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Fritz Laboratory Reports

Civil and Environmental Engineering

1969

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G. A. Alpsten

LEHIGH UNIVERSITY INSTITUTE OF RESEARCH

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ABSTRACT

Hardness tests were carried out on the Fritz Laboratory end fixtures to determine the mechanical properties of the components adjacent to the rocking surface. The hardness values were transformed to tensile strength.

Using the mechanical properties as determined from the hardness tests, design loads were computed from available design specifications. Also, the ultimate load causing permanent deformations was estimated.

The results indicate that the current maximum load of 2 million pounds probably could be increased to 3 million pounds, that is, increased by 50%, or possibly even slightly more. Subsequent column tests have been carried out up to a load of 2.5 million pounds with no noticeable deformations.

INTRODUCTION

The column end fixtures available in Fritz Laboratory were designed in 1954 for the purpose of pinned-end column testing primarily in the five million pound testing machine. The end fixtures were designed for a maximum load of two million pounds. A detailed description of the equipment and of performance tests is given in Ref. 1.

Figure 1 shows the principal action of the end fixtures, simulating pinned-end conditions. The center of the radius of the cylindrical surface is located at the end of the test column. Thus, the resultant force will always act through this plane and the effective length of the column is equal to the actual length of the column specimen. A review of the procedure for column testing using these end fixtures is given in Ref. 2.

A close-up of the end fixture and a schematic view are shown in Figs. 2 and 3, respectively. The bottom end fixture is illustrated; the end fixture at the top of the column is identical. The major components of the end fixtures are the main cylindrical bearing, the bearing block and the adjusting assembly. The contact surface between the main cylindrical bearing and the bearing block provides for the possibility of the column base to deflect after buckling. This part of the end fixture is hidden behind side plates in Fig. 2; the purpose of the side plates is to keep the end fixture assembled during installation of end fixtures and column specimen in the testing machine. The side plates also prevent any accidental slip in the contact surface at high loads and deflections. The adjusting assembly provides the possibility of centering the load of the column.

No records could be found as to the type of material used for the main cylindrical bearing and the bearing block of the end fixtures. The only specifications refer to the yield point, given as 220 ksi 0.2% proof stress (drawing by A. W. Huber dated June 15, 1954) and to the surface hardness, given as 70-80 Scleroscope.[1] The hardness value corresponds to a tensile strength of the order of 300 ksi.[3] Apparently, the actual mechanical properties of these components were never given or measured. All other components except for the main cylindrical bearing and the bearing block are made of ASTM A7 steel with a minimum yield point of 33 ksi.

During the tentative design of new high-capacity end fixtures intended for the testing of heavy columns with a carrying capacity of up to 8 million pounds, it was realized that the actual capacity of the present end fixtures might be considerably higher than the design load of 2 million pounds. In order to determine the actual capacity it was necessary that some kind of mechanical testing be made of the critical parts, that is, the main cylindrical bearing and the bearing block. Obviously, only non-destructive testing methods could be considered and for this reason hardness tests were regarded as a possible and suitable testing procedure.

TEST PROCEDURE AND RESULTS

The major components of both top and bottom end fixtures were dismantled to allow testing on the contact surfaces. A portable Brinell testing instrument was used (King Portable Brinell; 3000 kg; 10 mm ball; instrument marked: Andrew King, Cons. Eng., Narberth, Pa.; U.S. Gauge 13335). In the Brinell test, a hardened steel ball is applied to the test surface using a specified load. The diameter of the intendation is measured with a special microscope and is a measure of the hardness of the material--the smaller the diameter of the intendation, the harder the material. Using standard tables the value of the diameter can also be converted to tensile strength.(4) Table 1, taken from the instruction folder to the particular instrument used for the measurements, gives the correlation between the measured diameter, the Brinell hardness, and the tensile strength in the range of interest here. The conversion is close to that given in Ref. 4.

A total number of 84 measurements were carried out on both sides of the four components. The location of the test points and the Brinell hardness numbers for all measurements are given in Figs. 4 through 7. The tensile strength as obtained from the conversion table is given in Figs. 8 through 11. The data has been summarized in Table 2.

The highest and lowest readings recorded correspondsto 354 ksi and 165 ksi, respectively. The maximum variation in readings obtained on a single specimen is approximately 140 ksi. The variation is partly due to actual hardness variation from point to point and for different sides of the specimen and partly due to the inaccuracies involved in the measurements.

For the main cylindrical bearing readings could be taken along the center-line at the ends only. At other points accurate readings were not possible because of the non-parallel surfaces and limitations of the equipment. While it can be expected that the strength of the thinner material at the edges of the bearing surface is higher than recorded along the center-line, this is not significant since the contact surface for practical deflections will remain close to the center-line.

It should be noted that the bearing blocks are symmetrical. It would therefore be possible to turn them in such a way that the face with the highest strength be placed on the rocking surface where the stresses are highest. Thus, the lowest reading of 165 ksi on one surface of the bearing block of end fixture B could be avoided on the rocking surface by placing this particular surface away from the rocking surface.

Arranging the bearing block in the most effective way will lead to a lowest average of 225 ksi and an overall average of approx. 240 ksi on all contact surfaces. Assuming $\frac{\sigma_{0.2}}{\sigma_u} = 0.9$ (this is expected to lead to a $\sigma_{0.2}$ value on the safe side for this kind of hardened steels), $\sigma_{0.2}$ of approx. 200 and 220 ksi, respectively, is obtained.

THEORETICAL CONSIDERATIONS

The purpose of this section is to determine the allowable load as obtained from various design specifications and to estimate the actual capacity of the end fixtures. The yield point was chosen to be 220 ksi and 200 ksi, corresponding to the estimated overall average on contact surfaces and lowest average on a single contact surface, respectively.

The equation given by the AASHO Specifications[5] to compute the allowable load for the contact surface between the main cylindrical bearing and the bearing block can be written

$$P_{allow.} = \frac{\sigma_y - 13\ 000}{20\ 000}\ 600DL \qquad (1)$$

where σ_y is yield strength in tension (psi), D is diameter of roller (inch) and L is length of roller (D<25inch).

Inserting D=20 inches and L=24 inches gives

$P_{allow.} = 3.0*10^6$ lb for σ_y = 220 000 psi

and $P_{allow.} = 2.7*10^6$ lb for σ_y = 200 000 psi

The AISC Specification[6] gives

$$P_{allow.} = \frac{\sigma_y - 13\ 000}{20\ 000}\ 660DL \qquad (2)$$

or

$$P_{allow.} = 3.3*10^6 \text{ lb for } \sigma_y = 220\,000 \text{ psi}$$

and

$$P_{allow.} = 3.0*10^6 \text{ lb for } \sigma_y = 200\,000 \text{ psi}$$

The local bearing stress at the contact area between the main cylindrical bearing and the bearing block is[7]

$$\sigma_{Hertz} = 0.591\sqrt{\frac{PE}{DL}} \quad (3)$$

where P is load (psi), E is elastic modulus (psi), D is diameter of roller (inch), and L is length of roller (inch). It is further assumed that Poisson's ratio is equal to 0.3. Inserting numerical values for E, D, and L gives

$$\sigma_{Hertz} = 148\sqrt{P} \quad (4)$$

According to investigations referred to in Ref. 7 appreciable permanent set, that is, a spread of 0.001 in/in, is produced by a load corresponding to a stress of

$$\sigma_{Hertz} = 1.66\,\sigma_y \text{ to } 1.72\,\sigma_y \text{ for } \frac{D}{L} = 0.1 \text{ to } 10,$$ respectively (Jensen and Roark),

and in another investigation

$$\sigma_{Hertz} = 1.65\,\sigma_u$$ (Whittemore).

Assuming a permanent deformation when $\sigma_{Hertz} > 1.5\,\sigma_u$ in this case, Eq. (4) will give a relation between the load causing permanent set and the tensile strength of the material

$$P_u = 110\left(\frac{\sigma_u}{1\ 000}\right)^2 \tag{5}$$

For σ_u = 240 000 psi and 225 000 psi as indicated from the hardness tests, Eq. (5) gives P_u equal to 6.4 and 5.6 million pounds, respectively.

A basis for a judgement on the influence of the variation in mechanical properties of the critical components can be found in Figs. 12 and 13. The individual hardness readings on the critical surfaces (assuming the bearing block of end fixture A to be turned over as explained above) have been converted to tensile strength in Fig. 12 and to ultimate load applying Eq. (5) in Fig. 13. The lowest hardness reading, corresponding to a tensile strength of 193 ksi, gives an ultimate load of 4.1 million pounds. The highest reading, 354 ksi, corresponds to over 13 million pounds.

Since the yield strength of the fixture plate and wedges adjacent to the bearing components (see Fig. 3) is much lower than the strength of the bearing components (σ_y = 33 ksi versus approx. 200 ksi) the stress should be checked for these elements. According to the AISC Specification(6) the allowable force is

$$P_{allow} = 0.90\ \sigma_y\ BL \tag{6}$$

Assuming that the bearing on the rocking surface is distributed along 45° angles, the width B of the contact area considered is

$$B = 2t \, tg \, 45° + b \qquad (7)$$

where t is the thickness of the element between the contact surface considered and the rocking surface and b is the width of the bearing area on the rocking surface. Inserting t equal to 4 inches and assuming safely that b is equal to 0 gives B equal to 8 inches. The allowable force according to Eq. (6) is then 5.7*10 lb. This load is higher than the allowable load for the rocking surface as computed above.

SUMMARY

During the design of new high-capacity end fixtures intended for the testing of heavy columns with a carrying capacity of up to 8 million pounds, it was realized that the actual capacity of the present end fixtures might be considerably higher than the design load of 2 million pounds. In order to determine the actual capacity, Brinell hardness tests were made on the critical parts of the end fixtures, that is, the main cylindrical bearing and the bearing block.

The hardness tests have indicated that the tensile strength of the critical components of the end fixtures is approx. 240 ksi (overall average for all bearing contact surfaces) with a lowest average of 225 ksi for the individual surfaces. The hardness of the surface designated "opposite surface" of the bearing block of end fixture B indicates a higher strength on this surface than on the present "bearing surface". It has been anticipated here that this block is turned over to provide maximum strength.

Assuming that $\frac{\sigma_{0.2}}{\sigma_u} = 0.9$ for this hardened steel the yield strength ($\sigma_{0.2}$) corresponding to the above values for tensile strength is 220 ksi and 200 ksi, respectively. The allowable load according to the AISC Specification is 3.0 million pounds if $\sigma_{0.2} = 200$ ksi.

Estimates on the ultimate load indicate, from the limited information available, that the load corresponding to appreciable permanent set of the critical components is of the order of 5-6 million pounds. The lowest single reading on the critical components, 193 ksi tensile strength, corresponds to an ultimate load of 4.1 million pounds.

It appears from this study that the design load of 2 million pounds is unnecessary low. A maximum load of 3 million pounds, or possibly even slightly higher, seems feasable. This would mean an increase of 50 percent or more over the current maximum load. The increased load capacity would be applicable to centric loading only. In tests with intentional excentricities and/or high shear forces at the end of the column, the maximum capacity is dependent upon the actual loading conditions, and for tests at high loads the capacity should be estimated for the particular loading conditions.

Subsequent column tests have been carried out up to a load of slightly more than 2.5 million pounds. No permanent deformation could be observed after the test. If column tests are to be made at loads above 2.5 million pounds, the initial test should be made carefully with small load increments and continuous observation of the bearing surfaces of the end fixtures.

ACKNOWLEDGMENTS

The report presents the results of an investigation carried out in conjunction with a study on column testing of heavy shapes at Fritz Engineering Laboratory, Lehigh University. The study is part of a research project "Residual Stresses in Thick Welded Plates", sponsored by the National Science Foundation. Lambert Tall is Principal Investigator of the project, and thanks are due him for fruitful discussions during this investigation. The report was typed by Miss Joanne Mies.

TABLE AND FIGURES

TABLE 1

Hardness Conversion Numbers for Steel

Diameter of Indentation (mm)	Brinell Hardness Number (BHN)	Tensile Strength (ksi)
2.30	713	354
2.35	683	341
2.40	652	329
2.45	627	317
2.50	600	305
2.55	578	295
2.60	555	284
2.65	532	273
2.70	512	263
2.75	495	253
2.80	477	242
2.85	460	233
2.90	444	221
2.95	430	211
3.00	418	202
3.05	402	193
3.10	387	185
3.15	375	178
3.20	364	171
3.25	351	165

TABLE 2

Summary of Tensile Strength as Obtained from Hardness Tests

Specimen			Tensile Strength, ksi				
End Fixture	Component	Surface	Highest	Lowest	Mean	Median	Standard Dev.
A	Bearing Block	Bearing	305	211	240	235	20
A	Bearing Block	Opposite	317	193	245	250	35
A	Main Cylindrical Bearing	Bearing	263	193	225	220	--
A	Main Cylindrical Bearing	Opposite	221	202	210	210	10
B	Bearing Block	Bearing	295	165	230	235	35
B	Bearing Block	Opposite	354	211	260	255	35
B	Main Cylindrical Bearing	Bearing	263	233	250	250	--
B	Main Cylindrical Bearing	Opposite	242	211	225	220	--

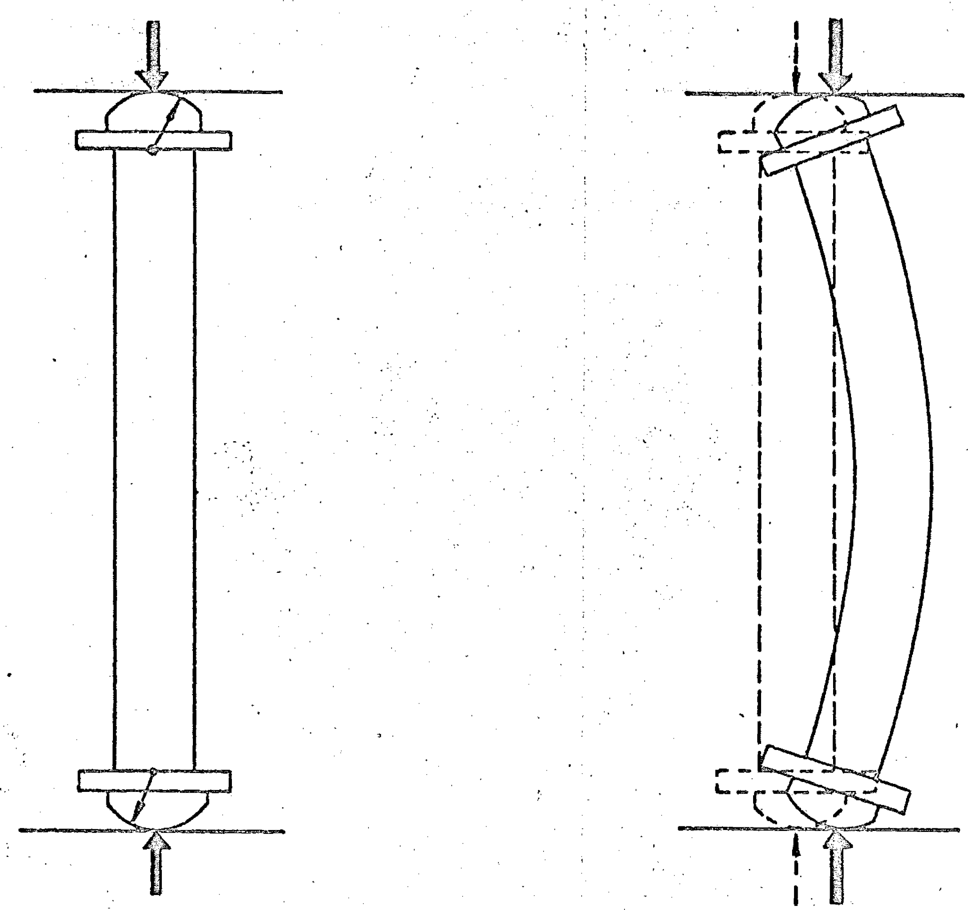


Fig. 1 Principle for end fixture action

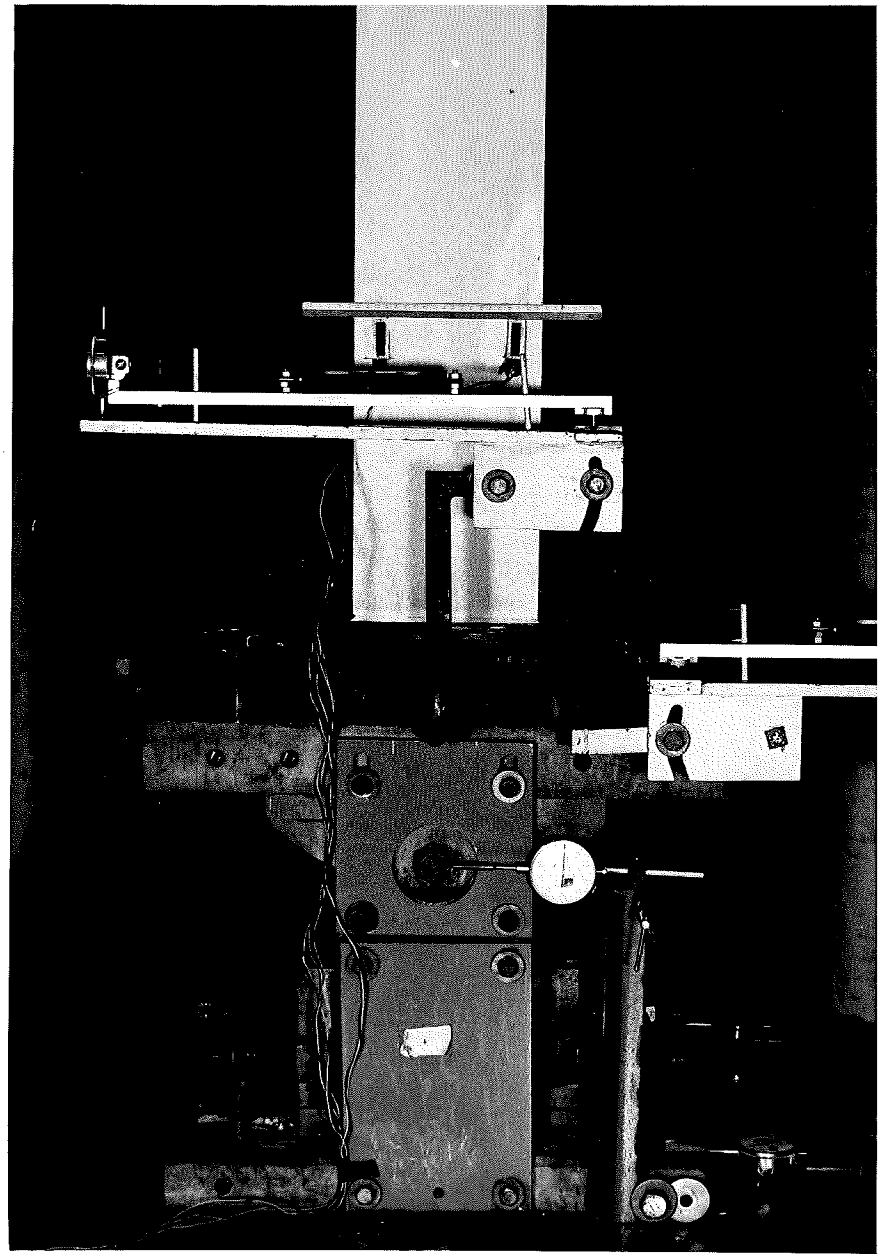


Fig. 2 Close-up of end fixture (bottom)

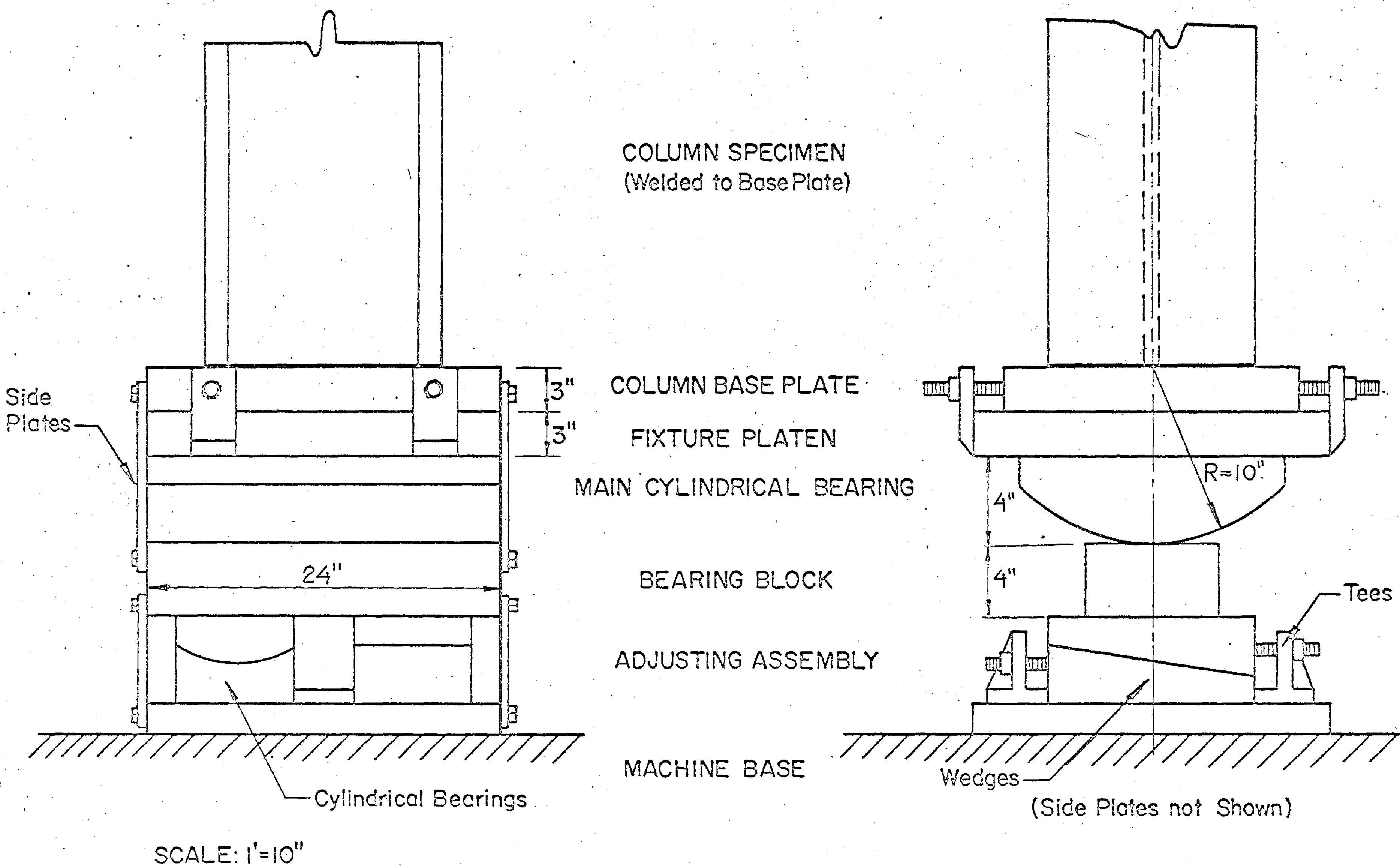
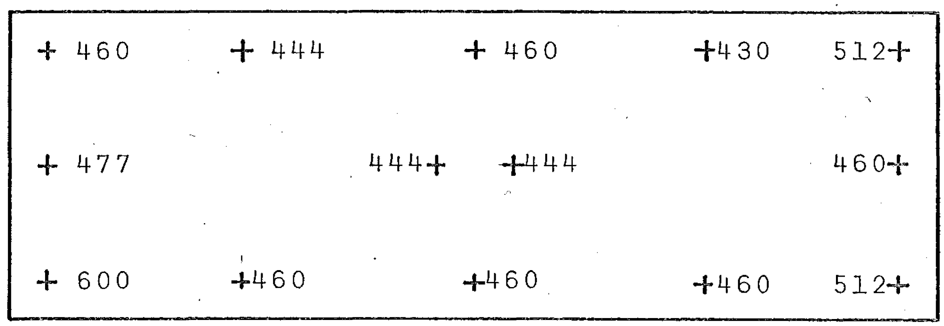
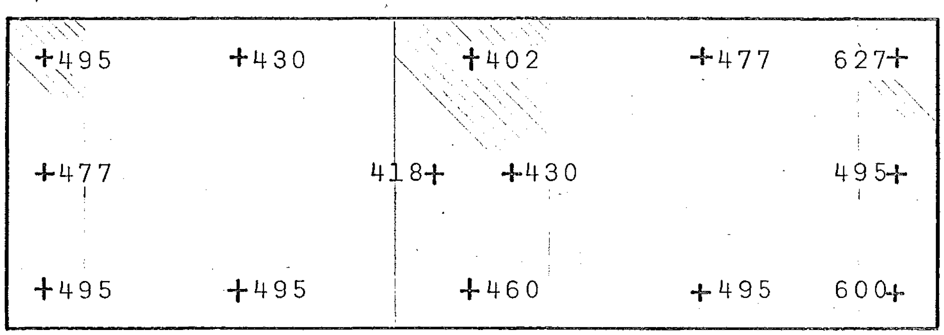


Fig. 3 Schematic view of end fixture

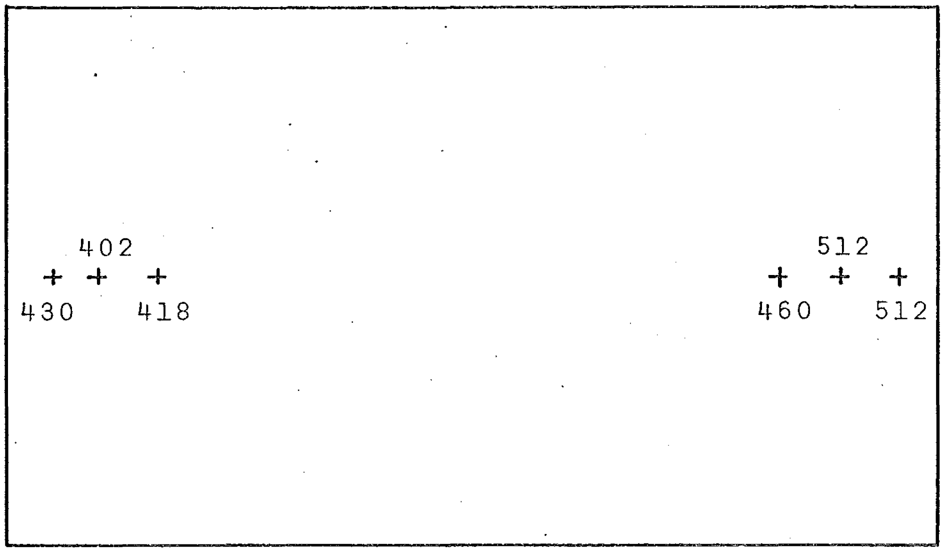


a) Bearing Surface

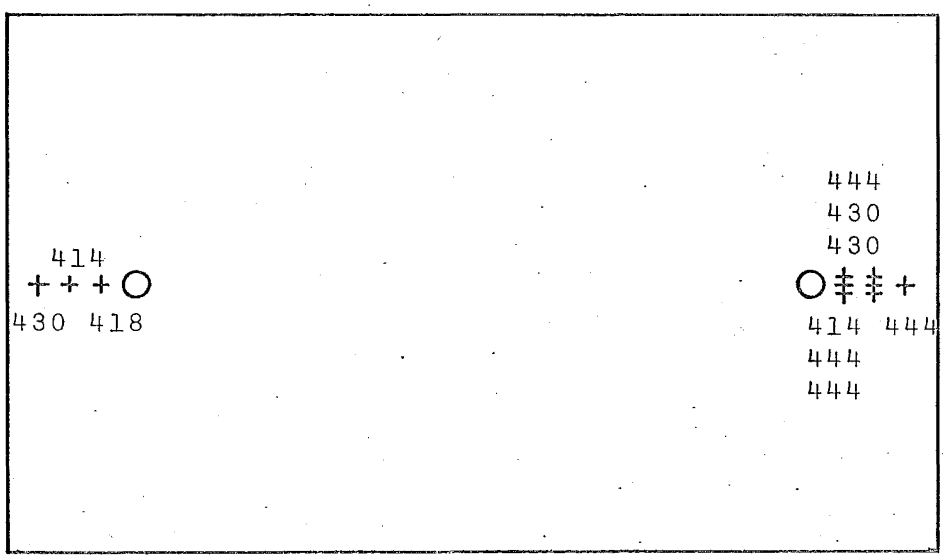


b) Opposite Surface

Fig. 4 Brinell tests on bearing block, end fixture A. Values in BHN.

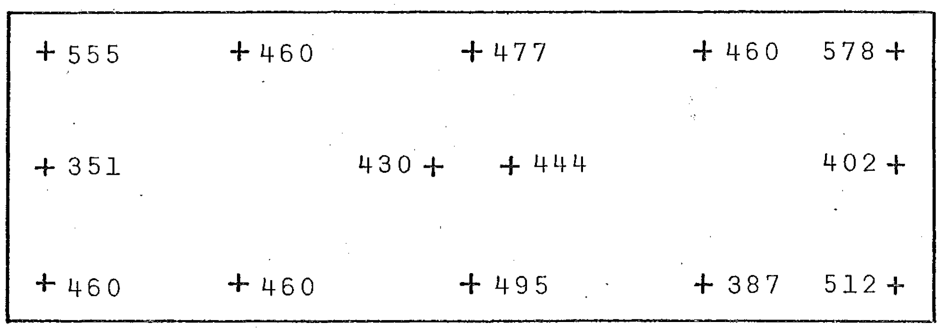


a) Bearing Surface

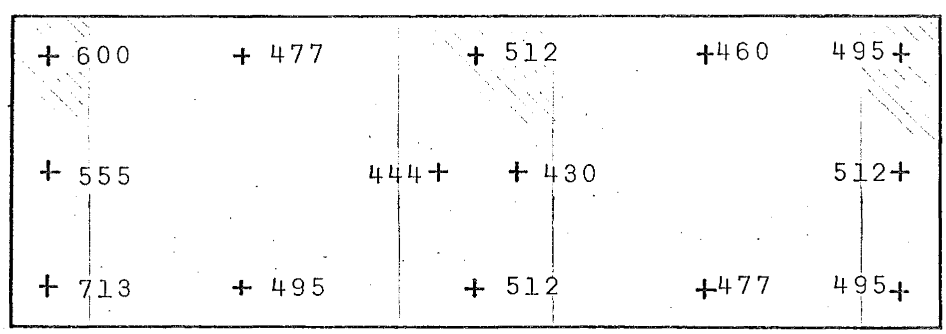


b) Opposite Surface

Fig. 5 Brinell tests on main cylindrical bearing, end fixture A. Values in BHN.

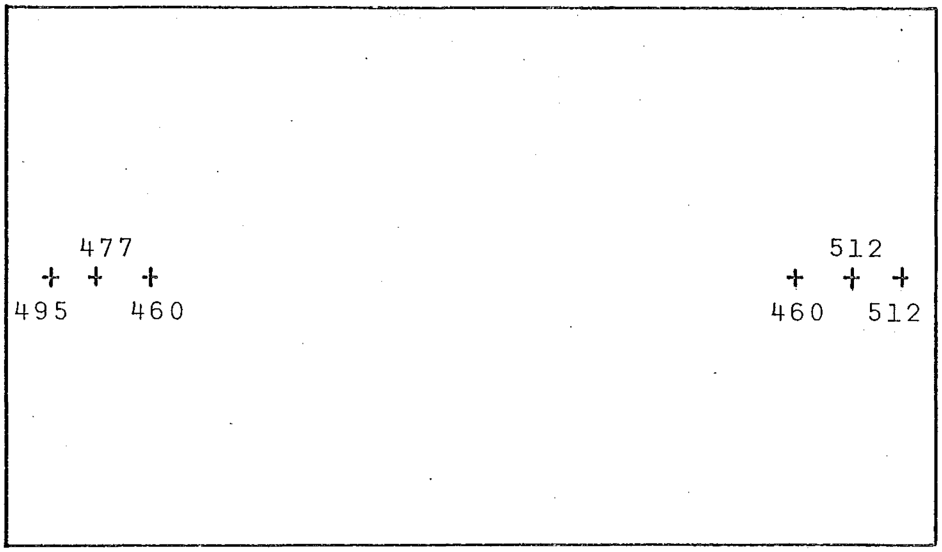


a) Bearing Surface

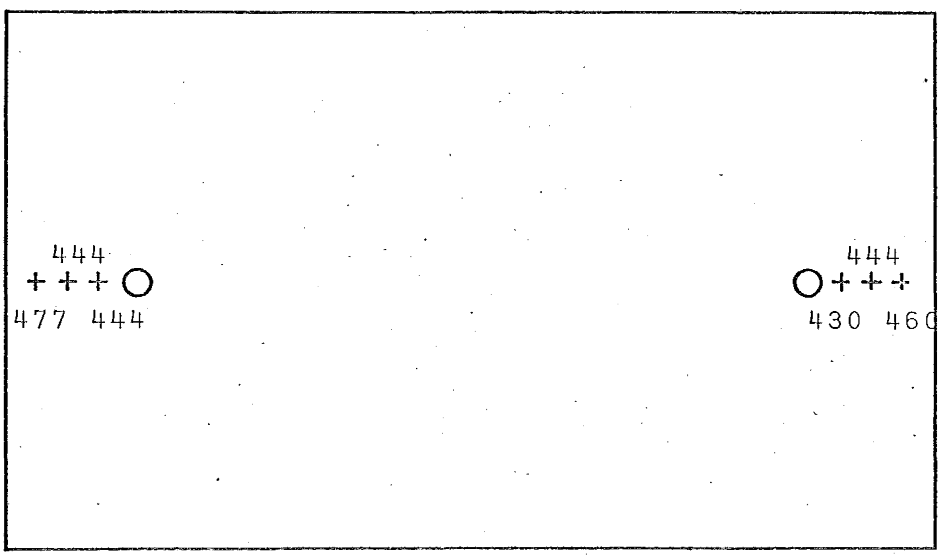


b) Opposite Surface

Fig. 6 Brinell tests on bearing block, end fixture B. Values in BHN.



a) Bearing Surface



b) Opposite Surface

Fig. 7 Brinell tests on main cylindrical bearing, end fixture B. Values in BHN.

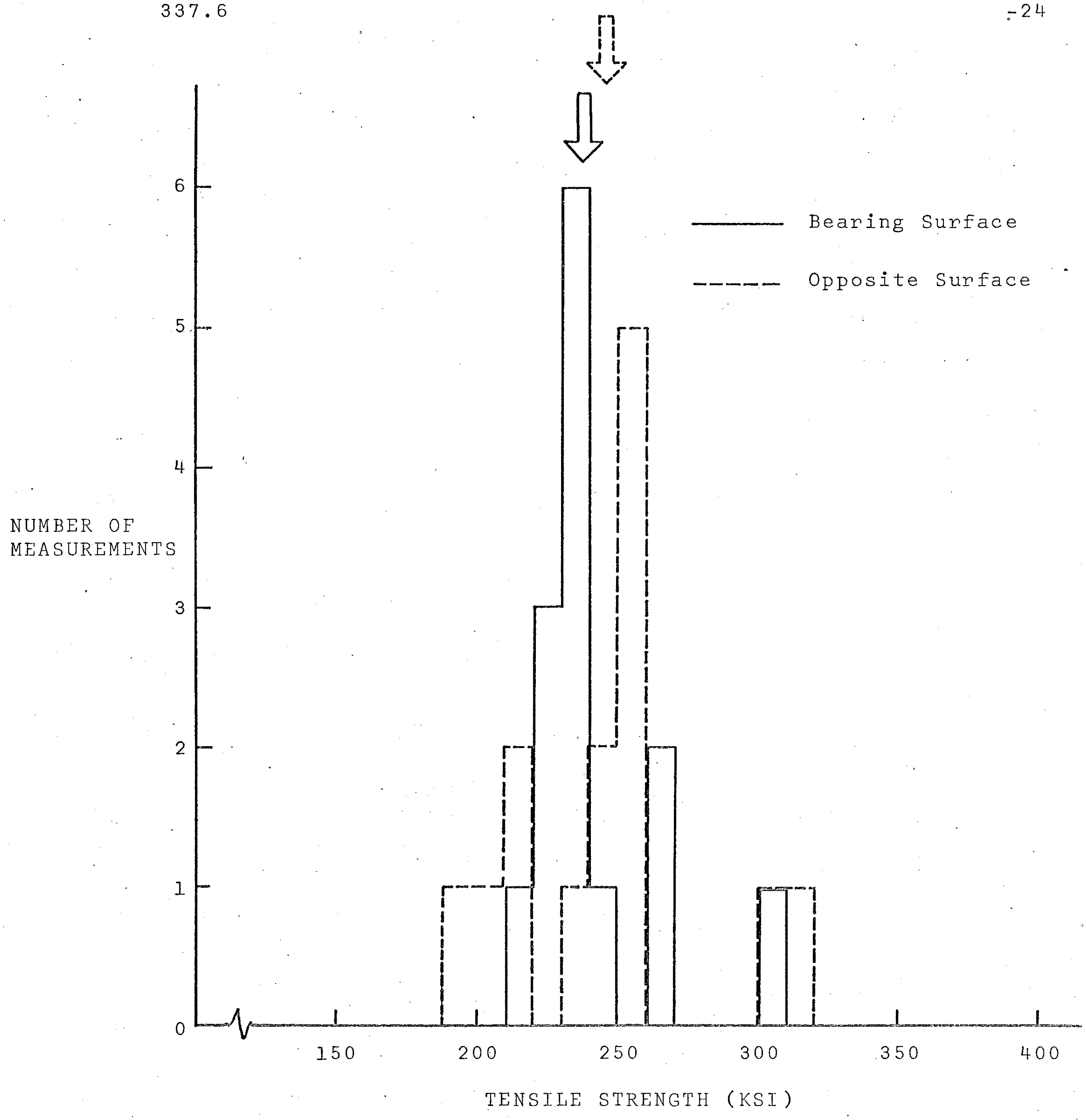


Fig. 8 Tensile strength of bearing block, end fixture A. Arrows indicate mean values.

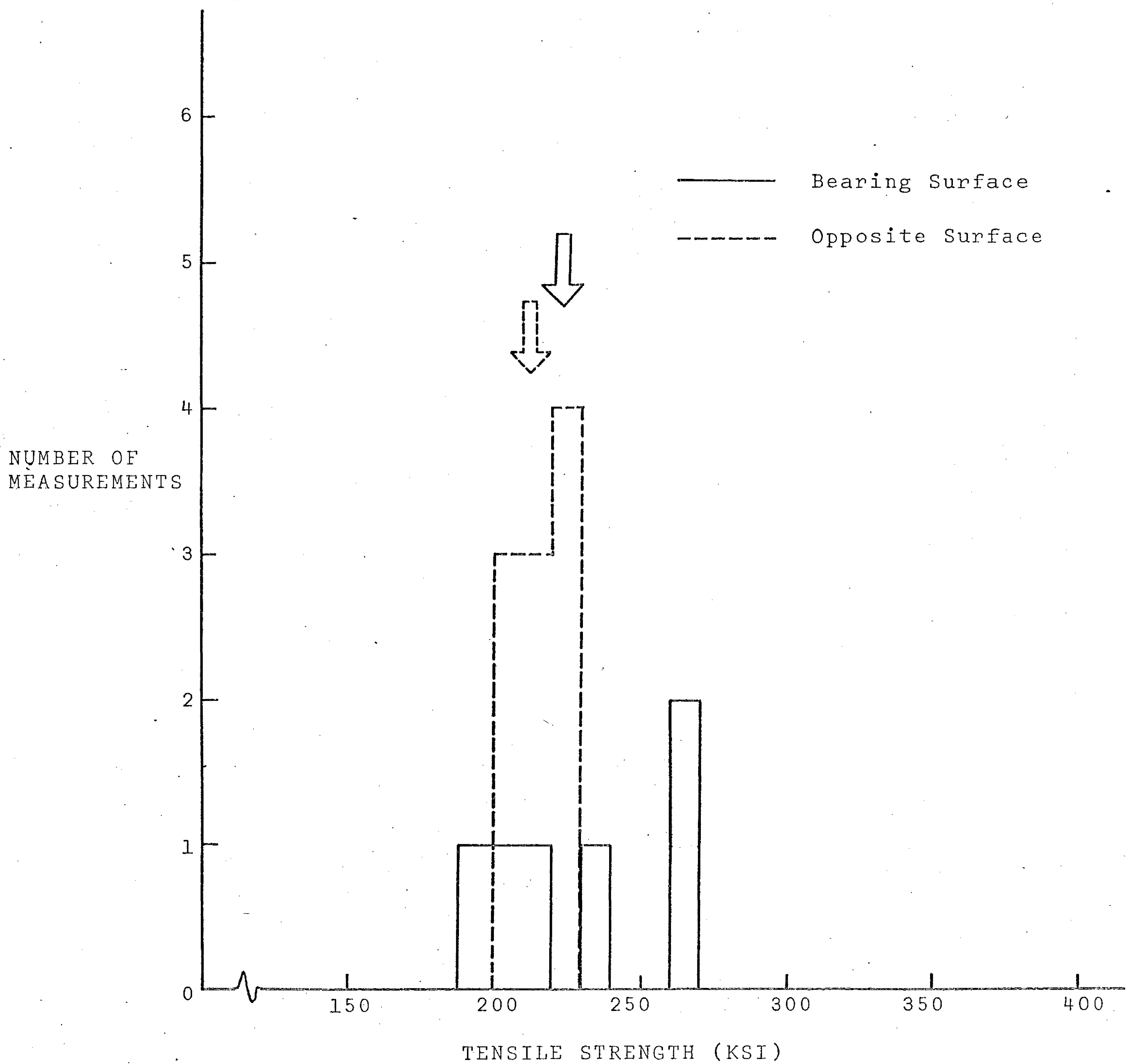


Fig. 9 Tensile strength of main cylindrical bearing, end fixture A. Arrows indicate mean values.

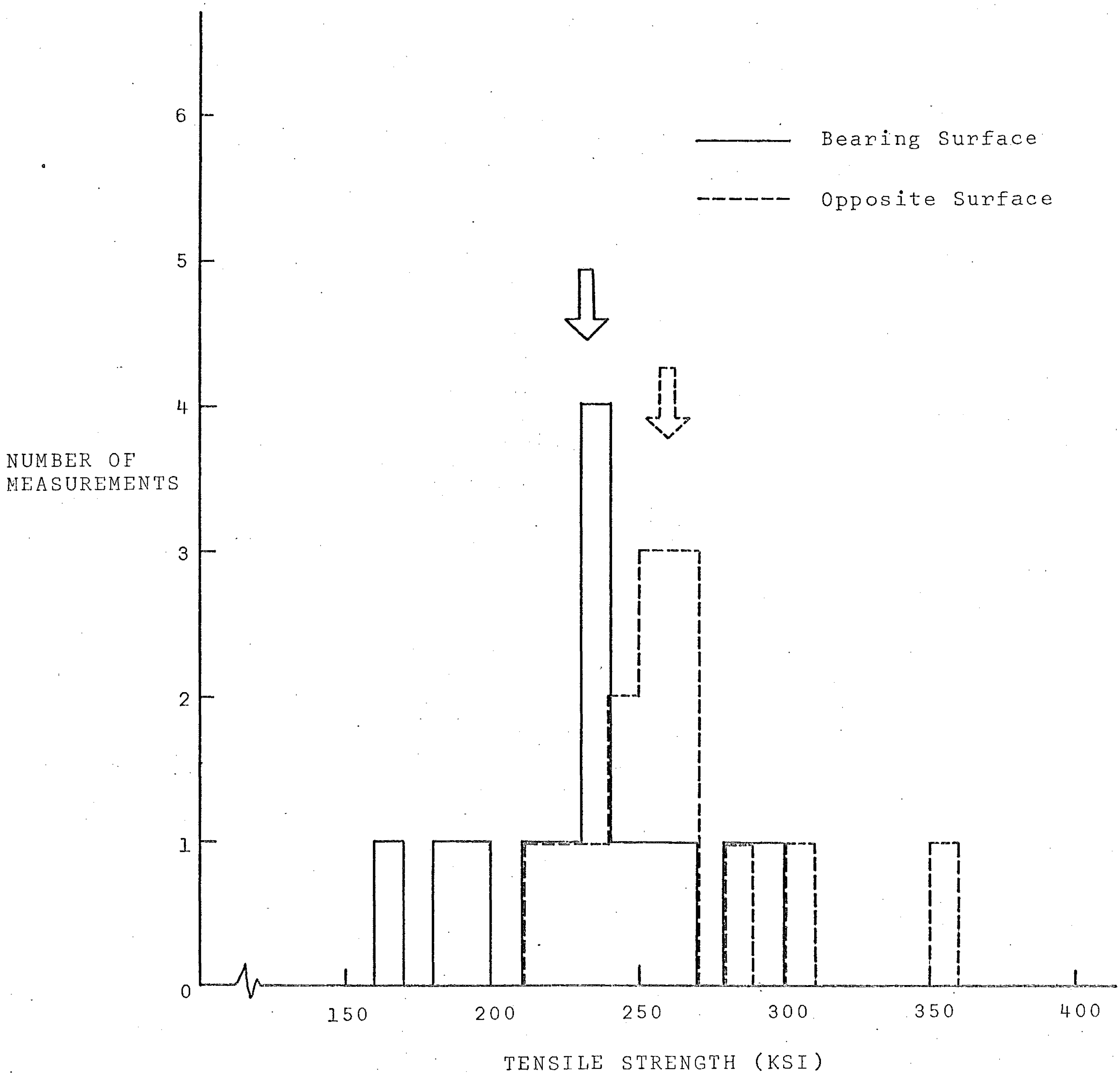


Fig. 10 Tensile strength of bearing block, end fixture B. Arrows indicate mean values.

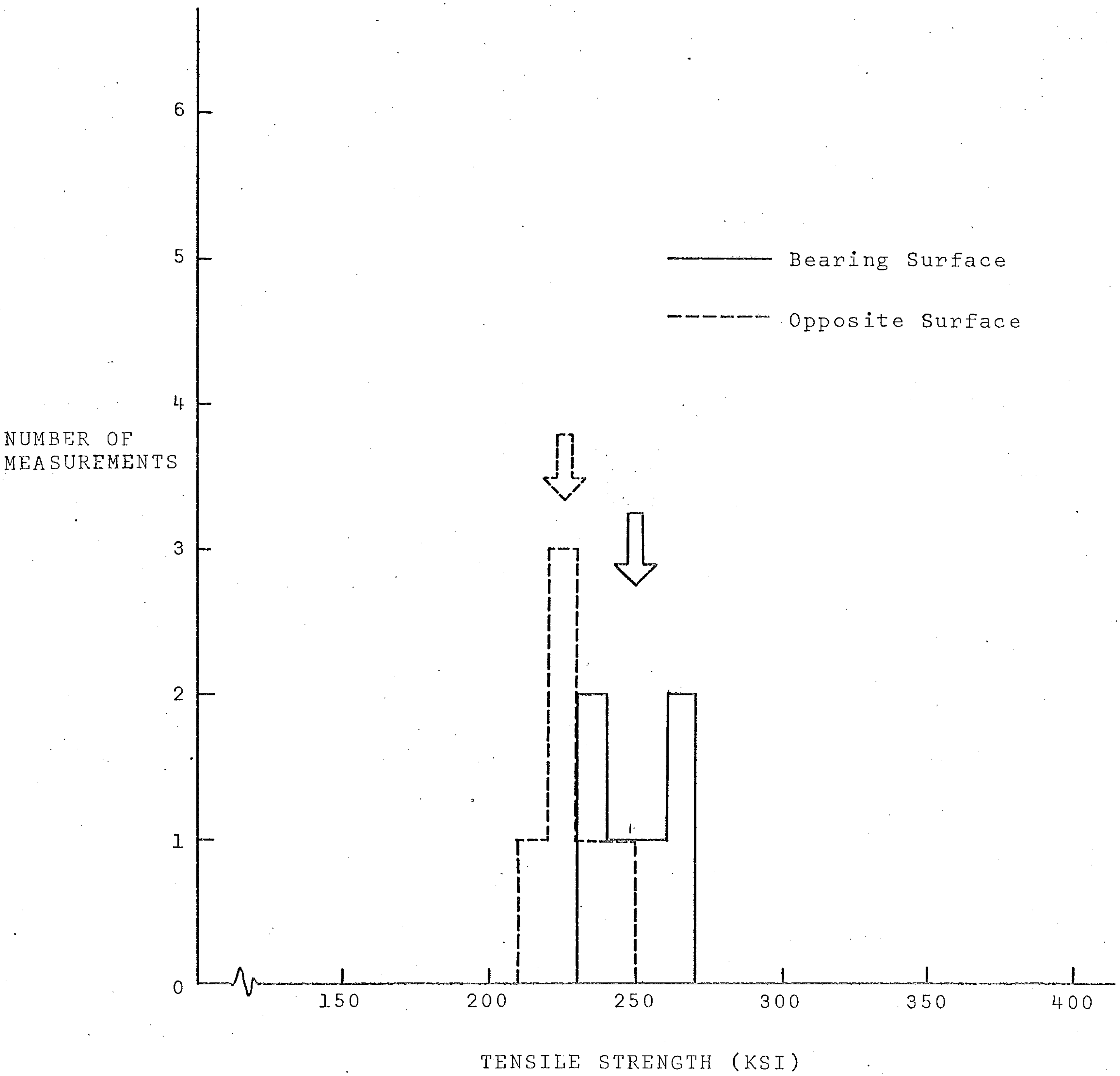


Fig. 11 Tensile strength of main cylindrical bearing, end fixture B. Arrows indicate mean values.

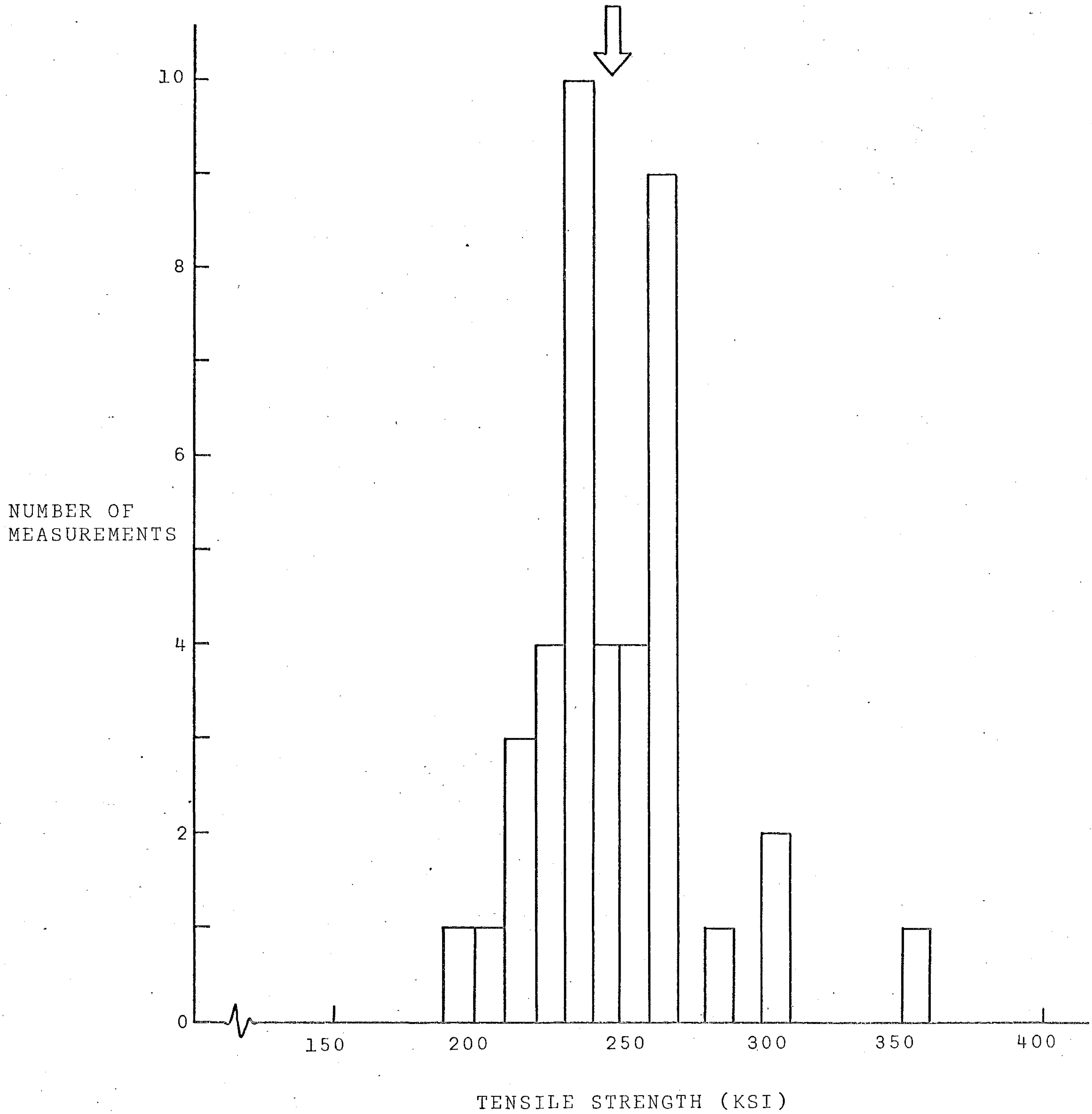


Fig. 12 Tensile strength of all critical bearing surfaces (assuming the bearing block of end fixture A is turned over). Arrow indicates mean value.

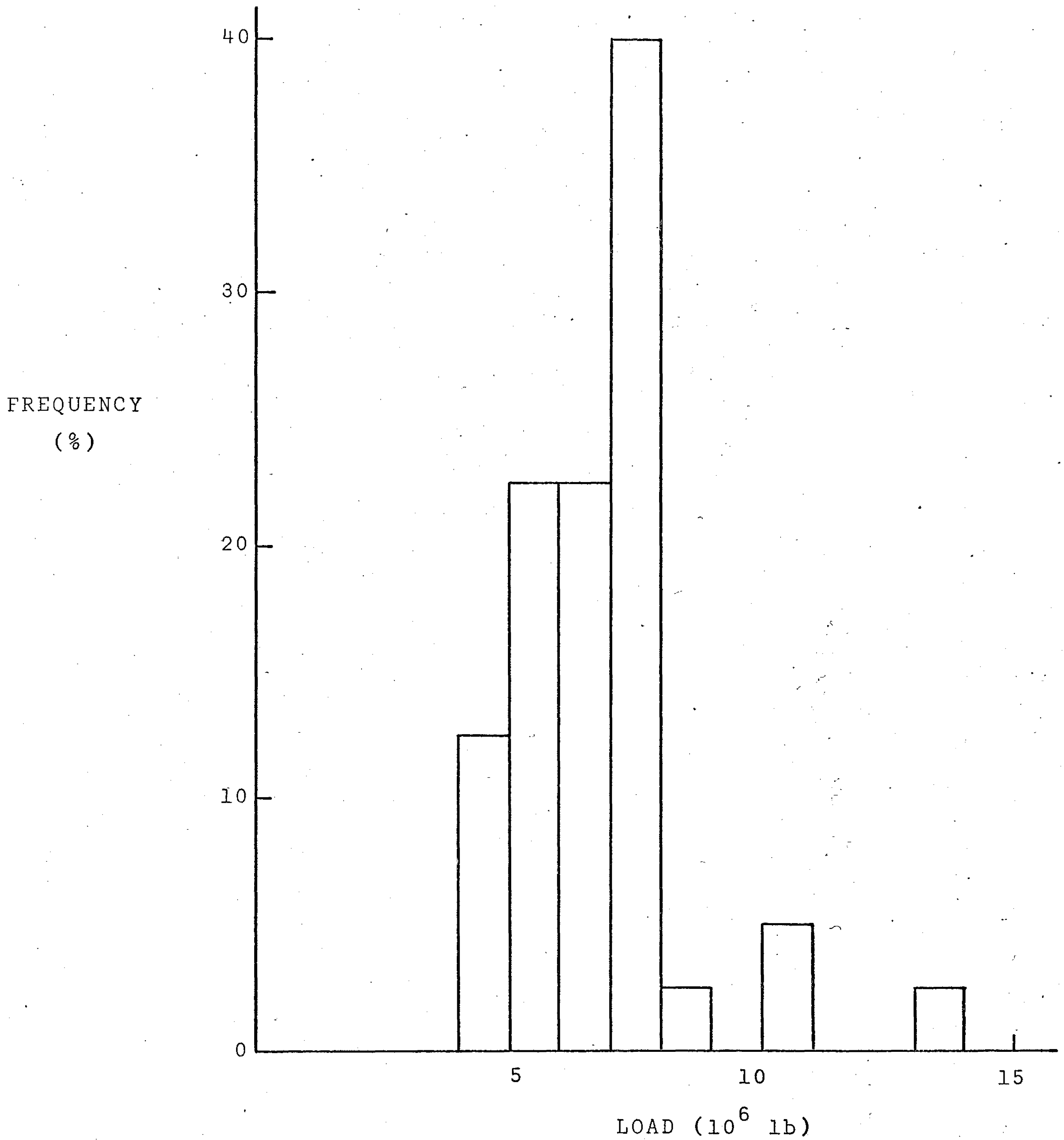


Fig. 13 Loads causing permanent deformation as determined from the different hardness readings (Fig. 8 through 11) and Eq. (5).

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