Balbach ~ Comparative strength of various concrete tunnel section

SUPPLEMENTARY MATERIAL IN BACK OF BOOK

T H E S I S.

C O M P A R A T I V E S T R E N G T H O F V A R I O U S C O N C R E T E T U N N E L S E C T I O N S.

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1904

THESIS

The building of tunnels has been practiced for ages; but although many different shapes and various materials have been used in their construction, no tests have ever been made to ascertain which shape is the stronger. With this object in view our tests were conducted.

No matter of such a nature being available for reference we were obliged to make our own assumptions and trust that they were correct. In the first place, we assumed that if we constructed some small tunnels of various common shapes and proportioned them as near as possible like full sized sections and loaded them to destruction the same relative result would be obtained as by crushing full sized sections. Four different shapes were then made, namely: a section with perpendicular sides and semi-circular arch; one section of horse-shoe shape, semi-circular arch; another with horse-shoe for inside and straight on outside, semi-circular arch; and one perpindicular on inside and slanting on outside, so as to make the base thicker. (See Blue Print)

To mould these sections forms were made of galvanized iron and wood. Ribs of wood were sawed out to the shape desired and the sheet iron nailed on these. A form of the inside and one for the outside were made and the concrete was rammed in between these and allowed to set. The inside mould was then

forced out and the outside mould sprung off. The tunnels were made two feet long and three of each kind were made. The composition consisted of three (3) parts of common sand, passed through a one-fourth (1/4") inch mesh sieve to one part of Portland cement from Jonesville, Michigan. About 10% of water was used.

The intention was then to break these at the same age but owing to the limited time at our disposal this could not be done. They were, therefore, all broken in one week, with the age varying from five weeks to nine weeks. They were all allowed to set dry.

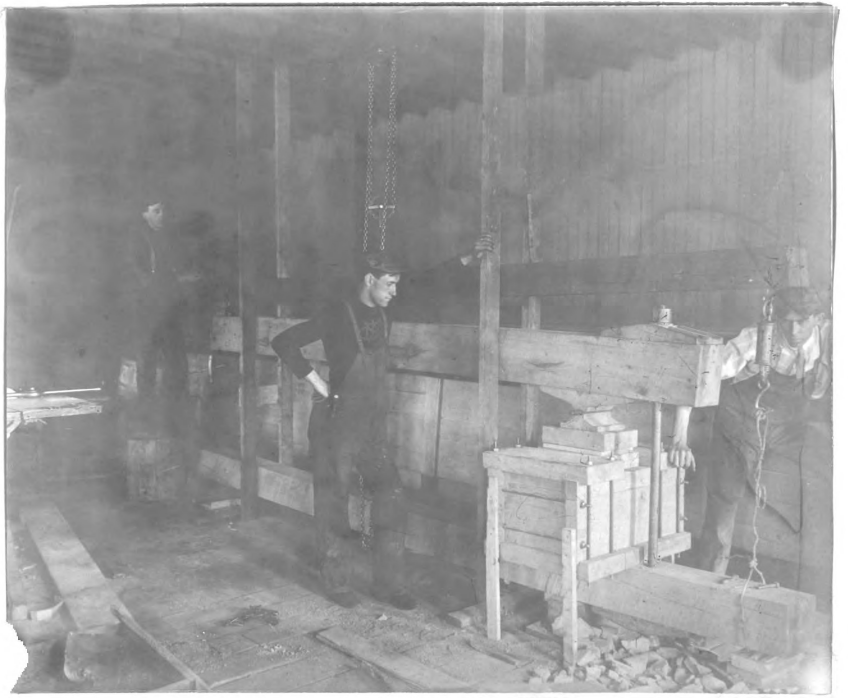
Some concrete beams were also made; one consisting of a block 6"x11"x2" with straight sides and one of the same dimensions with arched sides. Thirteen of these were made, seven (7) of the former and six (6) of the latter, the composition being the same as for the tunnels. The molds were made of wood.

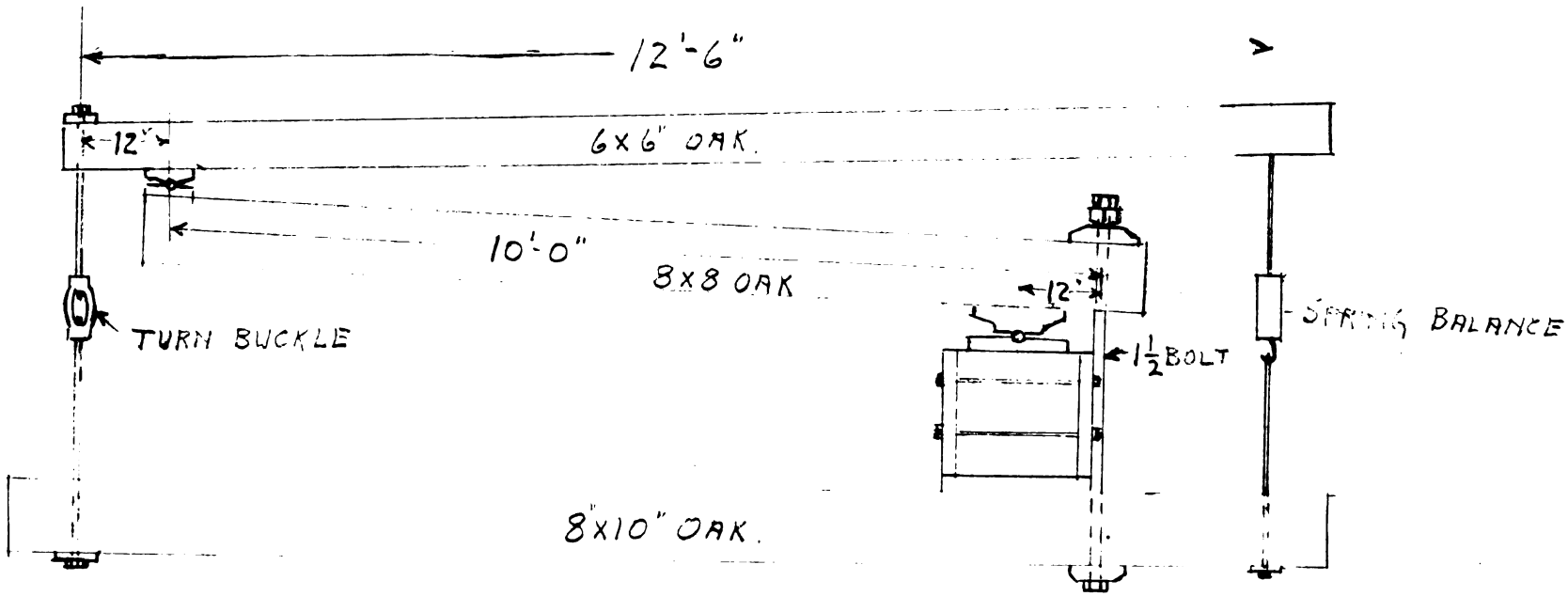
In breaking the tunnels the attempt was made to approach natural conditions as near as possible. A special machine was constructed for this purpose, consisting of a compound lever and acting on the principle of a nut cracker. A photograph of the machine in operation is included in this report. The upper lever is a 6"x6"x14ft. with a lever arm of 12-1/2 ft. The lower lever is an 8"x10"x12ft. with a lever arm 10 ft., all

of oak. The combined leverage was then 12-1/2 x 10 = 125. A spring balance was attached at the end of the upper lever as shown and the pressure on the tunnel thus ascertained. The bearings were made as small as possible with safety so as to minimize the friction. Cast iron plates were bolted on the timbers in order to prevent the crushing of the wood. (See Photograph and Blue Print.)

A wooden box was constructed in which the tunnels were placed for testing. A layer of sand, about 1-1/2", was placed in the bottom of the box and the tunnel placed upright on this. The box was then compeltely filled with sand, making about two inches (2") of sand over the top of the tunnel. The box was completely closed over with the exception of one square foot in the top through which the pressure was applied. Dry sand was used. A pressure applied through this opening would then distribute through the sand to the sides and practically the same condition be produced as in actual practice.

The pressure due to the weight of the levers alone was determined as follows: A Buffalo scale was placed at some distance from the crushing point and a lever placed so as to reach under the pressure point and supported a short distance beyond. The machine lever was then allowed to rest upon this small lever and the turn-buckle on the machine drawn up until





ARRANGEMENT OF LEVERS.

the upper lever just balanced. The scales then read 770#. The lever arm of the scale was 7 ft. 9-3/4 in. and that of the pressure arm was 4-1/2 in. Therefore 770 x 7' 9-3/4" ÷ 4-1/2" = 16040#, the constant of the machine. This is somewhat smaller then the theoretical constant for some of the power is consumed in friction. The load on the tunnel then will be the reading of the spring balance x 125 + the constant of the machine. In this way the breaking loads were determined in each case. The machine was designed for 50000# but this pressure was not reached. The following table gives a record of the results. (See Table 1)

Description of Fracture.

No. 1 was not full length, one end being broken off but it was tested. It broke very easily, requiring but 10# pressure on the lever. After uncovering, it was found to be completely fractured, the arch crushed in and the sides and bottom broken into small pieces. No. 2 was sound and after uncovering was found to have the entire arch crushed in; the sides and bottom were but slightly cracked. No. 3 was sound and after uncovering was found to have the arch crushed entire length and the sides slightly cracked but standing. The bottom was cracked but little.

Table No. 1.

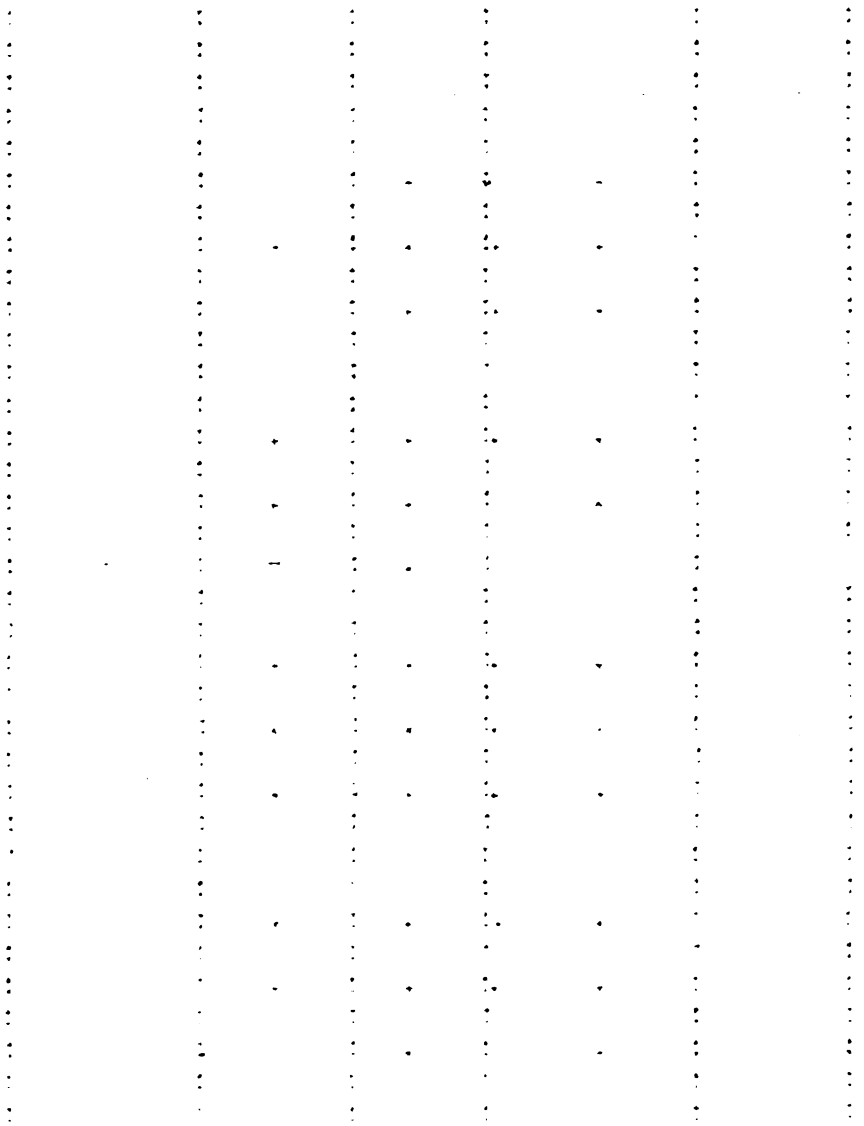
L O G O F R E S U L T S.

No.	Date Made	Date Broken	Age	Shape	Weight	Spring Reading	Total ж Pressure
1	April 6	May 16	5 Wk. 5 Da.	Fig. 1	50#	10#	17290
2	March 18	May 16	8 Wk. 3 Da.	Fig. 1	49.6	130	32290
3	March 16	May 19	9 Wk. 1 Da.	Fig. 1	51	120	31040
						Average	31665
4	March 18	May 17	8 Wk. 4 Da.	Fig. 2	55.4	115	30415
5	April 6	May 18	6 Wk.	Fig. 2	54.6	67	24415
6	March 16		Fractured	Fig. 2	--	--	--
						Average	27415
7	April 9	May 18	5 Wk. 4 Da.	Fig. 3	58.8	125	31665
8	April 12	May 19	5 Wk. 2 Da.	Fig. 3	59.3	85	26665
9	April 13	May 17	4 Wk. 6 Da.	Fig. 3	60.8	135	32915
						Average	30415
10	April 9	May 17	5 Wk. 3 Da.	Fig. 4	57.3	117	30665
11	April 12	May 19	5 Wk. 2 Da.	Fig. 4	56.4	132	32540
12	April 13	May 18	5 Wk.	Fig. 4	58	105	29165
						Average	30790

Constant = 16040#

ж Total pressure = scale reading x 125 + constant (16040#)
' Made of Wabash Portland Cement
• Only Nos. 2 and 3 were used to get average of Fig. 1

Fig. 1 - Horse-shoe
Fig. 2 - Straight Outside and Inside
Fig. 3 - Straight Inside Slant Outside
Fig. 4 - Straight Outside Horse-shoe Inside



No. 4 was sound and after uncovering was found in same condition as No. 3.

No. 5 was also sound but after applying the load the arch was found crushed in, also one side; the other side remained standing but cracked, the bottom also cracked.

No. 6 was dropped by accident and fractured and so could not be tested.

No. 7 was sound but after test was found with the arch crushed in as in the others. The sides were badly broken but still standing. The bottom was slightly cracked.

No. 8 was in good condition and after test showed the arch completely crushed in. The sides and bottom were but slightly broken.

No. 9 was perfectly sound but after load was supplied showed arch badly crushed in with the sides and bottom in fairly good condition.

No. 10 was sound and after test showed arch crushed in with the sides and bottom but slightly cracked.

No. 11 was in good condition before test but afterwards showed complete crushing in of the arch and extensive fracture of the sides and bottom.

No. 12 was perfect before the test and afterwards showed the arch crushed in as far as the springing line. The

rest of the walls and bottom were very slightly injured.

General Conclusions:-

In every case the tunnel failed by crushing in the arch a little above the springing line. The sides in some cases were quite extensively broken and in others showed but few cracks. In nearly every case the bottom held together well and was fractured but slightly.

Taking the average load of the three tunnels of the same shape we find the horse-shoe shape to be the strongest. This shape was the lightest weight indicating that less material was necessary for construction. This would perhaps be offset by the greater difficulty of construction. The only advantage that is obtained by Fig. 3 is the greater base area where heavy traffic is to take place in the tunnel. Fig. 4 does not give greater base area and besides has less room on the inside and uses more material.

If more tunnels of each variety had been made our results would have been more reliable. The difficulty of getting all tunnels alike makes the result more or less uncertain where the average is taken. For instance, in the test of Fig. 3, one test showed a low result whereas the other two showed high results. This may have been due to construction. Judging from the results as a whole, would say that there is no advantage in thickening the sides for ordinary conditions as most of the pressure seems to come on the arch above the springing line. Our conditions perhaps were not ideal for we had but two inches

(2") of sand above the highest point of the arch and the pressure was therefore greatest there. If the depth of sand had been greater better results would have been obtained, without doubt.

Breaking of Beams.

As before stated, beams of concrete were constructed of the shape of the sides of the tunnels Nos. 1 and 2 for the purpose of comparing their strength. In a tunnel the pressure from the load on the arch is sustained by the side walls. Also the lateral pressure of the earth on the sides must be sustained by the side walls of the tunnel. To obtain such loading a machine was designed to operate in conjunction with the Tinius Olsen testing machine in the M. A. C. laboratory. This consisted of a timber 6"x6"x6', on top of which was placed a casting supporting the two ends of the concrete beam. One of these supports was fixed rigidly and the other was mounted on rollers in order to reduce friction. This movable and was attached to a dynamometer consisting of a cylinder with a tight fitting piston, compressing oil. A screw pressed against the dynamometer and by turning the same the pressure in the dynamometer could be regulated. This machine was placed in the testing machine and the load brought directly over the beam.

All of the beams were broken with such double loading excepting one which was broken with a load only from the top.

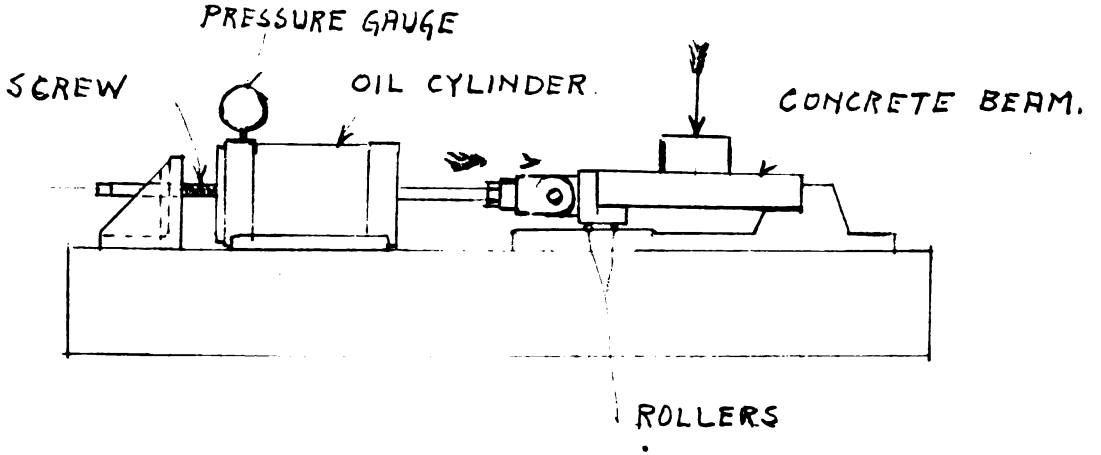
(See drawing for arrangement of machine.)

The diameter of the piston was 5" making an area of 19.635 sq. in. The area of the end of the beam was 2"x6" = 12 sq. in. Therefore the end pressure per sq. in. on the beam was $\frac{19.635}{12}$ x gage reading. The beams were of different ages but one of each kind of the same age was selected to be broken with the same end pressure. In this way two of each kind were broken under 50# end pressure per sq. in. by the gage, two under 75# pressure per sq. in. and two under 100# pressure per sq. in. by the gage.

The load was applied at the center of the beam with a block 3"x5" and the results tabulated below. It will be seen that the one broken without end pressure sustained but a very small load compared with the others; also that the breaking load for all of the arched beams was greater than that for the straight beam with the exception of No. 12. This one was very weak and should not be considered in the results.

In every instance, the beam would first crack on the under side either parallel to the load or at an angle of 45°. After cracking, the load could be considerably increased before the beam would yield.

DEVICE FOR APPLYING END PRESSURE ON BEAMS,



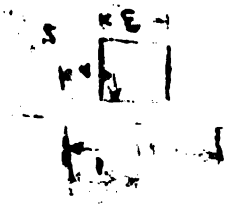


Table No. 11.

S T R A I G H T S I D E S.

NO.	Date Made	Date Broken	Age	Gage Reading	Total End Pressure	Balance Reading •	Average of Two
1	April 6	May 28	7 Wk. 3 Da.	50#	9812.5#	2330#	_____
2	April 8	May 28	7 Wk. 1 Da.	50	9812.5	2350	2340#
3	April 9	May 28	7 Wk. 0 Da.	75	14720	3350	_____
4	April 11	May 28	6 Wk. 5 Da.	75	14720	3400	3375
5	April 15	May 28	6 Wk. 1 Da.	100	19625	3450	_____
6	April 16	May 28	6 Wk. 0 Da.	100	19625	3650	3550
7	April 12	May 28	6 Wk. 4 Da.	0	0	1200	1200
			C I R C U L A R				
8	April 8	May 28	7 Wk. 1 Da.	50#	9812.5#	3200#	_____
9	April 16	May 28	6 Wk. 0 Da.	50	9812.5	2750	2975#
10	April 9	May 28	7 Wk. 0 Da.	75	14720	3610	_____
11	April 11	May 28	6 Wk. 5 Da.	75	14720	3540	3575
12	April 12	May 28	6 Wk. 4 Da.	100	19625	2990 ✱	
13	April 15	May 28	6 Wk. 1 Da.	100	19625	3900	3900

✱ This reading not used in comparison.

• Balance reading contains dead weight of the machine which was 120#.

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