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DEAD-WEIGHT MACHINES OF 111,000- AND 10,100-POUND CAPACITIES

By

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PREFACE

The calibration of testing machines, for applying forces to specimens of engineering materials and structures, has long been recognized as an important problem by both producers and users of engineering materials. Many methods of calibration have been devised for calibrating small testing machines, but only by means of elastic calibration devices can the larger testing machines be calibrated to capacity. The development at the National Bureau of Standards of the proving ring, one type of elastic calibration device, resulted in a greatly increased use of elastic calibration devices and made necessary the provision of facilities for the calibration of such devices. The two dead-weight machines described in this Circular were designed and installed to calibrate such devices. In these machines the accurately known tensile or compressive forces necessary for the calibration of elastic devices may be applied.

Lyman J. Briggs, *Director.*

DEAD-WEIGHT MACHINES OF 111,000 AND 10,100-POUND CAPACITIES

By Bruce L. Wilson, Douglas R. Tate, and George Borkowski

A dead-weight testing machine of 102,000-lb capacity was installed at the National Bureau of Standards in 1927 to provide means for calibrating elastic calibration devices, which are used to calibrate force-indicating testing machines. To obtain a larger number of test loads the original machine was altered by the addition of nine 1,000-lb weights and an operating mechanism. To obtain the smaller test loads necessary for the calibration of elastic calibration devices having smaller capacities a new machine of 10,100-lb capacity was installed. The two machines are described and the errors of the weights of the machines are discussed.

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I. INTRODUCTION

To meet the increasing need for determining the errors in the force indications of testing machines used for determining the strength and other properties of structural materials, the Whittemore-Petrenko proving ring,[1] one type of elastic calibration device, was developed. Briefly, this device consists of a heat-treated steel ring having integral external bosses through which forces are applied to the ring and integral internal bosses to which a vibrating reed and micrometer screw deflection-measuring apparatus is attached. The deflection of such a ring bears a definite relationship to the applied load. After this relationship has been determined by applying accurately known forces to the ring in dead-weight machines,[2] the ring may be used to determine the errors of the indicated loads of testing machines. The development of the proving ring, which made available a convenient, accurate, portable calibrating device, led to a greatly increased use of elastic calibration devices, displacing some of the other methods of calibration which are outlined in the American Society for Testing Materials Standard Methods of Verification of Testing Machines.[3]

[1] Proving ring. U. S. Patents 1,648,375 and 1,927,478, issued to H. L. Whittemore and S. N. Petrenko.
[2] L. B. Tuckerman, H. L. Whittemore, and S. N. Petrenko, *A new dead-weight testing machine of 100,000-pounds capacity*, BS J. Research 4, 261 (1930) RP147.
[3] Am. Soc. Testing Materials Standards I, 889 (1942).

They are used for the original adjustment of the weighing systems of new machines and for the regular recalibration of machines. This has led to a greatly increased demand for the calibration of elastic calibration devices by the National Bureau of Standards.

Experience in using the 102,000-lb-capacity dead-weight machine installed at the Bureau in 1927 (see footnote 2) indicated the necessity of applying 8 or 10 different test loads to determine with sufficient accuracy the relationship between the load and the deflection of an elastic calibration device. With this original machine only 11 test loads from 2,000 lb to 102,000 lb by 10,000-lb increments could be applied. It was, therefore, not adequate for calibrating devices having capacities less than about 100,000 lb.

To provide adequate facilities for calibrating elastic devices having capacities less than 100,000 lb, the original machine was altered, and a new, smaller machine was installed. With the large machine, test loads from 2,000 lb to 111,000 lb by 1,000-lb increments may now be applied. With the small machine, test loads from 200 lb to 10,100 lb by 100-lb increments may be applied.

The machines are suitable for calibrating elastic calibration devices, but they are not suitable for determining the strengths of materials or structures.

II. DESCRIPTION OF THE 111,000-POUND-CAPACITY MACHINE

A diagrammatic sketch of the 111,000-lb-capacity dead-weight machine is shown in figure 1. Drawings of the weight linkages and bevel seats are shown in figure 2, and the machine is shown in figures 3, 4, 5, and 6.

The machine (fig. 1) consists essentially of a hydraulic jack, an upper and a lower frame, and flat cylindrical weights. The weights, not all of which are shown in the sketch, may be applied to the lower frame. The upper frame is supported by a ball that rests on the ram of the jack. The upper frame is connected to the lower frame only by the elastic calibration device.[4] Loads are applied to the calibration device by raising the upper frame with the jack. The calibration device, being connected between the upper and lower frames, lifts the lower frame and the weights supported by it as the upper frame is raised. The number of 10,000-lb weights applied to the lower frame depends on the height to which the frame is raised. The number of 1,000-lb weights applied to the lower frame is adjusted by means of motor-driven gearing attached to the upper frame.

The machine, which is located in the laboratory of the Bureau's Engineering Mechanics Section, is about 30 feet high by about 12 feet wide. The weights are on the first floor of the laboratory building, the forces are applied to calibration devices on the second floor, and the hydraulic jack for lifting the weights is on the third floor. The room on the second floor through which the frames of the machine pass is equipped with temperature-control apparatus by means of which the temperature may be maintained constant to within $\pm 0.5°$ F.

[4] The term "elastic calibration device" is defined by the American Society for Testing Materials (see footnote 3) as follows:

"An elastic calibration device for use in verifying the load readings of a testing machine consists of an elastic member to which loads may be applied combined with a mechanism for indicating the magnitude of deformation under load."

The term "elastic calibration device" includes proving rings, solid bars, hollow bars, elastic loops, and other members whose elastic deformation can be measured.

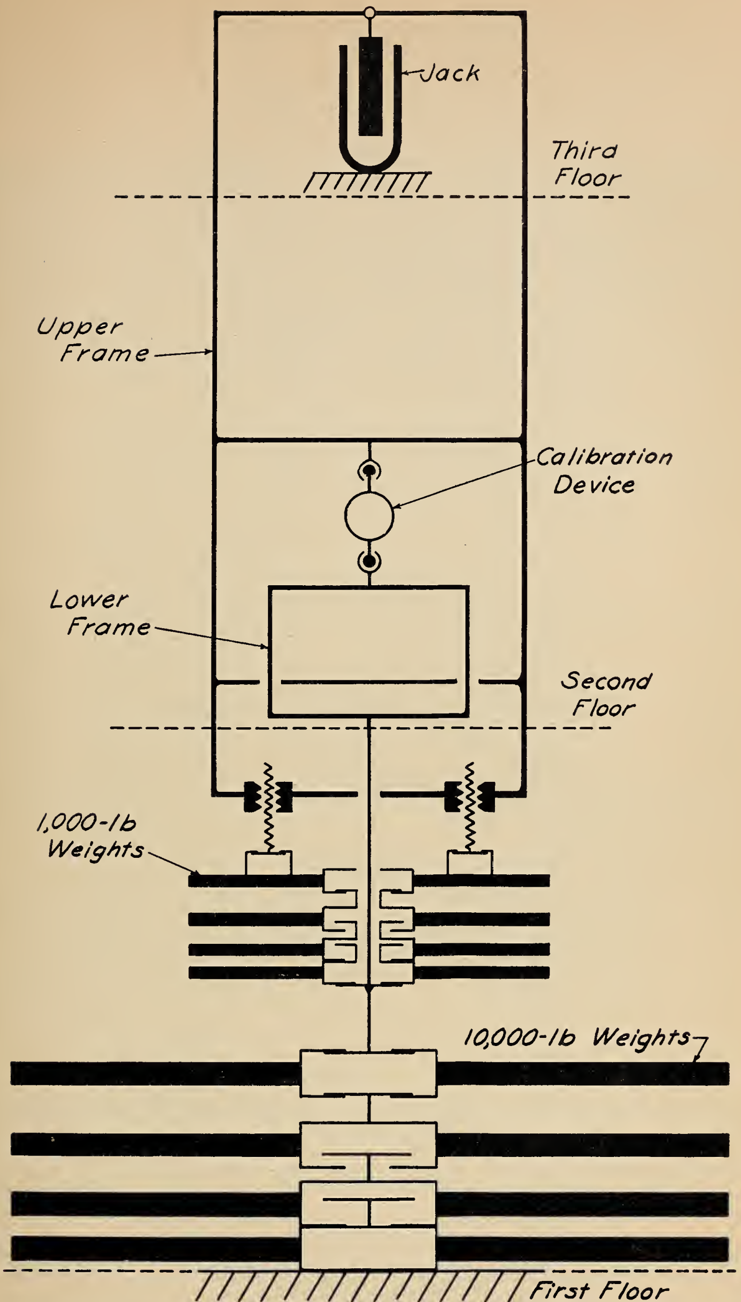

FIGURE 1.—*Diagrammatic sketch of the 111,000-lb-capacity dead-weight machine.*

The machine consists essentially of a hydraulic jack, an upper and a lower frame, and weights that may be applied to the lower frame. Forces are applied to the calibration device, which forms the only connection between the upper and lower frame, by raising the ram of the jack.

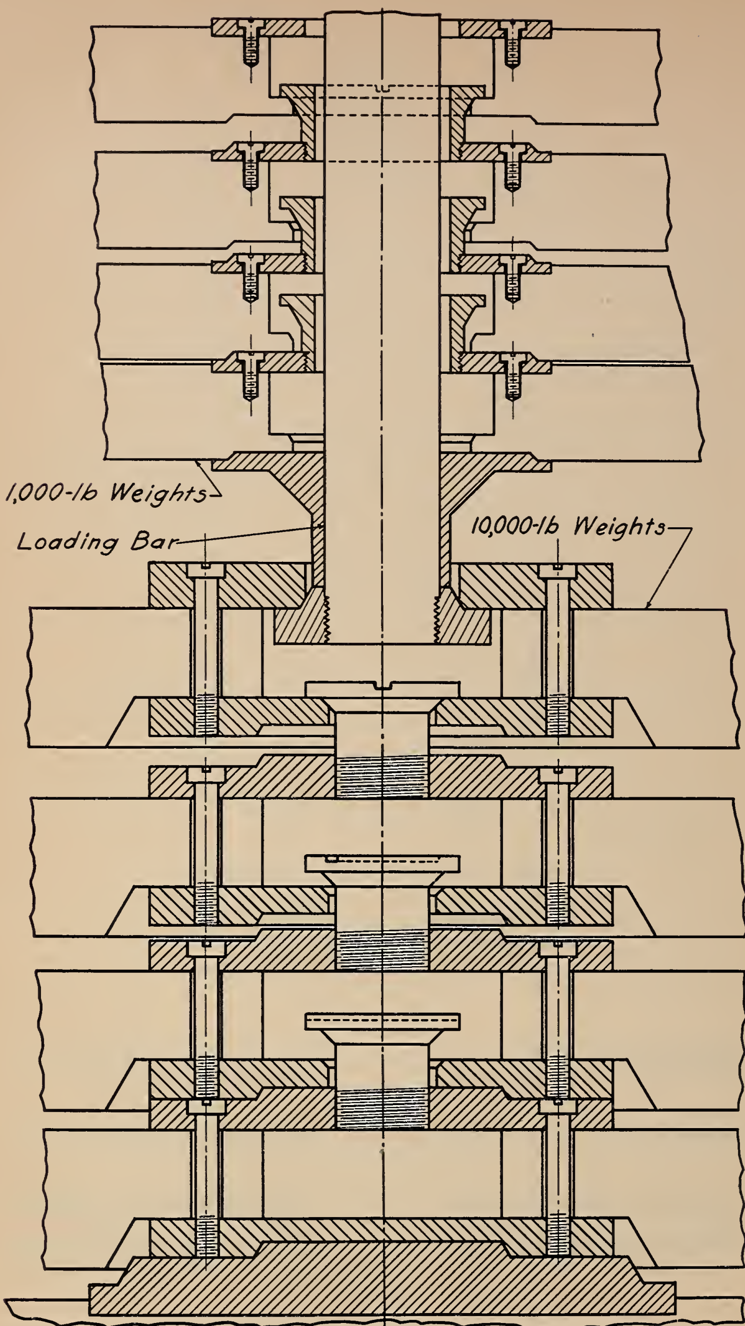

FIGURE 2.—*Bevel seats and weight linkages of the 111,000-lb-capacity dead-weight machine.*

It is normally kept at 70° F. The frame of the machine consists of two reinforced-concrete columns, *A–A* (figs. 3 and 4), which extend from the concrete foundation of the machine to the third floor where two steel **I**-beams, *B* (fig. 6), are placed across the tops of the columns. A bevel seat (fig. 2) for the bottom 10,000-lb weight is built into the

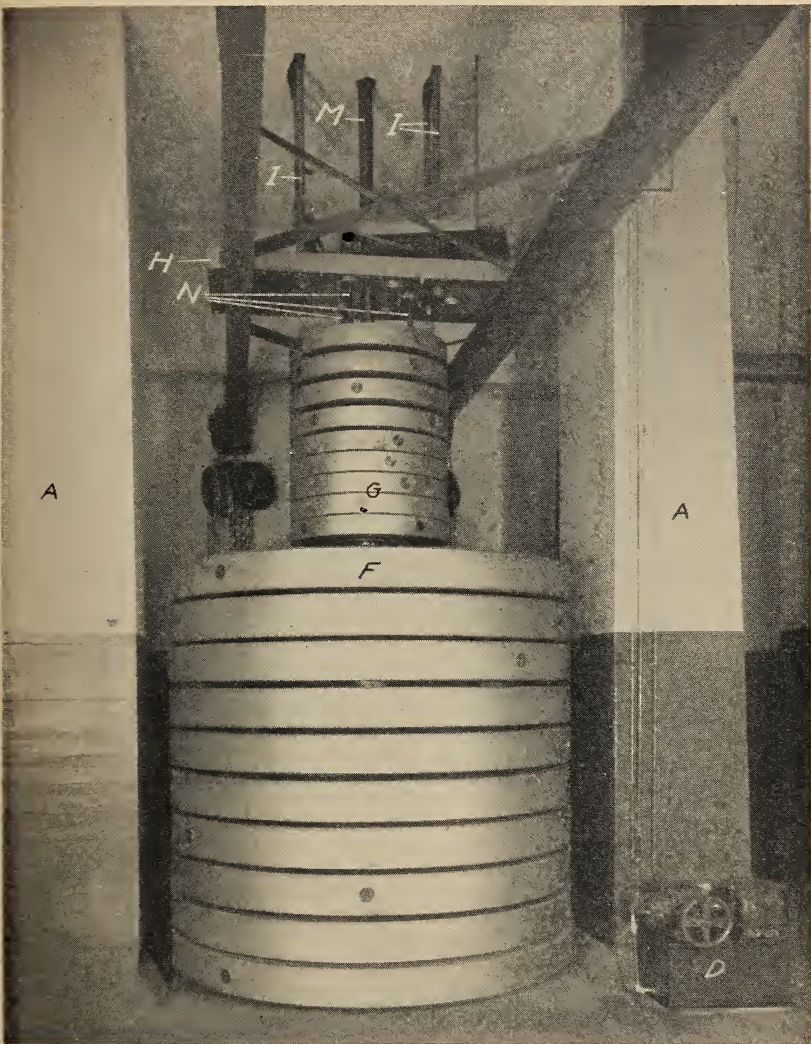

FIGURE 3.—*Part of the 111,000-lb-capacity dead-weight machine located between the first and second floors.*

Any number of the nine 1,000-lb weights, *G*, and the ten 10,000-lb weights, *F*, may be applied to the loading bar, *M*, which is suspended from the lower frame. The two **I**-beams and chain hoists suspended from the second floor are completely independent of the machine. They are used only to lift the weights during disassembly and assembly of the machine.

foundation. The hydraulic jack, *C* (fig. 6), which is operated by an electrically driven multiple cylinder pump, *D* (fig. 3), is supported by the **I**-beams. Control valves and electrical switches for operating the machine are located in the case, *E* (figs. 4 and 5), on the second floor.

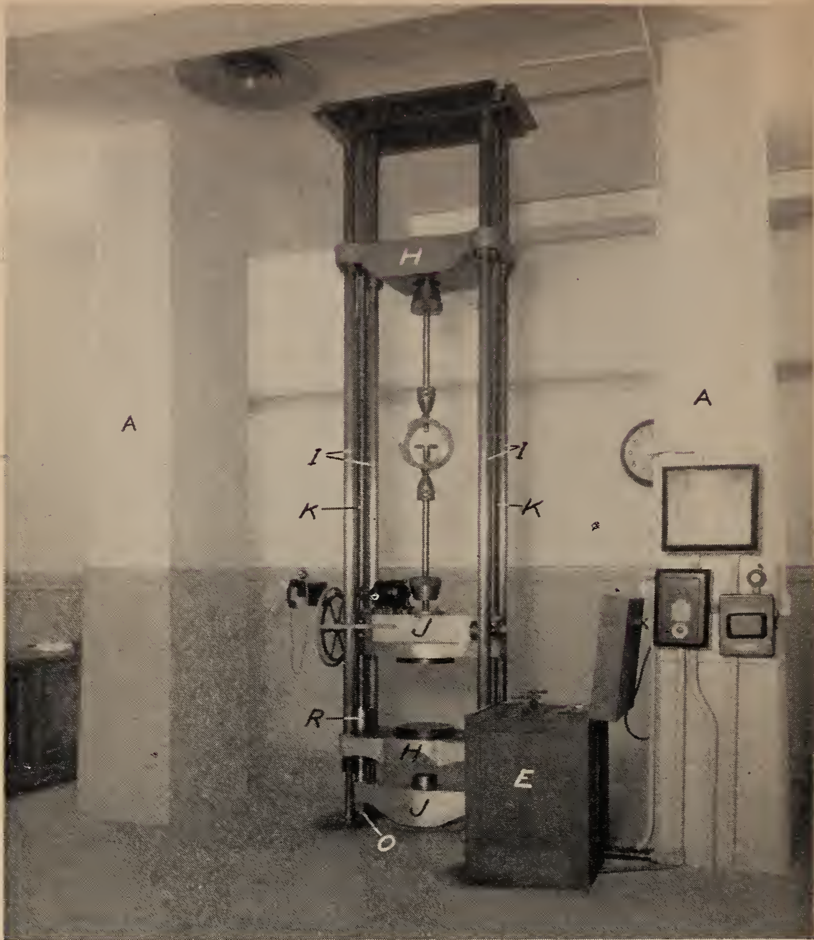

FIGURE 4.—*Part of the 111,000-lb-capacity dead-weight machine located between the second and third floors.*

The upper frame *H–H* and *I–I* is raised by the hydraulic jack on the floor above. The loading bar, to which the weights may be applied, is suspended from the lower frame, *J–J* and *K–K*. The 100,000-lb-capacity proving ring ready for calibration in tension connects the upper and lower frames.

The cast-iron 10,000-lb weights, *F* (fig. 3), are about 7½ in. thick by 84 in. in diameter. The steel 1,000-lb weights, *G* (fig. 3), are about 4 in. thick by 33½ in. in diameter. The adjusting cavities in the sidewalls of the weights are closed by threaded plugs.

The apparatus for applying forces to the device to be calibrated consists of two frames. The upper frame consists of four yokes, *H*, connected by four rods, *I* (figs. 3, 4, 5, and 6). To limit swinging of the upper frame, guides are provided for the rods where they pass through the second floor. The top yoke, *H* (fig. 6), rests on a steel ball on the ram of the jack. The bottom yoke, *H* (fig. 3), carries the operating mechanism for the 1,000-lb weights. The two intermediate yokes, H, which are the lower compression and upper tension heads of the machine, are fixed in position on rods I.

The lower frame consists of two yokes, J (figs. 4 and 5), connected by two rods, K (figs. 4 and 5). The upper, unthreaded portions of these rods move vertically in guides, which can be rotated by hand to decrease the friction on rods K in the upper yoke H of the upper frame shown in figure 4. These guides are sufficient to keep the lower frame in proper alinement with respect to the upper frame, provided cali-

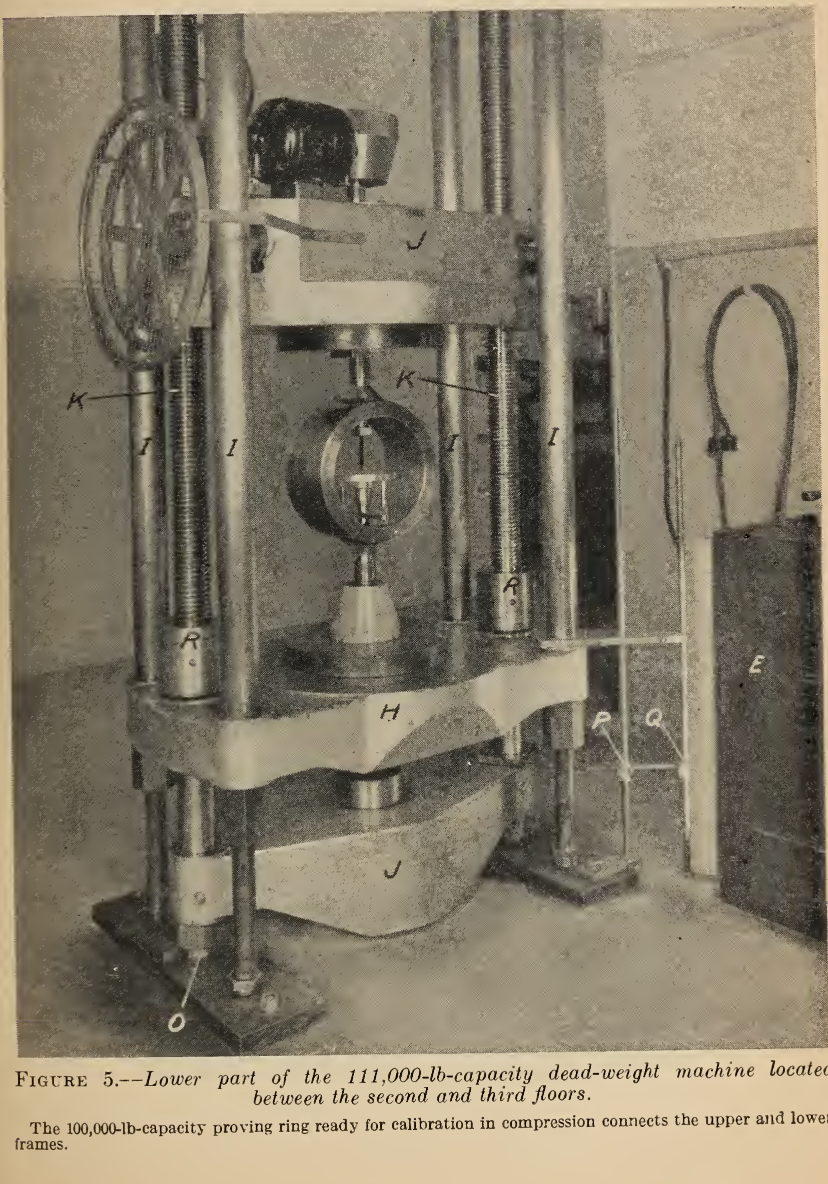

FIGURE 5.—*Lower part of the 111,000-lb-capacity dead-weight machine located between the second and third floors.*

The 100,000-lb-capacity proving ring ready for calibration in compression connects the upper and lower frames.

bration devices are properly centered in the machine. Tests have shown that the friction does not produce any detectable difference in the readings of the devices calibrated in this machine. The upper yoke of the lower frame, which is the upper compression and lower tension head of the machine, may be adjusted vertically on the

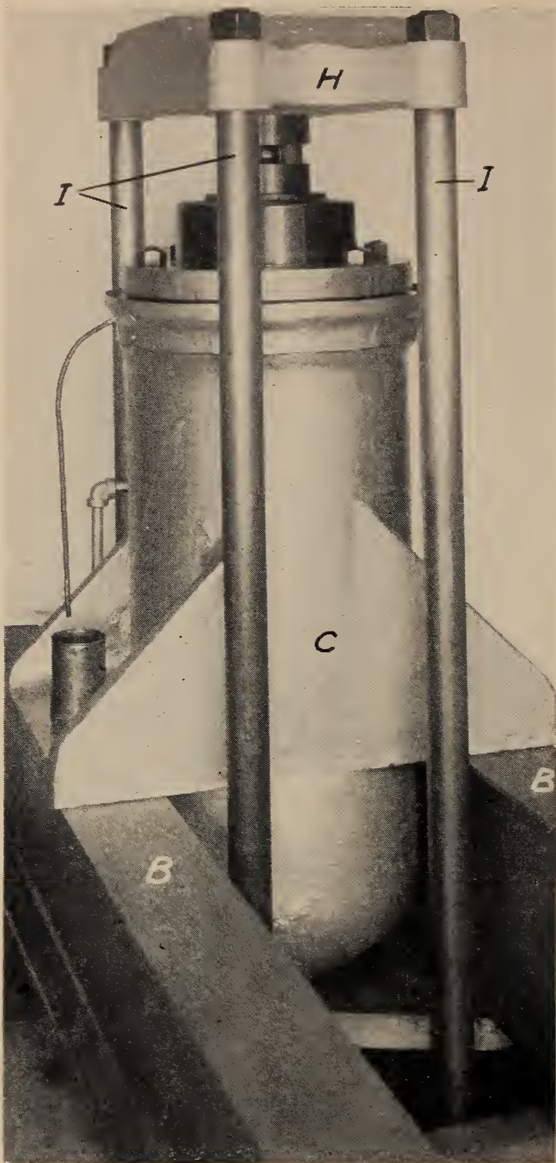

FIGURE 6.—*Part of the 111,000-lb-capacity dead-weight machine located above the third floor.*

The upper frame, *H* and *I–I*, is supported by a ball on the axis of the ram of the jack. Forces are applied to the device to be calibrated by raising the ram of the jack.

threaded rods, *K*, by rotating the nuts in the yoke by means of the electric motor and gearing shown in figures 4 and 5. Devices up to about 6 ft in length can be calibrated in either tension or compression.

The loading bar, *M* (fig. 3), is suspended from lower yoke *J*. This bar passes through the bottom yoke of the upper frame and the nine 1,000-lb weights. At its lower end it carries a bevel seat (fig. 2) for the bottom 1,000-lb weight and a head which projects below a plate (fig. 2) attached to the top 10,000-lb weight.

The 1,000-lb weights are supported by three threaded rods, *N* (fig. 3), which engage bevel seats in plates attached to the top 1,000-lb weight. These rods may be moved vertically by means of an electric motor and gearing attached to the bottom yoke of the upper frame. With the upper frame and the loading bar at any heights within their operating ranges, any number of the nine 1,000-lb weights may be supported from the rods *N* by means of the connecting pieces which link the weights together. The weights not supported from the rods *N* are supported on the bevel seat attached to the loading bar, each weight above the bottom weight being supported on a bevel seat on the weight below. A movement of about 11 in. of the rods *N* is required to transfer the support of all the weights from the loading bar to the rods *N*.

When the loading bar is not in contact with the top 10,000-lb weight, the bottom 10,000-lb weight is supported on the bevel seat (fig. 2) built into the foundation, and each of the other weights rests on a similar seat (fig. 2) on the weight below. The 10,000-lb weights are supported by the loading bar when the jack, through a calibration device, lifts the lower frame. When the loading bar has been raised about ¾ in. from its lowest position, the head on the end of the bar engages a bevel seat on the lower side of a plate attached to the top weight, thus applying the top weight to the loading bar. As the bar is raised farther, a connecting piece attached to the second weight engages a bevel seat in the top weight, and similarly the other weights are suspended in succession. All 10 weights are suspended when the loading bar has been raised about 10 in.

When the lower frame of the machine is not supported by a calibrating device, it is supported on two bevel seats, *O* (figs. 4 and 5), which are supported by the second floor of the building.

The position of the lower frame and the number of weights supported by the loading bar are shown by indicators *P* and *Q* (fig. 5). The total weight supported by a calibration device is the sum of the weight of the lower frame, 2,000 lb, and the weights shown on indicators *P* and *Q*.

If a calibrating device should fail under load, the weights it carried would fall. To prevent possible damage from this cause, the nuts, *R* (figs. 4 and 5), on the threaded rods, *K*, are adjusted so that there is a small clearance between their lower surfaces and the upper surface of one of the yokes of the upper frame. This limits to a safe distance the possible fall of the weights.

A proving ring of 100,000-lb capacity is shown in the dead-weight machine ready for calibration in tension in figure 4. The same ring is shown ready for calibration in compression in figure 5. To insure that forces applied to calibration devices will be axial, devices placed in the machine are carefully centered so that the axes of the devices coincide with the axis of the machine.

III. DESCRIPTION OF THE 10,100-POUND-CAPACITY MACHINE

The 10,100-lb-capacity dead-weight machine is shown in figures 7 and 8. Figure 7 shows the machine as it was originally installed on the first floor of the laboratory building. The machine as it is now installed is partially shown in figure 8.

The machine is about 14 ft high by about 5 ft wide. It rests on a concrete column, the top of which is about 10 ft above the first floor of the building. The machine projects through the second floor into the temperature-controlled room, which also surrounds the frames of the 111,000-lb-capacity machine. The column and the machine

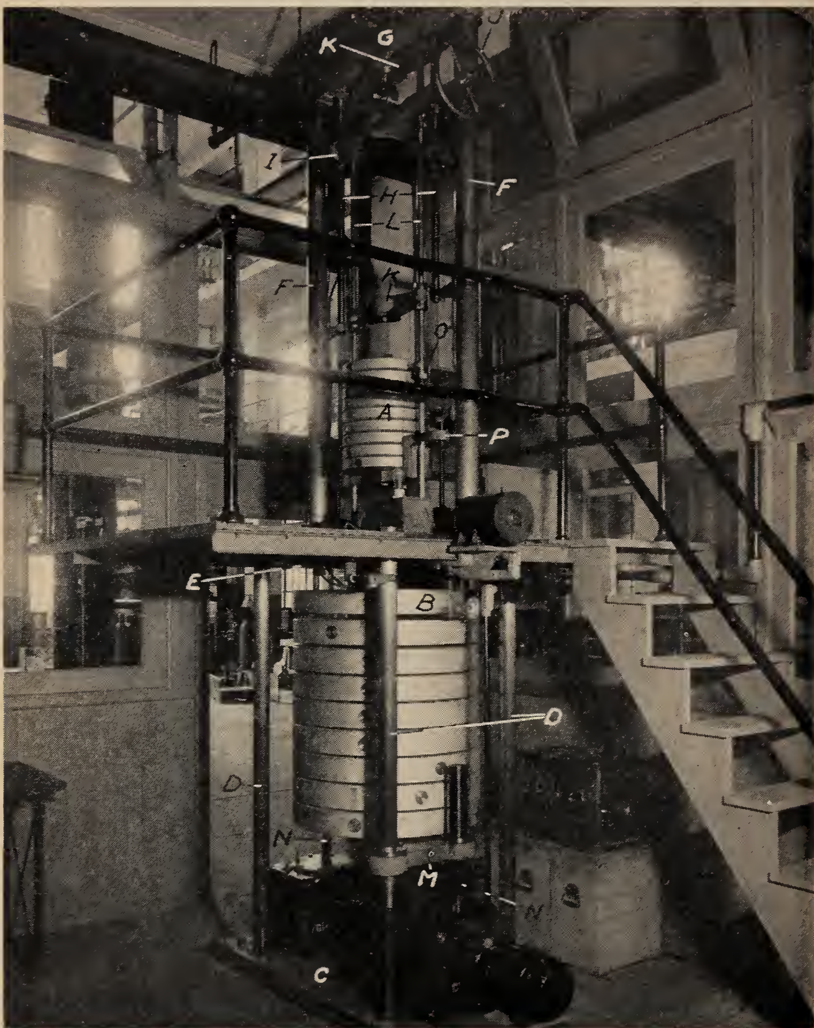

FIGURE 7.—*10,100-lb-capacity dead-weight machine as it was originally installed.*

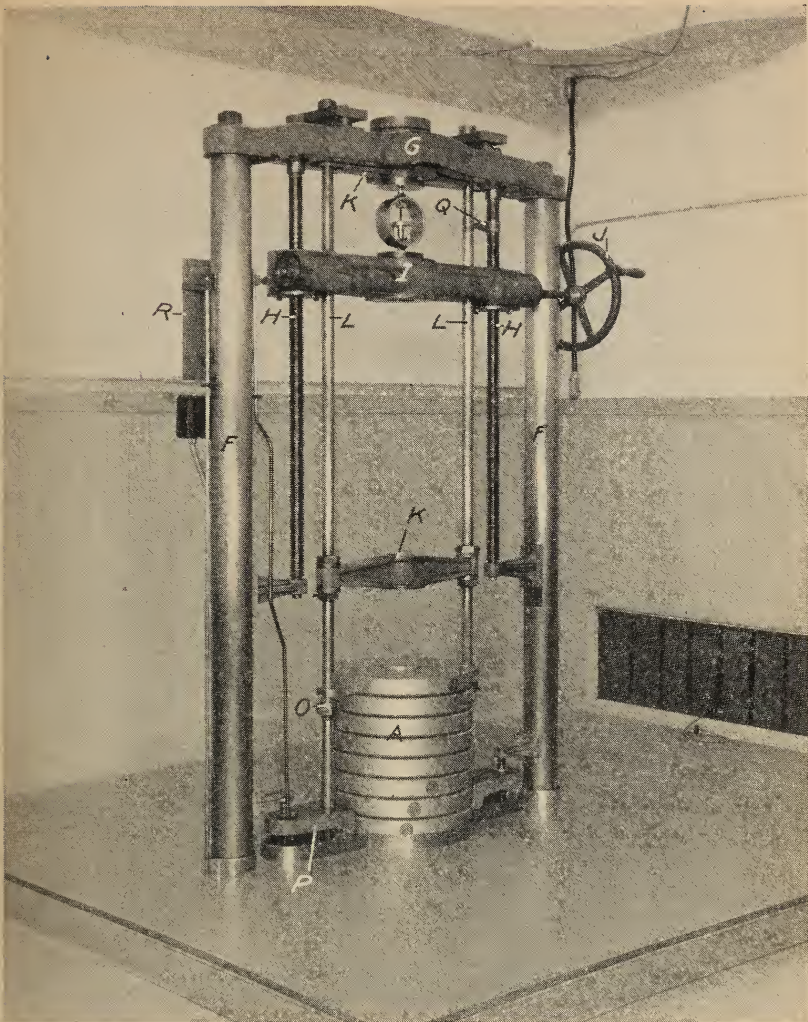

FIGURE 8.—*Loading frame and 100-lb weights of the 10,100-lb dead-weight machine.*

A 3,000-kg. capacity proving ring is shown ready for calibration in compression.

are not connected structurally to the floors of the building or the platform around the machine.

Both the 100-lb weights, *A* (figs. 7 and 8), and the 1,000-lb weights, *B* (fig. 7), are steel. The 100-lb weights are about 2 in. thick by 15½ in. in diameter, and the 1,000-lb weights are about 4 in. thick by 33 in. in diameter. The adjusting cavities in the sidewalls of the weights are closed by threaded plugs.

The frame of the machine consists of a base-plate, *C* (fig. 7), connected by four rods, *D* (fig. 7), to an upper plate, *E* (fig. 7), which supports two rods, *F* (figs. 7 and 8), the upper ends of which are connected by yoke *G* (figs. 7 and 8). Two screws, *H* (figs. 7 and 8), are attached to yoke *G*, and by these, yoke *I* (figs. 7 and 8) is supported. Yoke *I* may be moved vertically by means of gears which are actuated by turning the handwheel, *J* (figs. 7 and 8). Devices up to 34½ in. in length may be calibrated in either tension or compression.

The loading frame consists of three yokes, *K* (figs. 7 and 8), connected by two rods, *L* (figs. 7 and 8). The bottom yoke *K*, which connects the lower ends of rods *L*, does not show in the photographs. In this smaller machine, friction due to the rubbing of the frame against other parts of the machine, which is negligible in the 111,000-lb machine, could produce appreciable error. For this reason an electronic device is used to indicate mechanical contact of the loading frame and the weights suspended from it with other parts of the machine. By taking readings only when there is no such contact, no frictional errors are introduced into the forces applied to calibration devices.

When the connecting piece attached to the top 1,000-lb weight is not in contact with the loading frame, the weights are supported on the crosspiece, *M* (fig. 7), which is moved vertically by means of the motor-driven screws, *N* (fig. 7). The bottom weight rests on a bevel seat in *M*, and each of the other weights rests on a similar seat on the weight below. As the crosspiece is lowered the connectting piece attached to the top weight engages a bevel seat in the bottom yoke of the loading frame, and the weight is supported by the loading frame. As the crosspiece is lowered farther, the weights are transferred one after another to the loading frame. A movement of about 6 in. is required to transfer all of the nine 1,000-lb weights from the crosspiece to the loading frame. The weights are removed by raising the crosspiece.

When the lugs attached to the top 100-lb weight are not in contact with the bevel seats, *O* (figs. 7 and 8), on the loading frame, the weights are supported on yoke *P* (figs. 7 and 8), which is moved vertically by means of motor-driven screws. The bottom weight rests on a bevel seat in yoke *P*, and each of the other weights rests on a similar seat on the weight below. As yoke *P* is lowered, the lugs attached to the top weight engage the bevel seats on the loading frame and the weight is transferred to the loading frame. As the yoke is lowered farther, the weights are transferred one after another to the loading frame. A movement of about 9 inches is required to transfer all of the nine 100-lb weights from yoke *P* to the loading frame. The weights are removed by raising yoke *P*.

The bevel seats and connectors for the individual weights in this machine are similar in principle to those for the 10,000-lb weights of the 111,000-lb machine shown in figure 2.

When the loading frame is not supported by a calibration device, it is supported on two bevel seats attached to the yoke *G*. The position of the loading frame is shown by the pointer, *Q* (fig. 8). The total weight supported by a calibration device, which consists of the loading frame, 200 lb, and the weights applied to the loading frame, is shown on the indicator, *R* (fig. 8). Auxiliary weights are added to the frame to obtain test loads which are not multiples of 100 lb.

A proving ring of 3,000-kg capacity is shown in the machine ready for calibration in compression in figures 7 and 8.

IV. ACCURACY OF THE MACHINES

1. THE 111,000-LB-CAPACITY MACHINE

The maximum error in the weight of the lower frame or any one of the 10,000-lb weights was determined to be about 0.1 lb when the machine was installed in 1927.

The maximum error of the 1,000-lb weights was determined to be about 0.0005 lb when they were installed in 1931.

The errors of the weights and the lower frame were redetermined in 1938. The nine 1,000-lb weights were calibrated by the method of substitution against standard weights on a special testing beam. The nine 1,000-lb weights and 1,000 lb of standard weights were combined to form the standard which was used to calibrate the 10,000-lb weights by the method of substitution on a 10,000-lb capacity platform scale. The smaller parts of the lower frame were calibrated on a balance, and the larger parts were calibrated by the method of substitution against standard weights on a platform scale. For each of the ten 10,000-lb weights no mean computed error exceeded 1 lb, or 0.01 percent. For each of the nine 1,000-lb weights no mean computed error exceeded 0.05 lb, or 0.005 percent. The 2,000-lb lower frame differed from the nominal value by less than 0.5 lb, and it was adjusted to weight 2,000.0 lb. No adjustment was made to the weights because the observed errors were of the same order of magnitude as the errors of the calibration equipment.

2. THE 10,100-LB-CAPACITY MACHINE

The maximum error of the 1,000-lb weights did not exceed 0.005 lb when the machine was installed in 1931. The maximum error of the 100-lb weights did not exceed 0.001 lb when the machine was installed in 1931. The error of the 200-lb frame did not exceed 0.01 lb.

The errors of the weights and the loading frame were redetermined in 1938. The nine 1,000-lb and the nine 100-lb weights were calibrated by the method of substitution against standard weights on a special testing beam. Part of the loading frame was weighed on the special testing beam and the remainder was weighed on a balance. For each of the nine 1,000-lb weights the maximum error did not exceed 0.05 lb, or 0.005 percent. For each of the nine 100-lb weights the maximum error did not exceed 0.005 lb, or 0.005 percent. The error of the 200-lb loading frame did not exceed 0.005 lb. No adjustments were made to the weights or frame because the observed errors were of the same order of magnitude as the errors of the calibration equipment.

V. USE OF THE MACHINES

The dead-weight machines are used to calibrate elastic calibration devices, which are used to calibrate testing machines. The American Society for Testing Materials Standard Methods of Verification of Testing Machines (see footnote 3) requires that an elastic calibration device be calibrated by dead weights known to be accurate within 0.02 percent for loads not exceeding 100,000 lb. Since no other machines which comply with this requirement are available in the United States, the machines described are used not only for calibrating elastic calibration devices for government laboratories, but also for calibrating devices for the public.

The machines are not suitable for determining the strengths of materials or structures.

VI. CONCLUSIONS

The dead-weight machines described in this paper are suitable for calibrating proving rings and other elastic calibration devices under test loads from 200 lb to 111,000 lb. Test loads from 200 lb to 10,100 lb by 100-lb increments and from 2,000 lb to 111,000 lb by 1,000-lb increments may be applied. The errors of the test loads do not exceed 0.02 percent.

The maximum observed errors of any of the weights was less than 0.01 percent in 1938, which is less than one-tenth the maximum allowable percentage error for elastic calibration devices. The maximum allowable error specified by the American Society for Testing Materials for primary standards for calibrating elastic calibration devices is 0.02 percent. It is believed that the weights of the machines are now sufficiently stable so that the errors will not, under normal circumstances, exceed 0.02 percent for a period of 10 or 20 years.

The machines were designed by the Bureau's Engineering Mechanics Section, under the supervision of L. B. Tuckerman and H. L. Whittemore, in cooperation with The A. H. Emery Co., Stamford, Conn., and built by The A. H. Emery Co. They were installed with the assistance of A. H. Stang and L. R. Sweetman.

The weights of the machines were calibrated by the Bureau's Division of Weights and Measures, under the supervision of F. S. Holbrook and R. W. Smith.

WASHINGTON, January 25, 1943.

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