LATERAL PRESSURE OF FLUID CONCRETE

Thesis for the Degree of M. S.

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Robert Charles McLravy

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This is to certify that the

thesis entitled

LATERAL PRESSURE OF FLUID CONCRETE

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LATERAL PRESSURE OF FLUID CONCRETE

By

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INTRODUCTION

During the summer of 1949, the occasion arose for the investigation and checking of the design of the formwork for a concrete bridge abutment. There was some doubt as to correct intervals for placing the walers and tie rods for holding the form together. In order to compute the pressure exerted by the fresh concrete against the form, some value for the unit lateral pressure of fresh concrete had to be selected.

Upon consulting the text books, it was found, as was to be expected, different authors recommended various values for this pressure. These values ranged from as low as 120 psf to 145 psf, the full weight of the concrete. The majority of authors made no differentiation between stiff or lean mixtures of concrete, although they stated that this factor would influence the correct value to be used. If the concrete were to be vibrated into place, instead of hand spaded, most recommended the use of the full equivalent fluid pressure of concrete, generally accepted as 145 psf.

The design of the formwork was then checked, using the 145 psf value. The results showed that the stresses in the tie rods would be almost at the failure point and no additional strength would be provided for impact, vibration and other factor of safety stresses.

When the abutment was poured a close watch was kept upon the formwork. No failure or yielding of the formwork was observed either during the pour or the stripping of the forms afterward. As a result, the impression was formed that the lateral pressure of fluid concrete against formwork was not as great as generally believed.

Thus, the idea of this thesis was born.

PROCEDURE

At the start of this thesis, it was thought that the Goldbeck Pressure Cells would be used. It was soon discovered, however, that they were not available through the Civil Engineering department and that the cost of them would be greater than this experiment justified. Consequently, another method had to be devised.

After consulting with Dr. Harris, Professor Cade, and Dr. Pian, an arrangement was devised using electric strain gages. This arrangement was made in the form of a wooden box approximately two feet square and five and one half feet high. The lower side of the box was cut out and made into a sliding panel. This panel was held in place by two one-quarter inch circular steel tie rods acting upon 4" x 4" walers across the front of the panel and the back of the form. The box was made of three-quarter inch plywood fastened to 2" x 4"'s and held together with built up 4" x 4"'s and one-quarter inch steel rods. It was so constructed, that the component parts could be stripped, cleaned and easily reassembled.

The forms were erected in the concrete laboratory and the sliding panel shaped until it slid smoothly. Six inch electric strain gages were applied to the two tie rods holding the panel in place. (These gages and the potentiometer for reading them were supplied through the courtesy of the Michigan State Highway Research Laboratory.) Marks were established at distances of two, three, four and five feet above the bottom of the form. The forms were then oiled with mineral oil to prevent bonding between the concrete and the wood.

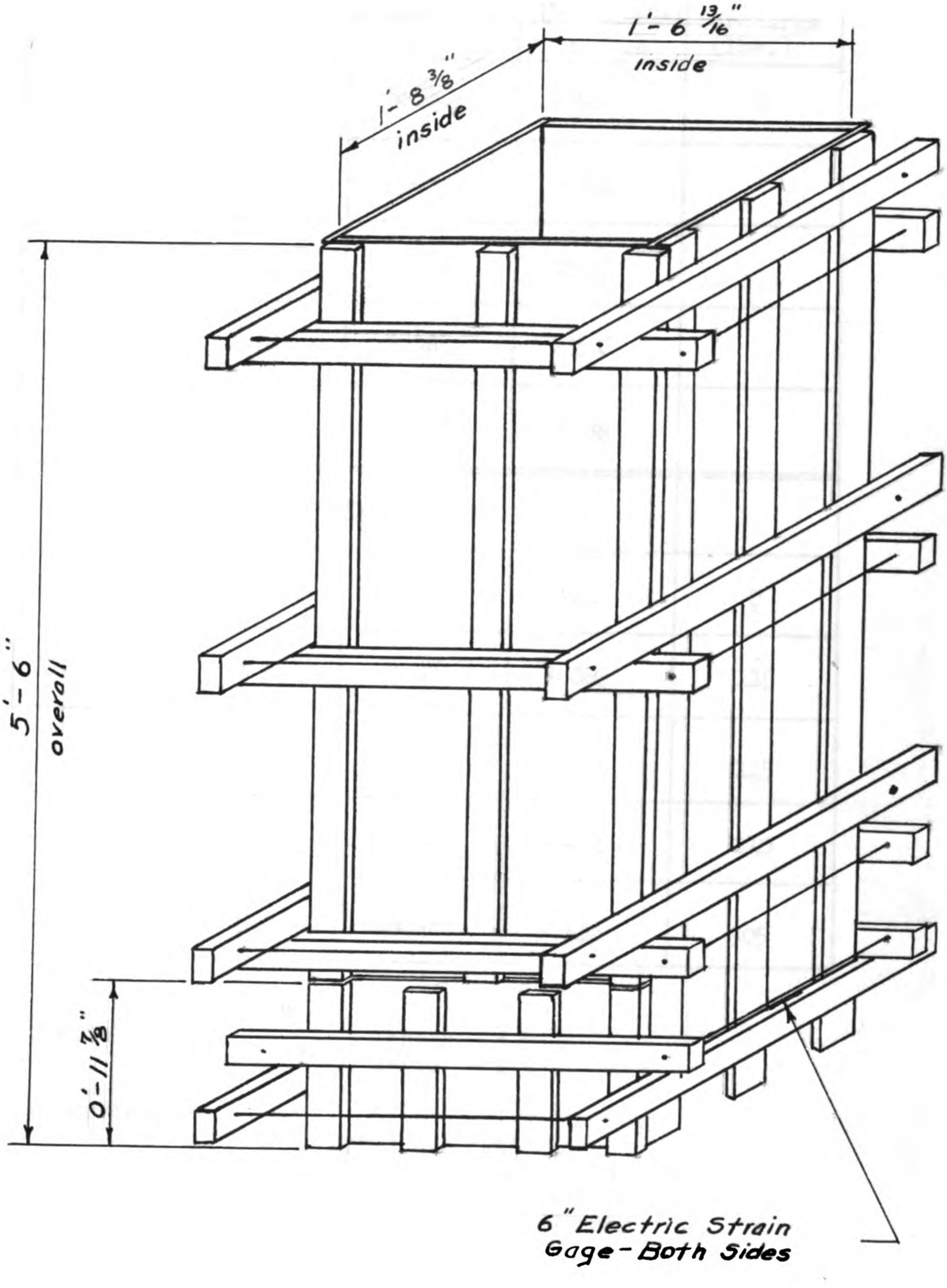
Concrete was then placed in the forms to the desired height and the deformation of the tie rods recorded by means of the electric strain gages. The concrete was vibrated before each reading using an electric powered, flexible cable type vibrator*.

When the forms were filled to the five foot mark, a platform was placed on the concrete and a surcharge added. This was an attempt to determine the elapsed time required to produce enough set in the concrete so that any additional increment of concrete would not produce a corresponding increase in lateral pressure at the bottom of the form.

At the end of the experiment the electric strain gages and the tie rods were placed in a tension machine and calibrated. Knowing the area of the movable panel and the force exerted upon the tie rods, the lateral pressure was computed for each depth of concrete. This information was plotted in the form of graphs for comparison between the stiff and the lean mixtures of concrete on the theoretical fluid pressure of each mix.

* The completion of this thesis was greatly facilitated by the help of Mr. Larry Childs of the Michigan State Highway Research Laboratory.

SKETCH OF TEST FORM



Data Sheet Trial #1

Time	Depth (ft.)	Strain Gage (micro in.)		Surcharge (lbs.)
		West Gage	East Gage	
11:02 AM	0	595R8	760R5	0
11:15	2.0	680R8	840R5	
11:20	3.0	755R8	910R5	
11:25	4.0	780R8	935R5	
11:31	5.0	800R8	950R5	
	Time of Set			
12:04 PM	5.0	790R8	920R5	0
12:07	5.0	790R8	960R5	115
12:32	5.0	795R8	960R5	115
12:45	5.0	800R8	968R5	210
1:00	5.0	800R8	965R5	305

Strain Gages: Length - 6.0"
Ratio - 2.13

Concrete : Slump - 1/2" to 3/4"
Aggregate - 6A
Cement - Air Entraining Penninsula
28 day strength - 2,085 psi
$T_o = 58^\circ F$
$T_f = 62^\circ F$

Computations

Test #1

Head = 1.5'	West Gage	East Gage	
	680	840	
	595	760	
difference	85	80	micro-inches

100 x 85 /74.33 = 114.5 lbs

100 x 80 /75.2 = 106.2 lbs

220.7 lbs

Panel area $\frac{18.82 \times 11.87}{144}$ = 1.550 sq. ft.

Lateral pressure 220.7 / 1.550 = 142.5 psf.

Head = 2.5'		
	755	910
	595	760
	160	150

100 x 160 / 74.33 = 215 lbs. ; 100 x 150 / 75.2 = 199.8 lbs.

215 + 199.8 = 414.8 lbs.

414.8 / 1.55 = 267 psf.

Head = 3.5'		
	780	935
	595	760
	185	175

185 x 100 / 74.33 = 249 lbs. 100 x 175 / 75.2 = 233 lbs.

249 + 233 = 482

482 / 1.55 = 311 psf.

Head = 4.5'	West Gage	East Gage
	800	950
	595	760
	205	190

100 x 205 / 74.33 = 276 lbs. ; 100 x 190 / 75.2 = 253 lbs.

276 253 529 lbs.

529 / 1.55 342 psf.

Weight per cubic foot

volume of container	0.1962 cu. ft.
weight of container	0.50 lbs.
full weight sample #1	29.19 lbs
#2	28.87
#3	28.63
	3 | 86.69

28.896 - 0.5 = 28.396 lbs.

28.396 / 0.1962 = 144.5 lbs. per cu. ft.

Compressive strength

10 day average	2018 psi.
28 day	2085 psi.

Strain Gage Calibration for Trial #1

East Gage

No	Load (pounds)	Gage Reading (micro inches)	Increment
1	1,000	729R6	
2	2,000	1491R6	762
3	2,000	846R7	
4	3,000	1587R7	741

1503/20 = 75.15 micro inches per 100 pounds

West Gage

No	Load (pounds)	Gage Reading (micro inches)	Increment
1	100	530	
2	200	605	75
3	300	682	75
4	400	756	74
5	500	832	76
6	600	905	73
7	700	976	73

446/6 = 74.33 micro inches per 100 pounds

Data Sheet Trial #2

Time	Depth (ft)	Strain Gage (micro in.)		Surcharge (lbs.)
		West Gage	East Gage	
10:05 AM	0	530R8	680R8	
10:15	2.0	650R8	755R8	
10:20	3.0	730R8	860R8	
10:24	4.0	785R8	920R8	
10:30	5.0	860R8	1000R8	
	Time of Set			
11:20	5.0	850R8	1005R8	0
11:30	5.0	835R8	995R8	0
11:35	5.0	840R8	1000R8	205
11:45	5.0	840R8	1000R8	205
12:00 PM	5.0	840R8	1000R8	205

Strain Gages:
Length - 6.0"
Ratio - 2.13

Concrete:
Slump - 2 1/2" to 3"
Aggregate - 6A
Cement - Air Entraining Penninsula
28 day strength - 3350 psi
$T_o = 65°F$
$T_F = 58°F$

Computations

Test #2

	West Gage	East Gage	
Head = 1.5'	650	755	
	530	680	
difference	120	75	micro-inches

100 x 120 / 74.33 = 161.5 lbs. ; 100 x 75 / 75.6 = 99.2 lbs.

161.5 + 99.2 = 260.7 lbs.

Lateral pressure 260.7 / 1.55 = 172 psf

Head = 2.5'	730	860
	530	680
	200	180

100 x 200 / 74.33 = 269 lbs. ; 100 x 180 / 75.6 = 238 lbs.

269 + 238 = 507 lbs.

Lateral pressure 507 / 1.55 = 327 psf.

Head = 3.5'	785	920
	530	680
	255	240

100 x 255 / 74.33 = 344 lbs. ; 100 x 240 / 75.6 = 318 lbs.

344 + 318 = 662 lbs.

Lateral pressure 662/ 1.55 = 427 psf.

Head = 4.5'	West Gage	East Gage
	860	1000
	530	690
	330	320

100 x 330 / 74.33 = 443 lbs. ; 100 x 320 / 75.6 = 423 lbs.

443 + 423 = 866 lbs.

Lateral pressure 866 / 1.55 = 560 psf.

Weight per cubic foot

volume of container	0.1962 cu. ft.
weight " "	0.50 lb.
full weight sample #1	30.25 lbs.
#2	30.19
#3	30.22
	3|90.66
	30.25 - 0.5 = 29.72 lbs.

29.72 / 0.1962 = 150.6 lbs. per cu. ft.

Compressive strength

14 day average	2,598 psi.
28 day "	3,350 psi.

Strain Gage Calibration for Trial #2

East Gage

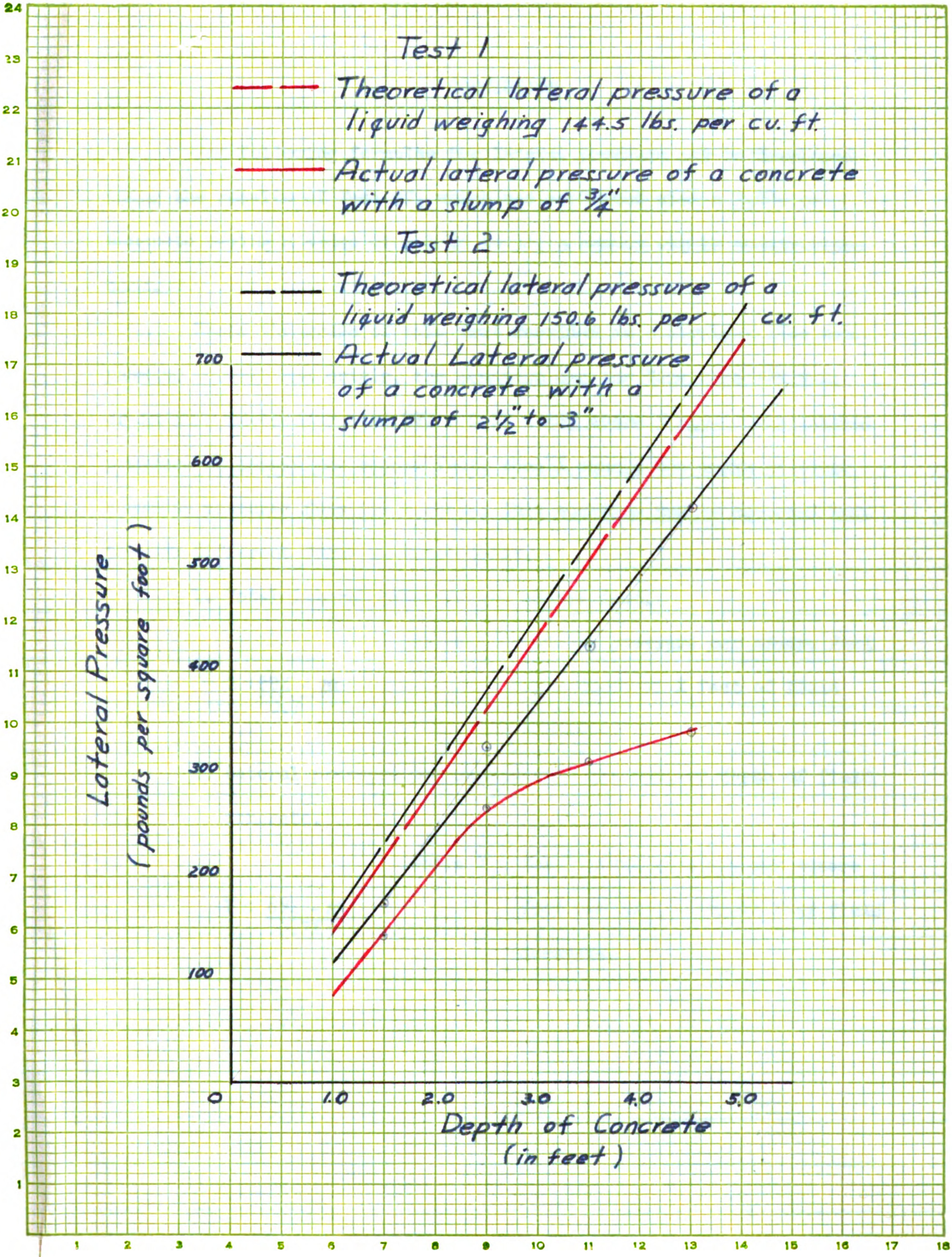
No	Load (pounds)	Gage Reading (micro inches)	Increment
1	200	885	
2	300	945	60 omit
3	400	1020	75
4	500	1096	76
5	600	1170	74
6	700	1245	75
7	800	1323	78

378/5 = 75.6 micro inches per 100 pounds

West Gage

No	Load (pounds)	Gage Reading (micro inches)	Increment
1	100	530	
2	200	605	75
3	300	680	75
4	400	756	76
5	500	832	76
6	600	905	73
7	700	976	73

446/6 = 74.33 micro inches per 100 pounds



Test 1
Theoretical lateral pressure of a liquid weighing 144.5 lbs. per cu. ft.
Actual lateral pressure of a concrete with a slump of 3/4"
Test 2
Theoretical lateral pressure of a liquid weighing 150.6 lbs. per cu. ft.
Actual Lateral pressure of a concrete with a slump of 2 1/2" to 3"
Lateral Pressure
(pounds per square foot)
700
600
500
400
300
200
100
0
1.0
2.0
3.0
4.0
5.0
Depth of Concrete
(in feet)

CONCLUSION

The following formulae for lateral pressure may be developed using the results of Test #2, which was performed with a 3,000 psi. concrete having a slump of 2 1/2" to 3", a common mix in construction work.

Since the graph of this test resulted in a straight line not passing through the origin, the equation has the form of $AX + BY = K$, or in this particular case $89X - 0.7Y = 10$, where Y equals the lateral pressure in pounds per square foot, when X equals the depth of fluid concrete measured from the surface. This equation can be arranged into the two different forms as shown below.

1. Total lateral pressure per square foot.

$$Y = \frac{89X - 10}{0.7}$$

where Y = lateral pressure per square foot at a depth of X feet of fluid concrete.

2. Lateral pressure per square foot per foot of depth of fluid concrete.

$$Y = \frac{89X - 10}{0.7X}$$

where Y = the lateral pressure per square foot per foot of depth X of fluid concrete.

Substituting values for X and Y in equation (2) gives the following results.

X = 1.0'	Y = 113.0 psf
X = 2.0'	Y = 120.0 psf
X = 3.0'	Y = 122.0 psf
X = 4.0'	Y = 123.8 psf
X = 5.0'	Y = 124.3 psf

As $X \to \infty$ the value of Y approaches a limit , thus:

$$\lim_{X \to \infty} \frac{89X - 10}{0.7X} = \lim_{X \to \infty} \frac{89}{0.7} = 127.3 \text{ psf}$$

Consequently, the results of these tests indicate that for forms whose dimensions compare with those of the test forms and where the rate of filling is not over five feet per thirty minutes at a minimum temperature of 60° F., the formwork should be designed to resist a lateral pressure of 125 psf per foot of depth of fluid concrete. This value of 125 is believed to be preferable to the actual computed value of 124.3psf for a five foot depth because it will include all the above stated depths and the designer has only one value to remember instead of several.

It was originally thought that as a collary of this thesis the determination of time of set of concrete in forms could be measured. The data gathered from this part of the work, however, was not conclusive. A different apparatus should be used for that determination. It can be seen from the data sheets that as the time interval increased after the last increment of concrete had been added, the strain gage readings started to decline although a surcharge was placed upon the fresh concrete. This was caused probably by the shrinkage of the concrete as it began to set. This does, however, indicate that as concrete takes its initial set, more concrete can be poured into the forms without an increase in the lateral pressure at the bottom of the form.

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