# THE DEVELOPMENT OF A PORTABLE STRENGTH OF MATERIALS DEMONSTRATOR

THESIS FOR THE DEGREE OF B. S.

WM. M. CADE

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# The Development of a Portable Strength of Materials Demonstrator

A Thesis Submitted to the Faculty of

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by

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THESIS

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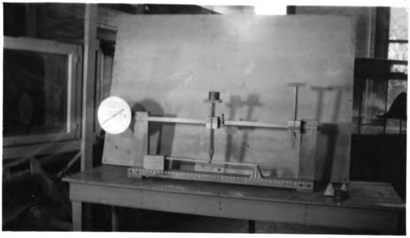
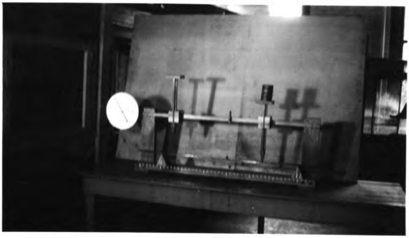


Photograph No. 1 Apparatus as
set up for a restrained end experiment



Photograph No. 2 Apparatus as
set up to determine the value of E

The writer chose as his thesis for a Bachelor of Science Degree in Civil Engineering the "development" of a portable Strength of Materials Demonstrator. The word, development, is used advisedly because the apparatus had already been designed and constructed by an F. E. R. A. student under the supervision of Professor C. M. Cade of the Civil Engineering department. However there were several mechanical difficulties which rendered the devise practically useless for the purpose for which it was designed. It therefore became a problem of redesigning and improving ~~and improving~~ the setup so that satisfactory results might be obtained.

Additional apparatus, namely a restraining end, was designed to further extend the useful~~l~~ness of the apparatus.

Next a series of experiments were run to test the setup and prove the value of the apparatus. These experiments were not intended to cover all the possibilities of the setup, but merely to assure ourselves that the apparatus would do the work it was intended to do. If the apparatus comes into use for classroom work in connection with the strength of materials courses, there will doubtless be numerous other experiments which will suggest themselves.

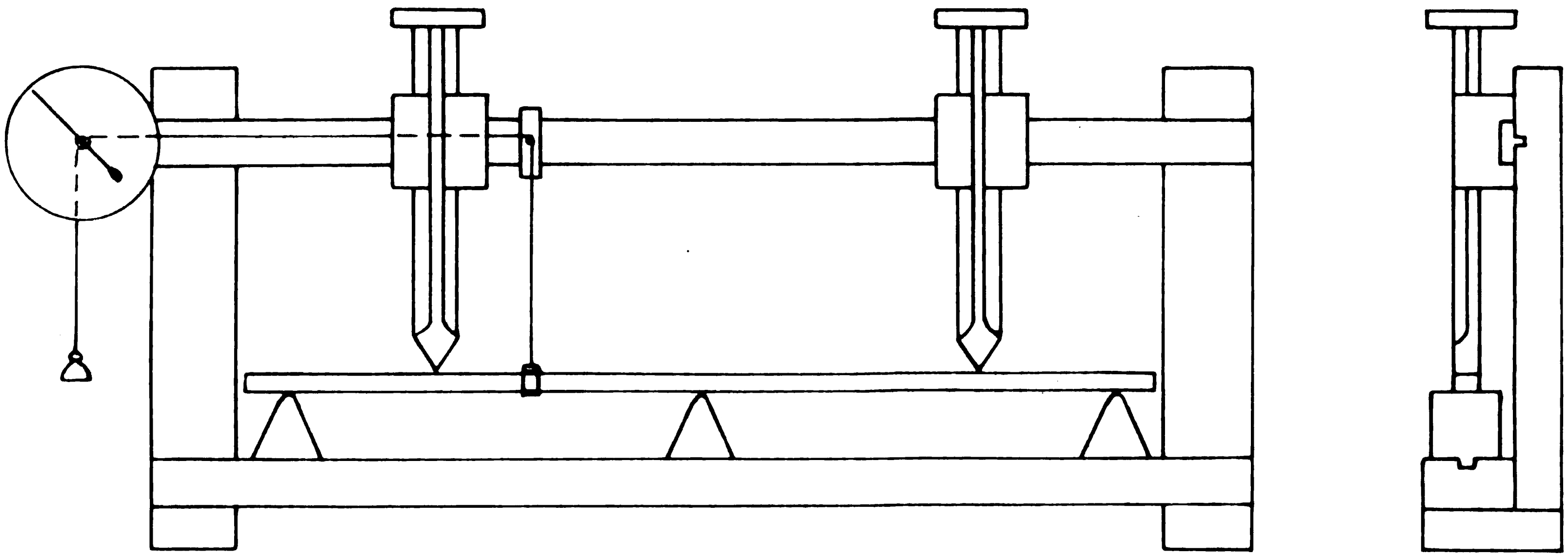


FIG. 1 ASSEMBLED VIEW OF APPARATUS. SHOWING SETUP FOR CONTINOUS BEAM OVER THREE SUPPORTS

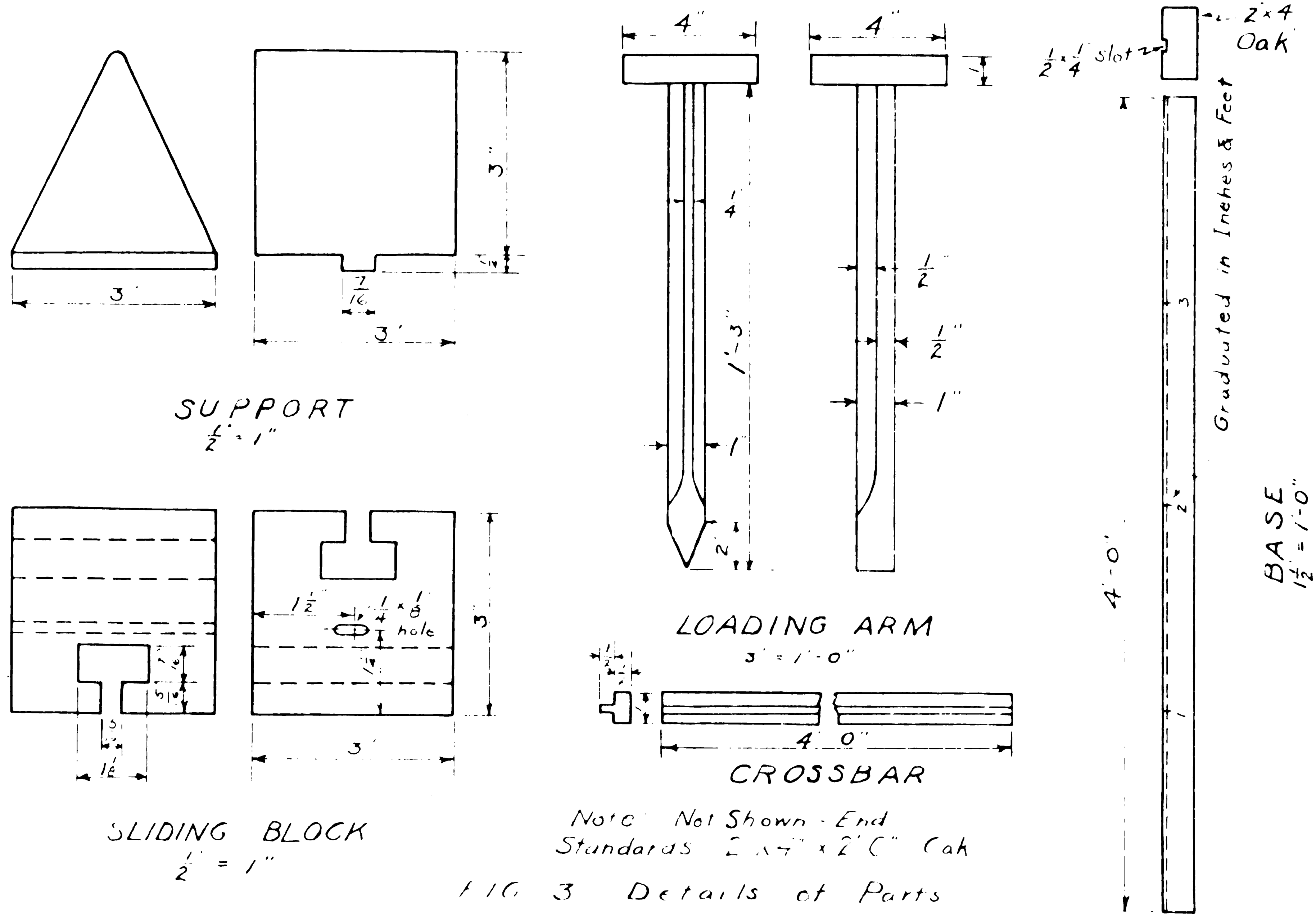



FIG 3 Details of Parts

There has been included in these experiments a short discussion of the fundamental principal and what it means, merely for the sake of completeness.

Finally a few notes on the technique have been written up as a sort of guide to a person unfamiliar with the apparatus. Like all apparatus of an experimental nature it is subject to considerable error if not handled properly, and furthermore, some practise in manipulating the thing is necessary before good results can be had.

It was originally contemplated that a case for the loose pieces be built to facilitate moving from class to class, however, due to lack of materials and funds, as well as time, this has not been possible. It is strongly recommended that such a case be built as soon as funds are again available, otherwise it is probable that difficulty will be encountered in keeping the several parts together.

## Improvements

Upon examination of the mechanism it was seen that the first problem to be solved had to do with the dial which recorded deflections. This was a dial mounted on the end of a shaft with a string wound around the shaft and fastened to the beam in such a manner as to register the deflection of the beam under various types of loads (Fig. 2). The trouble seemed to be that the string had insufficient leverage to overcome the friction and inertia of the dial and shaft. The first step consisted of putting in a larger shaft and improving the bearing surfaces. This seemed to be a step in the right direction, but not far enough, so a pulley with a radius one-fourth that of the dial was installed. This worked alright but the deflections of the beam were only multiplied about four times which was not enough to produce satisfactory readings. In looking around for some sort of substitute, a laboratory Manual of the University of Michigan was consulted, this illustrated the so-called "Michigan Dial", which with some changes seemed to fit our needs. The chief feature of the dial was the use of a movable pointer and a stationary dial, rather than a movable dial and a stationary pointer. This makes the movable

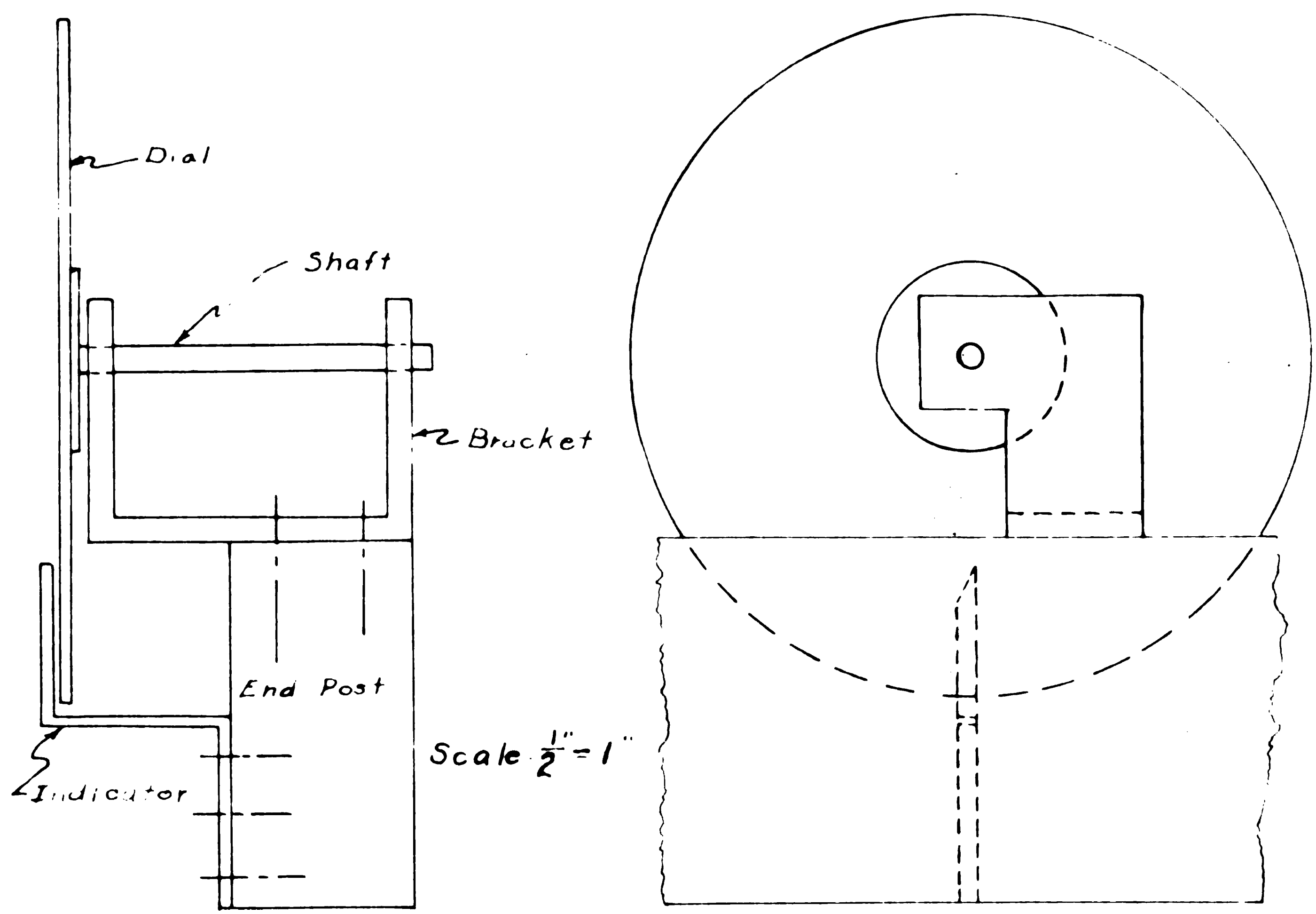



FIG. 2 ORIGINAL DESIGN OF DIAL

parts much lighter and consequently more sensitive.

Figures 4 and 5 give the assembly and details of the dial as it was finally adapted to our needs.

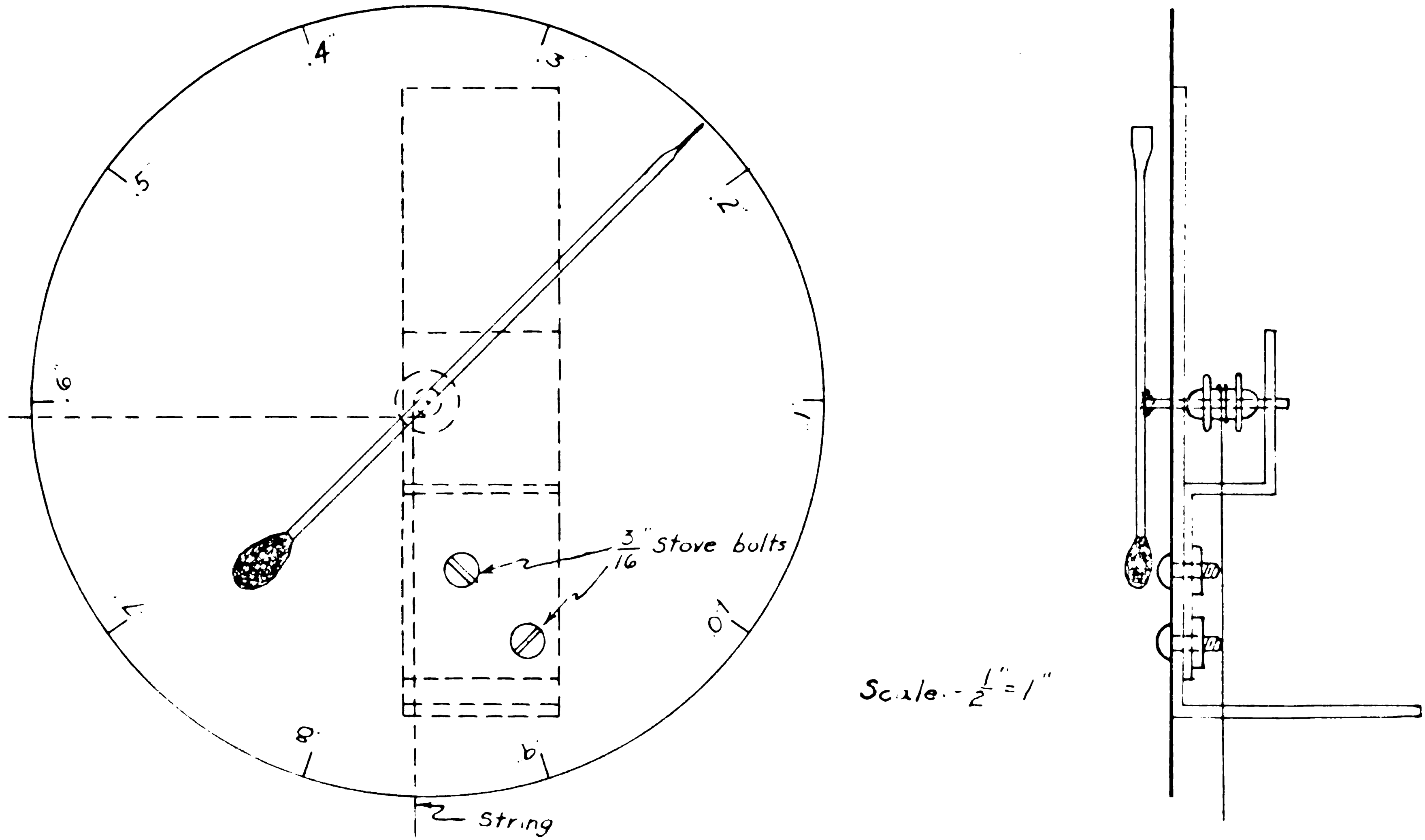
One interesting computation was carried out in connection with this construction, namely as to what diameter of pulley should be used. It seemed desirable that one inch deflection should cause one revolution fo the pointer. Therefore the circumference of the pulley be one inch.

Thus: $\pi \cdot d = 1''$ $\quad d = \frac{1}{\pi} = .318''$

This gave the effective diameter, which was greater than the actual diameter because of the effect of the size of the string which was wound around the pulley. The size of the pulley was gradually cut down until the effective diameter was .318", in other words one inch deflection gave one revolution of the pointer.

A ten inch sheet metal dial was cut out and a face of drawing paper glued on the dial. This was then divided into onehundred divisions, each division being one-hundredth of an inch deflection.

The calibration of the dial was then checked in the following manner: The apparatus was set up as it normally would be in running an experiment, but in addition a deflection measuring micrometer gauge was




Scale - 1/2" = 1"

FIG 4 ASSEMBLY OF DIAL

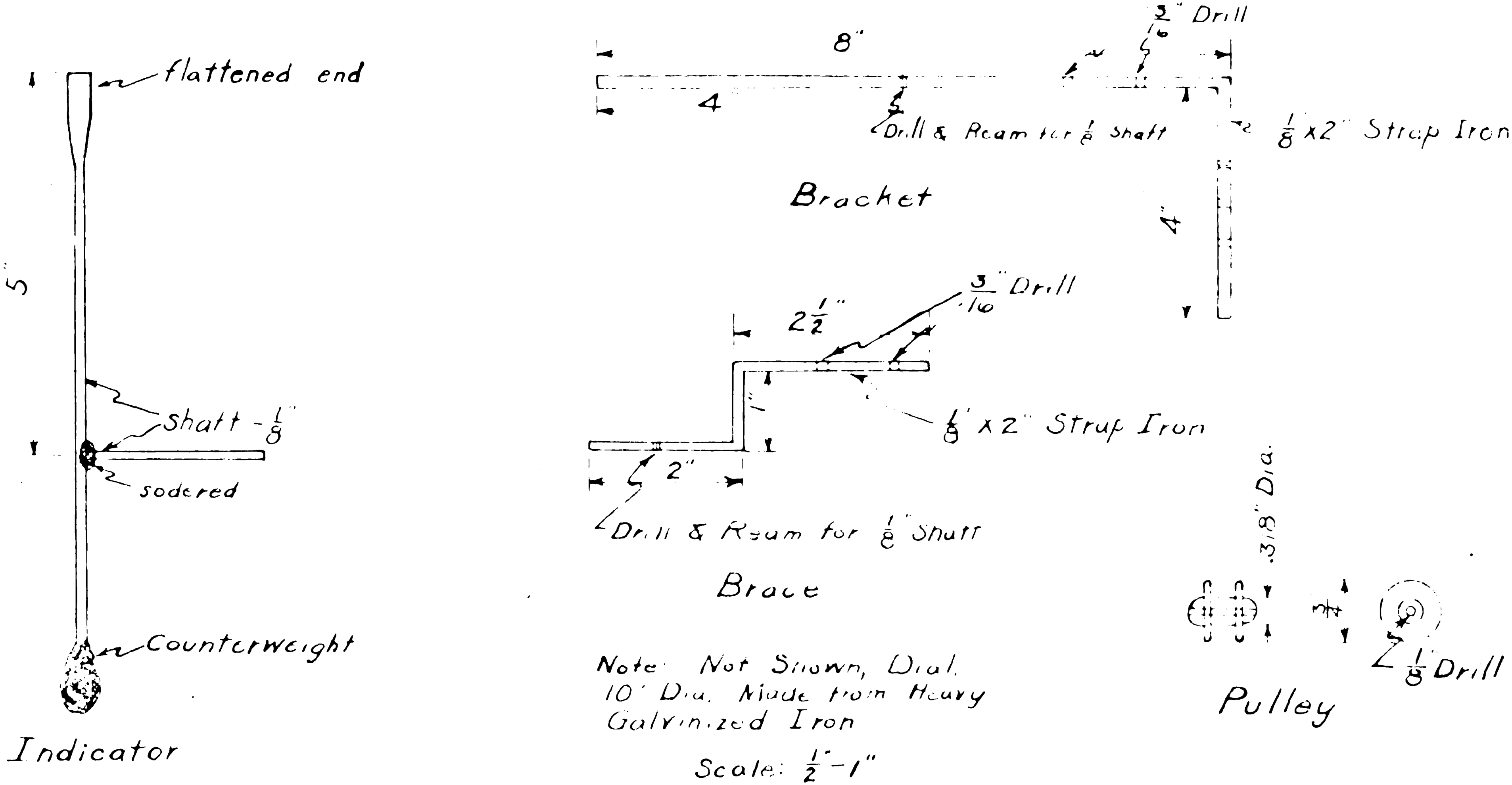



FIG. 5 DETAILS OF MICHIGAN DIAL

borrowed from the Mechanical Engineering department and placed so that it measured the deflection of beam at exactly the same point as was measured by the dial. This micrometer read to thousandths of an inch.

Then loads were applied to the beam so as to produce the deflection and readings of the deflections were taken. The results are tabulated below:

| Trial | Mike Reading | Dial Reading | Ratio |
|---|---|---|---|
| 1 | 45 | 45 | 1 |
| 2 | 82 | 89 | 1+ |
| 3 | 133 | 133 | 1 |
| 4 | 172 | 172 | 1 |
| 5 | 263 | 263 | 1+ ? |

As it is only contemplated that the dial be read to the nearest .01" or .005" it is apparent that the dial is calibrated accurately enough for our purpose.

The next difficulty to be overcome was the tendency for the loading arms to stick in the sliding blocks. Among the various lubricants used were soap, axel grease, beeswax, paraffine, and paraffine with flake graphite.

The paraffine with flake graphite was finally decided upon as giving the most satisfactory results.

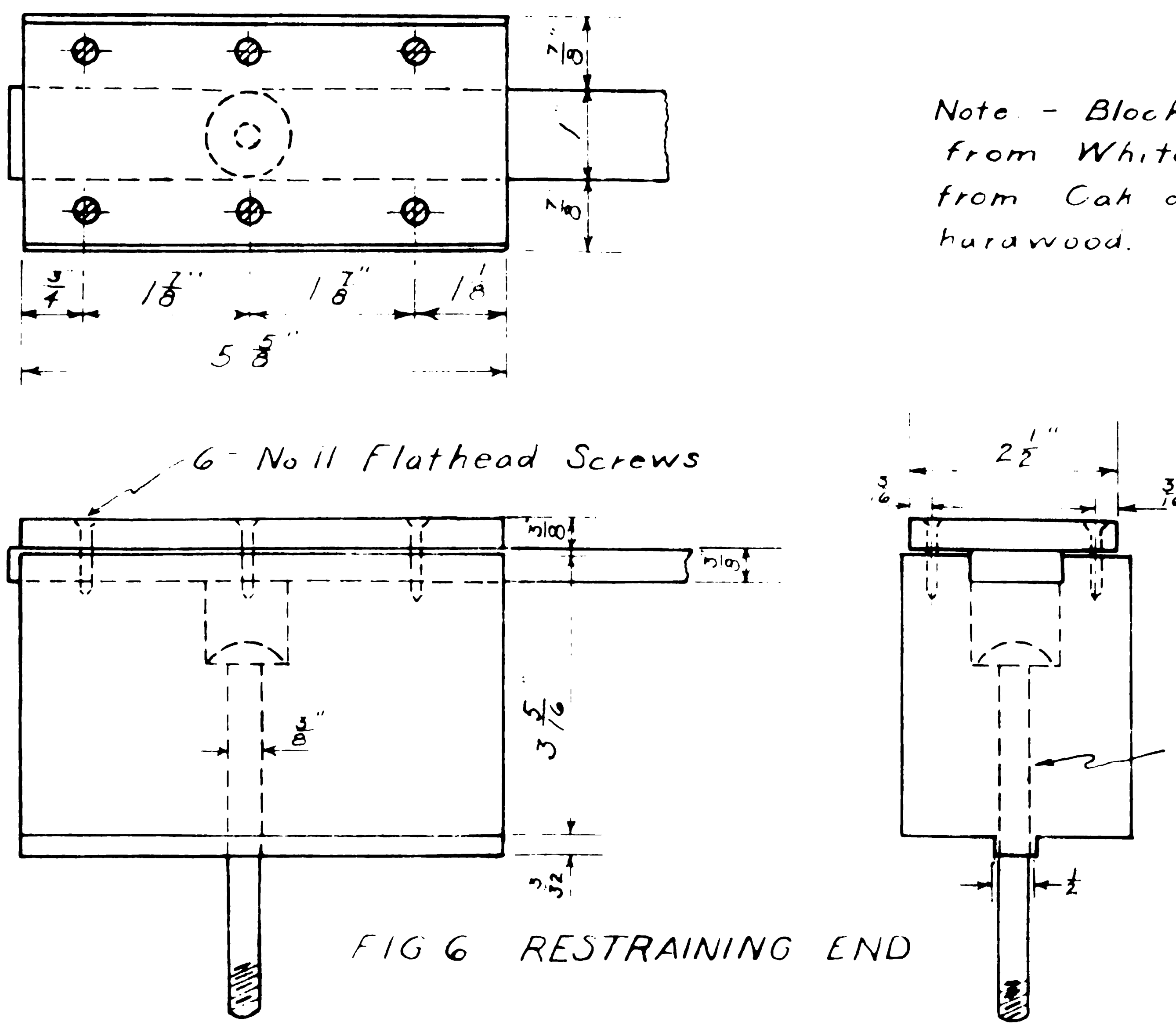
The effective weight of the loading arms was determined and found to be 230 grams or about .51 pounds. This was of importance in the experiments with wood beams, but produced no measurable deflections in the case of the larger steel beam and computed results showed up better if this quanity was neglected as being too small to have measurable effect.

A further extension of the usefulness of the apparatus was obtained in the addition of a restraining end. A drawing of the device is shown in figure 6. With its use, the principals of cantilever action and other restrained end phenomena can be studied.

## Experiments

We now had the apparatus in working order and it remained only to run a set of experiments to see just what results could be obtained and to develop some sort of rudimentary technique to improve the quality of these results.

The first experiment consisted in measuring the deflections at the center of a simple beam, the load applied at the quarter point. This particular



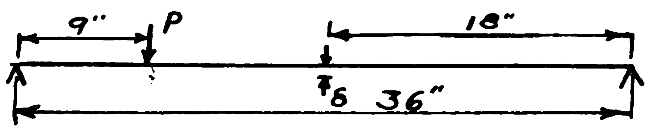

Note - Block to be made from White Pine; top from Oak or other hardwood.

Scale: 1/2" = 1"

FIG 6 RESTRAINING END

setup was chosen because it was simple to compute and furtheremore the various parts were well separated along the beam. From this data a value of E was computed and compared with values as found in various handbooks. The following data is the results of this experiment as performed on a number of beams:

Exp. 1. No. 1 Wood Beam- 1" x .246"[1]- White Pine.




$$\delta = \frac{Pb}{48EI}(3l^2 - 4b^2)$$ [2]

$$I = \frac{1}{12}bh^3 = \frac{1}{12}\cdot 1 \times (.246)^3$$

or $$E = \frac{Pb}{48\delta I}(3l^2 - 4b^2)$$

$$I = .00125 \text{ in}^4$$

$$E = \frac{P}{\delta}\cdot 537{,}000$$

| P | δ | E |
|---|---|---|
| .51# | .170" | $1.69 \times 10^6$ |
| .95# | .330" | 1.54"""" |
| 1.39# | .470" | 1.59"""" |
| 1.83# | .630" | 1.57"""" |
| 2.27# | .730" | 1.65"""" |
| 2.69# | .920" | 1.57"""" |

1 The beams were measured with micrometers at various points and a running average taken.

2 Timeshenko and McCullough, "Strength of Materials", pp 168.

This shows that while the results vary considerably in the third significant figure, they are accurate to about one or two percent which is all that can be expected from this apparatus. This value for the Modulus of Elasticity of White Pine falls within the limiting values as given in Engineering Handbooks.

Exp. 2 No. 1 Steel Beam- .250" x .748" (Cold rolled steel)

(Same setup as in Exp. 1 ) $I = .000974 \text{ in}^4$

$$E = \frac{702}{.000974} = 722500 \frac{P}{\delta}$$

| P | δ | E |
|---|---|---|
| 2# | .05" | $29 \times 10^6$ |
| 4# | .10" | " " " " " " |
| 6# | .15" | " " " " " " |
| 8# | .20" | " " " " " " |

Of all the experiments run, this particular beam gave by far the best results. It is with this beam that the effect of the loading arm must be neglected in order to obtain good values for the constants. This is justifiable because the loading arm produced no measurable effect.

Exp. #3 No. 2 Steel Beam .252x.252 (Cold rolled steel)

(Same setup as in Exp. 1)

$$I = \frac{1}{12} b^4 = .000336''^4$$

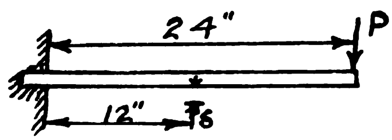
$$E = \frac{702}{.000336} \frac{P}{\delta} = 2{,}090{,}000 \frac{P}{\delta}$$

| P | δ | E |
|---|---|---|
| 1.61# | .115" | 29.1x10⁶ |
| 2.51# | .180" | 29.2" " " " |
| 2.69# | .190" | 29.6" " " " |
| 4.51# | .330" | 29.0" " " " |
| 6.51# | .470" | 29.2" " " " |

This beam also showed up much better than the wood beams. This would lead us to the conclusion that it is advisable to use a material which is more homogenous than wood for our experiments if we wish to carry out extensive computations and have them check closely with values measured in the experiment.

Exp. #4 Fixed-end Cantilever, load at end, deflection at the middle. Useing Wood beam No. 2- 1.00"x.346" White Pine.

Discussion: This particular beam furnished considerable trouble, as far as getting consistent results is concerned. The values of E ranged from 1.5 to 1.9 $\times 10^6$ depending upon the setup. However the results were quite constant for any particular experiment and the deflection was proportional to the load, E remaining constant thruout the experiment. The following tabulation represents the best "run" which was had.




$$\delta = \frac{Px^2}{6EI}(3l - x) \quad [1]$$

$$I = \frac{1}{12}\, 1.0 \times (.346)^3 = .00346''^4$$

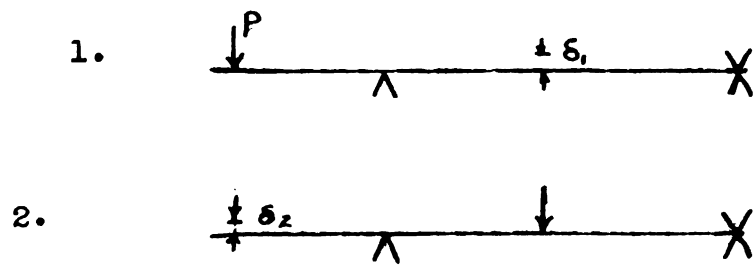
$$E = \frac{1440}{.00346}\,\frac{P}{\delta}$$

| P | δ | E |
|---|---|---|
| .51# | .125" | 1.70x10$^6$ |
| .95# | .230" | 1.72x""" |
| 1.39# | .335" | 1.73"""" |
| 1.83# | .450" | 1.69"""" |
| 2.27# | .550" | 1.72"""" |
| 2.69# | .655" | 1.71"""" |

1 Timeshenko and McCullough, "Strength of Materials", pp 168.

Exp. 5 Verification of Maxwell's Law or The Principle of Recprocial Deflections.

The law is stated as follows: The deflection at the point A caused by a load at the point B is the same as the deflection at the point B produced by moving the same load to the point A.[1] This is illustrated by the following special case which can also be proven mathematically.[2]




Prove that $\delta_1 = \delta_2$

| | P | $\delta$ |
|---|---|---|
| 1. | 2.0# | .025" |
| | 4.0# | .050" |
| | 6.0# | .080" |
| | 8.0# | .100" |
| 2. | 2.0# | .025" |
| | 4.0# | .050" |
| | 6.0# | .080" |
| | 8.0# | .100" |

1 Grinter, L. E., "Theory of Modern Steel Structures", pp. 41.

2 Tim. and Mc C., Ibid, prob. 246, pp. 175.

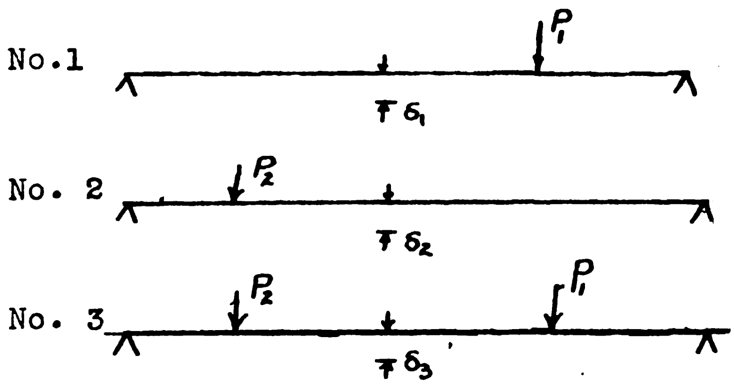
It is seen that for equal values of P equal values of delta were obtained.

Exp. 6 Illustration of the Principle of Superposition.

The general statement of the principle of superposition is this:

> The sum total of the effect of a set of mutually independent forces on a system is the same whether the forces act simutaneously or independently.

The principle is nicely illustrated in the following experiment in which it is shown that the sum of the deflections caused by two forces is the same whether they are measured seperately as in parts 1 and 2 or as a combined system as in part 3.




To show that $\delta_3 = \delta_1 + \delta_2$

| | $P_1$ | $P_2$ | $\delta$ | $\delta_1 + \delta_2$ |
|---|---|---|---|---|
| 1. | 2# | 0 | .095" | |
| | 4# | 0 | .175" | |
| 2. | 0 | 2# | .080" | .175" |
| | 0 | 4# | .140" | .315" |
| 3. | 2# | 2# | .175" | |
| | 4# | 4# | .315" | |

Notes on Operation

There were a number of ~~of~~ seemingly simple points about the operation of the apparatus which were essential to getting satisfactory results.

In the first place it was found that the apparatus needed a stable base in order to give good results. In performing the calibration experiment, the apparatus was rather carelessly set up on a warped table top and the results were so far out of line that it was positively disheartening. Then the same experiment was performed with the apparatus set up on a solid table and the results were quite satisfactory (see calibration experiment).

In carrying on the experiments it was found that the initial reading was likely not to be in keeping with the other readings. This was due to the fact that the beam would not be placed solidly on the supports or that there would be some slack in the string. The remedy for this was to load the beam and cause a deflection, then remove the load and adjust the pointer so as to read zero. This adjustment is best done by moving the clamp on the crossbar slightly one way or the other.

A marked difference in the amount of deflection was observed depending upon whether the weight was applied quickly or slowly. Part of the effect was due to impact on the beam, part due to the stretching of the string, and part due to the tendency of the loading arms to stick slightly. The combined effect was to make the readings too great if the load was applied quickly and too little if applied slowly. The following rule gives deflections which are satisfactory: Apply the load just quickly enough so that the pointer will very slightly past its final resting point, not more one-half of a division, and then move back to the true reading. This also applies to the removal of loads.

For the purpose of classroom demonstration, four lead weights were cast and machined down to two pounds weight. For experimental pourposes it was found that these did not provide enough combinations of weights to give the desired number of readings. Therefore 200gm. weights were used and converted to pounds, there being 453.6 gms in a pound.

In regard to the position of the clamp on the crossbar, it would theoretically have to be directly above the clamp on the beam in order to measure true deflections, this would preclude measuring deflections of the beam at the point of application of the load. However it was found that placing the clamps as near the loading arm as convienent and letting the string run at an angle to the perpendicular introduced no appreciable error.

In conclusion, it is hoped that this apparatus may find a useful place as an aid in the teaching of Strength of Materials and that it may serve as an inspiration for more and better apparatus, eventually developing into a full-fleged laboratory, for there is no doubt in my mind that the principles of Strength of Materials can be more easily grasped and better understood if some working models are available to "drive the points home."

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