DESIGN OF CONCRETE BEAM

TESTING MACHINE

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A Thesis Submitted to

The Faculty of

MICHIGAN AGRICULTURAL COLLEGE

By

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Bachelor of Science.

July, 1919.

INTRODUCTION.

When the fire of March 5th, 1916 destroyed the Engineering Hall and shops at M.A.C. it also, destroyed all the departmental equipment. The more necessary articles were replaced as soon as possible in order that the college work might be continued without interruption.

However, some things were not replaced immediately, and among them was a machine for testing concrete beams; a very necessary part of the Civil Engineering Department's equipment, for without a machine of this nature it has been impossible to obtain the best results in Masonry Design.

In conferring with Professor Vedder upon a thesis subject this year he suggested that a machine to test concrete beams for flexure be designed and built, and as the writers were interested in concrete design, they decided to take this subject for a thesis and by doing so add to their knowledge of concrete design, and, also, leave a useful instrument with the college.

The writers wish to express their appreciation to Professor Vedder for his help and many valuable suggestions as to the design of such a machine, and, also, to Messrs. Hool and Johnson, the authors of the Concrete Engineers Handbook which was used as reference thruout the work.

HISTORY.

Before starting our work we studied the design of similar machines that are on the market, for we wished to make ours as practical as possible. After looking thru the various manufacturers catalogues we decided on the design shown on the following pages of this thesis.

We chose hydraulic jacks as the means of applying the required pressures in the testing of beams, because the engineering department owned two available jacks that were not likely to be used for any other purpose.

Upon the suggestion of Professor Vedder the machine was designed for the maximum duty of breaking a reinforced concrete beam four by twelve inches in cross-section and twelve feet in length. Using a beam of the above dimensions as a standard and a basis of calculation, we computed the ultimate force that would be required to break it. To this result we applied a factor of safety of five and derived the size of our machine base.

After our general design was approved we started collecting the materials for the base-beam. The form was constructed of matched pine lumber that had been previously used in a shed door; so we were assured that it was thourly dried and would not warp.

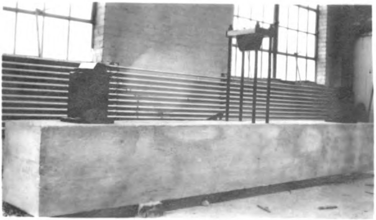
The work of building the form was carried on as rapidly as possible in order that the concrete might be poured and have at least twenty-eight days in which to set before undertaking the assembling of the machine. The concrete was mixed with a minimum percentage of water and well tamped in the form. After setting it was sprinkled with water several times a day for the first two weeks.

Due to the fact that when in use the tension side of the base-beam will be the top, we poured the base-beam up side down, and in this way avoided the necessity of having to work the concrete thru the reinforcing steel which is required in the top of the base-beam when the machine is assembled.

When the base-beam had set four weeks, we rolled it over using two pump jacks for the purpose, and when it was in position the machine was assembled and put in working order.

Concrete Beam Testing Machine

End View



Side View

DESCRIPTION.

The assembled concrete beam tester, shown in Fig. 1, was constructed in the cement laboratory. In designing it was found that the beam would stand the load without stirrups by placing thirteen 11/16"x16' round mild steel rods in the top of it. But this amount of steel was near the stress point and the writers decided to add stirrups in order to make it absolutely safe. So two rods 5/16"x16' were placed in the bottom to hook the stirrups over and then stirrups of 5/16" round rods were placed four inches apart for a distance of five feet four inches from each end of the beam. See Fig. 2, for the placing of the steel. The rods were held in place by wiring to the form and then after the beam had set the wires were cut.

After stripping the beam it was decided to paint it with cement to make a smooth finished surface.

The hydraulic jacks, rods and plates which were to be used had been thru the fire and, of course, were in a very rusty condition. To remove the rust they were first thorly soaked with kerosene and afterwards the rust was removed with sandpaper. The parts were then painted with machine enamel.

In drawing sketches and designs the writers decided to make the pump base of a concrete hollow square with a hardwood top. The base is made of 1:2:4 concrete with 1/4" deformed reinforcing rods at the corners. See Fig. 3. The outside dimensions are 18" x 24" and the inside 10" x 16"

allowing a four inch wall. In order to fasten the hardwood top to the concrete base it was decided to use six machine bolts inbedded in the concrete. In providing enough bond strength on these bolts, 1/2" x 10" machine bolts were requisitioned, and a two inch right angle bent on the end, These were inbedded in the concrete leaving 3-1/4" protruding above the top.

The hardwood top, shown in Fig. 4, was designed to be 3" x 18" x 24" and was built up in the carpenter shop. Hard pine two by four inch pieces were glued together and afterwards the whole piece was planed on the planer. Six 9/16" holes were drilled in this piece to correspond with the bolts in the concrete base. Two 1/2" holes were then drilled in the center to fasten the pump. A 1" hole was drilled to let the suction pipe down into the oil tank.

The writers designed an oil tank with an open top, shown in Fig. 5, of No. 18 gauge galvanized iron. This was designed to fit on the inside of the hollow pump base. The oil tank was made in the college shops. A heavy machine oil is to be used in this machine.

The machine as completed rests on four cast iron plates, Fig. 7, two at each end. At each end five feet nine inches from the center stands a hydraulic jack. (Fig. 11). There is a knife edge on the top of the jack and this rests on a small steel bearing plate, Fig. 6. The plate is designed to distribute the pressure so as not to crush the concrete. Thru the center of the beam are four

steel rods (Fig. 8) designed to carry the load by tying the standard beam to the base beam. The pressure is distributed by two 3" x 12" x 18" cast iron plates, shown in Fig. 9, one placed beneath the base beam the other at the top above the beam to be tested. The upper plate has a knife edge as shown in Fig. 10, attached beneath it by a half inch machine bolt. The upper plate is supported by two nuts placed beneath it at opposite corners.

The pressure is to be applied by a commercial hand force pump with a 1" plunger. It is connected to the jacks by a 3/4" flexible copper pipe to provide for varying the span between the jacks by allowing them to be moved. The pressure is measured by a gauge placed in the pipe line at the pump.

If it is desired to apply the load at third points a steel I-Beam may be used in the center.

The development of the formulae used, the analysis of the standard beam, the calculations for the base-beam of the machine, details and drawings of the machine are on the following pages.

STANDARD NOTATION.

f_s = Fiber stress of steel.

f_c = Fiber stress of concrete.

M = External bending moment in inch pounds.

E_s = Modulus of Elasticity of steel.

E_c = Modulus of Elasticity of concrete.

d = Depth of beam to steel.

d' = Total depth of beam.

b = Breadth of beam.

A_s = Area of steel.

$n = \frac{E_s}{E_c}$

k = ratio of depth of neutral axis to depth d.

j = ratio of lever arm of resisting couple to depth d.

p = steel ratio $= \frac{A_s}{bd}$

BILL OF MATERIALS.

REINFORCING STEEL.

13 pcs.	11/16" round rods	16' - 0"
32 pcs.	5/16" round rods	6' - 1'
2 pcs.	5/16" round rods	16' - 0"

CONCRETE.

18 sks. cement.

2 yds. 3/4" washed gravel.

2 yds. " sand.

FORM.

17 pcs. 1 x 6 - 16 Y.P. Flooring.

5 pcs. 2 x 4 - 12 Y.P.

4 pcs. 2 x 4 - 16 Y.P.

2# 6^D Nails.

2# 10^D Nails.

ACCESSORIES.

1 only 1" Single Acting Boiler Tester's Feed Pump.

2 pcs. 3/4" #4 gage seamless copper tubing 10 ft.

4 gasoline tubing connections.

2 - 3/8" Machine bolts and nuts.

1 - 9-1/2 x 15-1/2" x 14" galv. iron oil tank Pump Base.

1 Only 300# Gage.

1 - 3" x 18" x 24" built up wood top.

6 - 1/2 x 10 Machine bolts and nuts.

6 pcs. 1" x 6" x 24" Y.P. Flooring.

6 pcs. 1" x 6" x 20" Y.P. Flooring.

6 pcs. 1" x 6" x 16" Y.P. Flooring.

6 pcs. 1" x 6" x 9" Y. P. Flooring.

Formulae for Working Stresses

The formulas used may be developed as follows:

Total compressive resistance = total tensile resistance or $\frac{1}{2} f_c k b d = A_s f_s$ (a)

Assuming that deformations vary as the distances of the fibers from the neutral axis and assuming stress porportional to deformation $\frac{f_c}{E_c k d} = \frac{f_s}{E_s d(1-k)}$ which reduces to

$$f_s = f_c n \frac{1-k}{k}, \text{ or } f_c = \frac{f_s k}{n(1-k)}, \text{ or}$$

$$k = \frac{1}{1+\frac{f_s}{n}} \qquad (b)$$

The total resisting moment of the beam is the sum of the moments of the total compressive stresses and of the total tensil stresses about the neutral axis, or

$$M = \tfrac{2}{3} kd \left(\tfrac{1}{2} f_c k b d\right) + d(1-k) A_s f_s$$

$$= \tfrac{1}{3} f_c k^2 b d^2 + A_s f_s d(1-k) \qquad (c)$$

Eliminating k between equations (a) and (b) the following formula for steel ratio results.

$$p = \frac{\frac{1}{2}}{\frac{f_s}{f_c}\left(\frac{f_s}{n f_c}+1\right)}$$

Introducing the value of f_s into (a) from (b)

$$\tfrac{1}{2} k^2 b d - A_s n(1-k) = 0$$

$$\tfrac{1}{2} k^2 b - p b n(1-k) = 0$$

From which $k = \sqrt{2pn + (pn)^2} - pn = \frac{1}{1+\frac{f_s}{n f_c}}$ (1)

$$j = 1 - \tfrac{1}{3} k \qquad (2)$$

$$p = \frac{A_s}{bd} = \frac{f_c k}{2 f_s} \qquad (3)$$

Substituting the value of $A_s f_s$ from (a) into (c)

$$M_c = \tfrac{1}{2} f_c k (1 - \tfrac{1}{3} k) b d^2$$

$$M_c = \tfrac{1}{2} f_c k j b d^2, \text{ or } bd^2 = \frac{2M}{f_c k j}, \text{ or } f_c = \frac{2M}{k j b d^2} \qquad (4)$$

Substituting the value of f_c from (a) into (c) remembering $A_s = pbd$

$$M_s = p f_s j b d^2, \text{ or } bd^2 = \frac{M}{p f_s j}, \text{ or } f_s = \frac{M}{A_s j d} \qquad (5)$$

Solving (a)

$$f_c = \frac{2 f_s p}{k} \text{ or } \frac{f_s k}{n(1-k)}, \text{ or } p = \frac{f_c k}{2 f_s} \qquad (6)$$

Design of Machine Base

$f_c = 650$ $\quad f_s = 16000$ $\quad n = 15$

1:2:4 Concrete

Assume $b = 26$ inches

$$K = \frac{1}{1 + \frac{16000}{15 \times 650}} = 0.379 \qquad \text{From (1)}$$

$$j = 1 - \tfrac{1}{3} \times 0.379 = 0.874 \qquad \text{" (2)}$$

$$p = \frac{650 \times 0.379}{2 \times 16000} = 0.0077 \qquad \text{" (3)}$$

$M = 20000 \times 72 = 1440000$ inch pounds

$$bd^2 = \frac{2 \times 1440000}{650 \times 0.379 \times 0.874} = 13400 \qquad \text{From (4)}$$

$$d = \sqrt{\frac{13400}{26}} = 23.5''$$

$$d' = 25.5''$$

$A_s = 0.0077 \times 26 \times 23.5 = 4.7$ " (3)

Use 13 $\frac{11}{16}''$ rd. = 4.83

In order to prevent the ends of the beam shearing off due to the pressure under the jacks the base-beam was made 16 ft. long

Volume = $16 \times 2.17 \times 2.125 = 73.58$ cu. ft.

or 2.73 cu. yds.

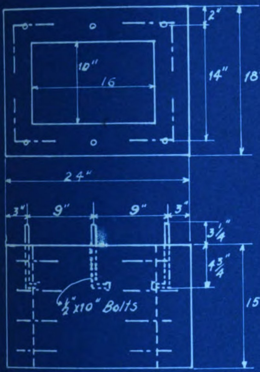


Fig 3

Concrete Pump-Base

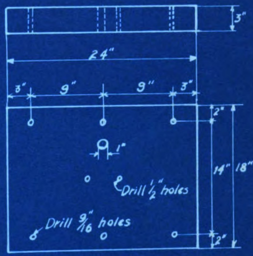


Fig 4

Hardwood Pump-Base

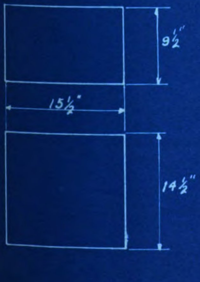


Fig 5.

Galvanized Iron Oil Tank.

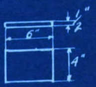


Fig 6

Steel Bearing Plate

CONCRETE BEAM TESTER DETAILS	
THESIS - HIMEBAUGH & MCGAW	
SCALE 1" = 1'	JULY 20, 1919

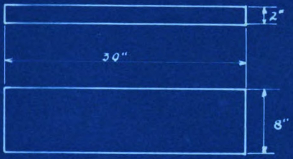


Fig 7 Cast Iron Plate.

Fig 8
1¼" Rod - Nuts to fit.

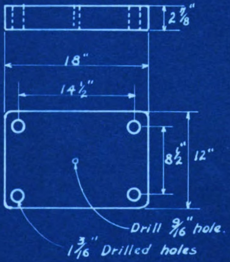


Fig 9 Cast Iron Plate.

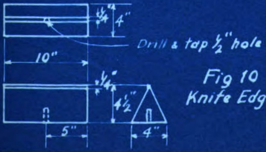


Fig 10
Knife Edge

CONCRETE BEAM TESTER DETAILS	
THESIS - HIMEBAUGH & MCGAW	
SCALE 1" = 1'	JULY 20, 1919

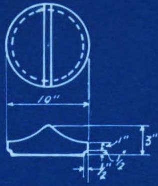


Fig 11 c
Knife Edge

Fig 11 a
Cylinder

Fig 11
Hydraulic Jack.

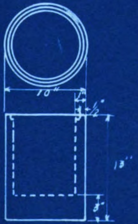


Fig 11 b
Plunger

CONCRETE BEAM TESTER HYDRAULIC-JACK	
THESIS - HIMEBAUGH & McGAW	
SCALE 1" = 1'	JULY 20, 1919

POCKET CONTAINS

FIG 1 ASSEMBLY PRINT 18"x24"

FIG 2 DETAIL of BASE PRINT 18"x24"

FIG 1