failure energies obtained with Lens-only test block

SPECTACLE IDENTIFICATION	SAMPLE SIZE	IMPACT FAILURE ENERGY* (ft-lbs) HIGH	LOW	MEAN ($\overline{x}$)	STANDARD DEVIATION (σ)
Willson-glass lens Wil-1-1 → Wil-1-10	20	3.73	1.10	2.14	.64
U.S. Safety glass lens USS-1-11 → USS-1-20	20	3.31	1.10	2.49	.51
Watchemoket glass lens WO-1-21 → WO-1-30	20	4.60	2.90	3.83	.47
Welsh polycarbonate lens WM-1-21	2	NO FAILURES AT 13.98 ft-lb			
H.L. Bouton polycarbonate lens HLB-1-11 → HLB-1-15	10	NO FAILURES AT 13.98 ft-lb			
Cesco CR39 lens CES-1-21 → CES-1-32	20	1.44	.74	1.02	.18

*All impact testing began at .61 ft-lb and the impact energy pattern shown in Table 3 was used for all batches.

Table 5

Results obtained with Lens-in-frame test block

		Number of failures by failure mode			Impact Failure Energy* (ft-lb)			
SPECTACLE IDENTIFICATION	SAMPLE SIZE	LENS DISLODGEMENT	LENS BREAKAGE	FRAME BREAKAGE	HIGH	LOW	MEAN ($\bar{X}$)	STANDARD DEVIATION (σ)
Willson glass lens Wil-1-11→W-1-21	20	17	3	0	1.44	.61	1.04	.20
Watchemoket glass lens WO-1-11→WO-1-20	20	16	0	4	2.16	.61	1.59	.45
American Optical glass lens AO-3-6→AO-3-10	10	6	3	1	2.40	1.23	1.78	.39
H.L. Bouton polycarb lens HLB-1-21→HLB-1-30	20	18	0	2	4.14	.98	1.76	.91
Cesco CR39 lens CES-1-11→ &CES-1-33→37	20	9	11	0	1.68	.74	1.06	.23

*All impact testing began at .61 ft-lb and the impact pattern shown in Table 3 was used for all batches.

Table 6

Results obtained with Proposed Z87.1 test stand

		Number of Failures by Failure Mode			Impact Failure Energy* (ft-lb)			
SPECTACLE IDENTIFICATION	SAMPLE SIZE	LENS DISLODGEMENT	LENS BREAKAGE	FRAME BREAKAGE	HIGH	LOW	MEAN ($\bar{x}$)	STANDARD DEVIATION (σ)
Willson-glass lens, plastic frame Wil-1-42→Wil-1-48	14	13	1	0	2.40	1.23	1.87	.36
U.S. Safety-glass lens, metal frame USS-1-1→USS-1-10	20	9	11	0	1.23	.61	.97	.14
Watchemoket-glass lens, plastic frame WO-1-1→WO-1-10	20 tested 14 data point 14	3	2	9	2.48	.61	1.56	.60
MSA-glass lens, metal frame MSA-1-1→MSA-1-10	20	20	0	0	.86	.61	.74	.10
American Optical-glass lens, plastic frame AO-3-1→AO-3-5	10	9	1	0	2.90	1.23	2.00	.53
Welsh-polycarb lens, metal frame WM-1-1→WM-1-10	20	20	0	0	.74	.61	.64	.05
H.L. Bouton-polycarb lens, plastic frame HLB-1-6→HLB-1-10 & HLB-1-16→HLB-1-20	20	20	0	0	2.16	.98	1.52	.35
Cesco-CR39 lens, plastic frame CES-1-1→CES-1-5 & CES-1-38→CES-1-42	20	18	2	0	2.40	1.44	1.84	.28

*All impact testing began at .61 ft-lb and the impact pattern shown in Table 3 was used for all batches.

Table 7

Results obtained with NIOSH test fixture No. 1

		Number of Failures by Failure Mode			Impact Failure Energy* (ft-lb)			
SPECTACLE IDENTIFICATION	SAMPLE SIZE	LENS DISLODGEMENT	LENS BREAKAGE	FRAME BREAKAGE	HIGH	LOW	MEAN ($\bar{x}$)	STANDARD DEVIATION (σ)
Willson-glass lens, plastic frame Wil-1-22→Wil-1-31	20	12	0	8	1.92	1.10	1.55	.26
U.S. Safety-glass lens, metal frame USS-1-21→USS-1-30	20	19	1	0	.98	.74	.90	.08
Watchemoket-glass lens, plastic frame WO-1-31→WO-1-40	20 tested 18 failure points	14	0	4	3.31	.61	1.70	.77
MSA-glass lens, metal frame MSA-1-11→MSA-1-20	20	20	0	0	.86	.61	.69	.09
H.L. Bouton-polycarb lens, plastic frame HLB-1-31→HLB-1-40	20	20	0	0	2.16	.86	1.16	.30

*All impact testing began at .61 ft-lb and the impact pattern shown in Table 3 was used for all batches.

Table 8

Results obtained with NIOSH test fixture No. 2

		Number of Failures by Failure Mode			Impact Failure Energy* (ft-lb)			
SPECTACLE IDENTIFICATION	SAMPLE SIZE	LENS DISLODGEMENT	LENS BREAKAGE	FRAME BREAKAGE	HIGH	LOW	MEAN ($\bar{x}$)	STANDARD DEVIATION (σ)
Willson-glass lens, plastic frame Wil-1-32→Wil-1-41	20	18	1	1	1.92	.98	1.47	.30
U.S. Safety-glass lens, metal frame USS-1-31→USS-1-40	20	17	3	0	.98	.74	.88	.06
Watchemoket-glass lens, plastic frame WO-1-41→WO-1-50	20	16	1	3	2.90	.61	1.65	.68
MSA-glass lens, metal frame MSA-1-21→MSA-1-30	20	20	0	0	.86	.61	.68	.09
H.L. Bouton-polycarb lens, plastic frame HLB-1-41→HLB-1-50	20	20	0	0	2.16	.98	1.22	.28

*All impact testing began at .61 ft-lb and the impact pattern shown in Table 3 was used for all the batches.

Table 9

Comparison of results obtained with all fixtures

SPECTACLE IDENTIFICATION	Z87.1 - 1968 Lens-only test block			Z87.1 - 1968 Lens-in-frame test block			Proposed Z87.1 test stand			NIOSH test stand No. 1			NIOSH test stand No. 2		
	Sample Size	Failure Energy		Sample Size	Failure Energy		Sample Size	Failure Energy		Sample Size	Failure Energy		Sample Size	Failure Energy	
		Mean ($\bar{x}$)	Std. Dev. (σ)		Mean ($\bar{x}$)	Std. Dev. (σ)		Mean ($\bar{x}$)	Std. Dev. (σ)		Mean ($\bar{x}$)	Std. Dev. (σ)		Mean ($\bar{x}$)	Std. Dev. (σ)
Willson-glass lens, plastic frame (Wil-1)	20	2.14	.64	20	1.04	.20	14	1.87	.36	20	1.55	.26	20	1.47	.30
U.S. Safety-glass lens, metal frame (USS-1)	20	2.49	.51	Not applicable			20	.97	.14	20	.90	.08	20	.88	.06
Watchemoket-glass lens, plastic frame (WO-1)	20	3.83	.47	20	1.59	.45	14	1.56	.60	18	1.70	.77	20	1.65	.68
MSA-glass lens, metal frame (MSA-1)				Not applicable			20	.74	.10	20	.69	.09	20	.68	.09
American Optical-polycarb lens, metal frame (AO-3)				10	1.78	.39	10	2.00	.53						
Welsh-polycarb lens, plastic frame (WM-1)	2	No failures at 13.98 ft-lb		Not applicable			20	.64	.05						
H.L. Bouton-polycarb lens, plastic frame (HLB-1)	10	No failures at 13.98 ft-lb		20	1.76	.91	20	1.52	.35	20	1.16	.30	20	1.22	.28
Cesco-CR39 lens, plastic frame (CES-1)	20	1.02	.18	20	1.06	.23	20	1.84	.28						

NOTE: All failure energy given in ft-lb.

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