Operator's Manual

Linear Asphalt Compactor

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"An Industry, Agency & University Partnership"

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Table of Contents

I. Introduction and Safety

The *Linear Asphalt Compactor (LAC)* was developed to produce asphalt slabs for use in the PURWheel; it simulates the compactive action of a static steel wheel roller and is seen in Figure 1.1. Compacted slabs produced with the *LAC* can also be cut into cores for other types of testing. The *LAC* features a two-part compaction mold (Figure 1.1) that produces rectangular slabs 29.3 x 62.4 cm (11.5 x 24.5 inch) and between 3.8 and 10.2 cm (1.5 and 4.0 inch) thick. One half of the compaction mold is fixed and the other half is detachable to allow for removal of the compacted slabs. During compaction, asphalt mix in the compaction mold is moved back and forth under a roller (Figure 1.1). The upper frame of the *LAC* to which the roller is attached is hinged at one end and pinned to a hydraulic cylinder at the other (Figure 1.1); the hydraulic cylinder provides the desired compactive force reaction at the roller. Vertically arranged plates spread the compactive force from the roller into the loose asphalt mix; as each plate passes underneath the roller it can slide past neighboring plates which applies a kneading action to the mix. The total compactive effort applied to the sample is a combination of two parameters: hydraulic cylinder system pressure and total number of passes of the compaction mold underneath the roller.

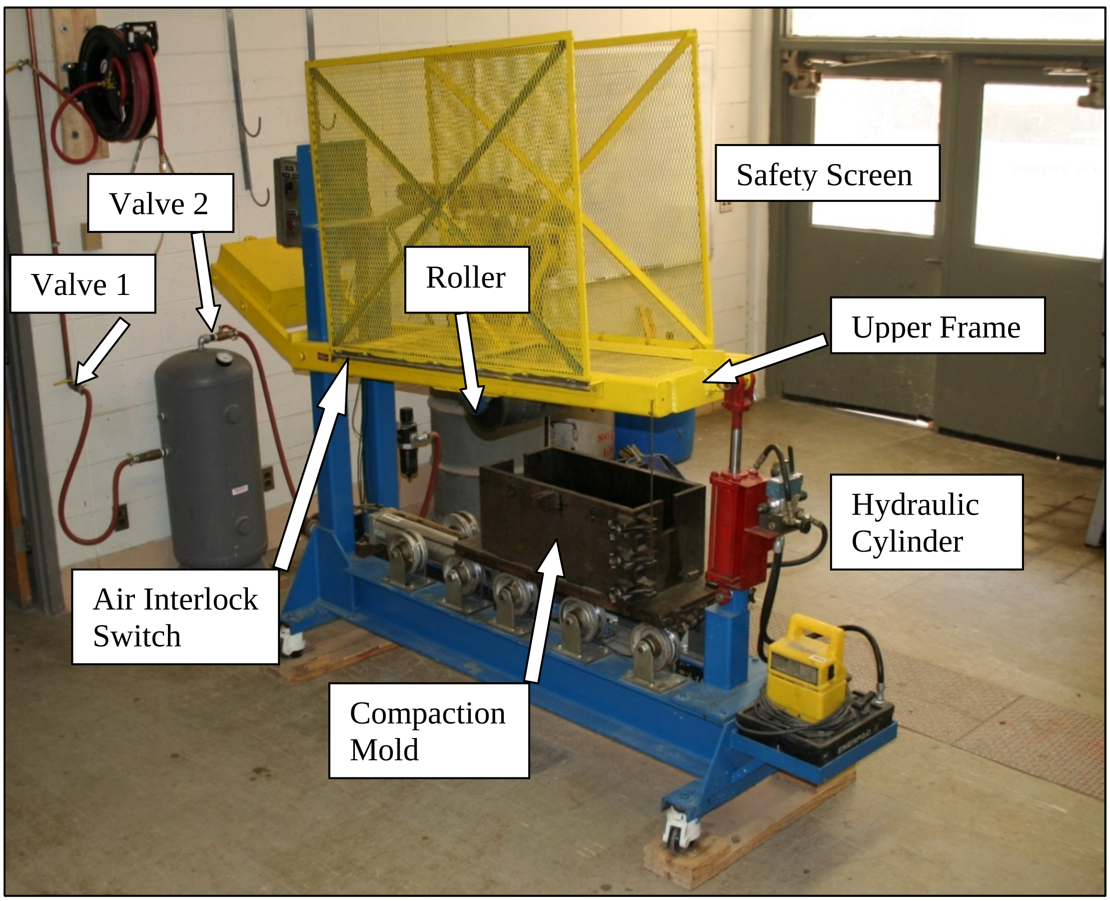


Figure 1.1 ***Linear Asphalt Compactor***

Two safety features are incorporated into the *LAC*: 1) expanded metal safety screens to shield the mold during compaction; and 2) air interlock switches to prevent the mold from moving in automatic compaction mode if the safety screens are not lowered and in position. There is a safety screen and an air interlock on each side of the upper frame. The safety screens are in the up position in Figure 1.1; they are hinged along the length of the upper frame. The air interlock switches are located between the safety screens and the upper frame near the hinge end of the upper frame (Figure 1.1).

A number of potential safety concerns exist with operation of the *LAC*; however with safety awareness by everyone involved in the compaction process, asphalt slabs can be compacted safely. Known safety concerns and items to be aware of during operation of the *LAC* include but are not limited to the following:

- Pinch points
    - When moving the detachable portion of the compaction mold
    - When placing or removing the compaction weights
    - While raising or lowering the upper frame
- Heavy pieces that could drop suddenly
    - Detachable portion of the compaction mold
    - Compaction plates whenever suspended by hoist
- Compaction mold could conceivably move unexpectedly whenever air pressure exists in system [valve 2 open (red handle)] even if the safety gates are up and air interlock switches are open
- The manual switch to move the compaction mold overrides the air interlock switches

All persons involved in operation of the *LAC* should use common sense and caution during its use. Always keep valve 2 (red handle) closed and no air pressure within the *LAC* system except when ready to compact samples. Never allow any parts of the body to be under the compaction weights while they are suspended. All other laboratory safety procedures apply when using the *LAC*. This is not intended to be comprehensive but rather to provide an overview of safety procedures specific to the *LAC*.

II. Operation

1. Preparation

To produce slabs of desired thickness the correct number of bottom plates (Figure 2.1) must be setup within the compaction mold. Bottom plates are steel and their dimensions are the same as the inside dimensions of the compaction chamber; they are either 1.3 cm (0.5 inch) or 2.5 cm (1.0 inch) thick. One of the two 2.5 cm (1.0 inch) plates is solid with rounded edges to fit snugly into the bottom corners of the compaction mold (2.5 cm solid in Table 2.1); the other has square edges and several holes drilled through it to reduce weight (2.5 cm holes in Table 2.1). The overall thickness of bottom plates (Figure 2.1) and final compacted mix target thickness within the compaction mold should be 12.7 cm (5 inch); the correct setups of bottom plates for various slab thicknesses are given in Table 2.1. In Table 2.1 bottom plate position refers to the order in which the bottom plates are stacked into the compaction chamber with position 1 being the first plate. Figure 2.1 illustrates the correct setup to compact a 7.6 cm thick slab as an example.

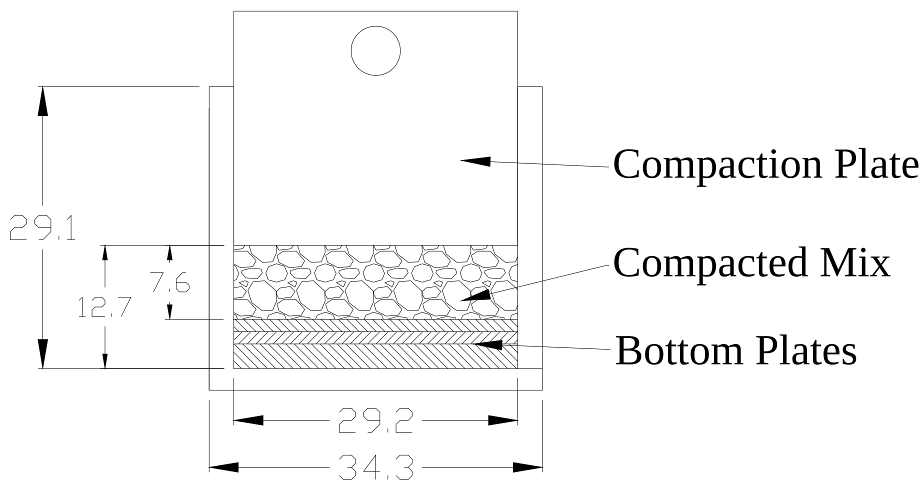


Figure 2.1 *LAC* Compaction Mold Cross-section View

Table 2.1 Bottom Plate Setup for Desired Slab Thicknesses

Slab Thickness	**Bottom Plate Thickness by Position**				
cm (inch)	**1**	**2**	**3**	**4**	**5**
3.8 (1.5)	2.5 cm solid	2.5 cm holes	1.3 cm solid	1.3 cm solid	1.3 cm solid
5.1 (2.0)	2.5 cm solid	2.5 cm holes	1.3 cm solid	1.3 cm solid	---
6.4 (2.5)	2.5 cm solid	2.5 cm holes	1.3 cm solid	---	---
7.6 (3.0)	2.5 cm solid	1.3 cm solid	1.3 cm solid	---	---
8.9 (3.5)	2.5 cm solid	1.3 cm solid	---	---	---
10.2 (4.0)	2.5 cm solid	---	---	---	---

Prior to compaction an infrared heater is used to heat the steel compaction mold to compaction temperature; the heater rests directly on top of the compaction mold (i.e. no vertical space between heater and mold). An average mold bottom surface temperature of 149 C (300 F) has been a target temperature. Variations of 28 to 39 C (50 to 70 F) have been seen between the highest and lowest measured surface temperatures on the bottom of the mold. At present, approximately three hours of preheating time before compaction should be used to reach compaction temperature when the mold is initially at room temperature. When multiple slabs are to be compacted consecutively, a one hour interval between subsequent compactions should be used to allow the mold to regain compaction temperature. With a 20 minute compaction turnaround time this provides 40 minutes of reheat time.

Several minutes prior to compaction, Air valve 1 (yellow handle) should be opened to pressurize the surge tank before the first compaction is scheduled to begin. Note that valve 2 (red handle) remains closed. Valve 2 is not opened until later in the compaction process as described in the following section.

2. Compaction Procedure

Just before compaction the infrared heater is removed; the compaction mold temperature is recorded and a piece of release paper is placed in the bottom of the compaction mold. A quantity of short term aged asphalt mixture is then introduced into the compaction chamber (Figure 2.2a). Figure 2.2b shows how the asphalt is leveled to produce a slab of uniform thickness; the temperature of the mix is recorded at this point. A second piece of release paper is placed on top of the mix followed by a thin piece of sheet metal; the sheet metal prevents the plates from settling too deeply into the loose mix before compaction. The sheet metal should be roughly flattened before each compaction and placed in the mold with the short ends curved up, away from the mix to ensure smooth ends of the compacted slab. Finally a set of 47 steel compaction plates totaling approximately 313.6 kg (690 lbs) are lowered on top of the mix in the compaction mold (Figure 2.2c). Only 45 plates are initially hoisted into the compaction mold, the final two plates are inserted with the aid of a large steel pry bar and a hammer. The pipe used for lifting compaction plates should be centered within the plates before compaction (Figure 2.2*d*).

The upper frame of the *LAC* is brought down and pinned to the hydraulic cylinder (Figure 2.2*d*). For best results the compaction mold should be centered under the roller before starting compaction. The safety screens are flipped down before compaction. The hydraulic pump is operated continuously while a relief valve holds the pressure in the system constant such that a constant force is exerted through the roller and into the asphalt mix. The hydraulic direction lever should be to the right for compaction (Figure 4.1*b*). Once the hydraulic system pressure has stabilized a separate compressed air system is actuated to move the compaction mold back and forth on roller guides for a specified number of passes. The stroke select should be set to *Long Stroke* for compaction (Figure 4.1*a*). A compaction pass is defined as one full extension or retraction of the air cylinder. Valve 2 (red handle) should be opened and the red stop button should then be turned to the left (Figure 4.1*a*) for operation. Once the desired number of compaction passes is completed, the red stop button is pushed in and valve 2 (red handle) is closed. The direction lever (Figure 4.1*b*) should be flipped to the left to reverse flow and extend the hydraulic ram. The safety screens are secured, the hydraulic ram un-pinned and the upper frame is returned to the up position. The compaction mold clamps should be loosened to allow removal of all 47 compaction plates at once. Figure 2.2*e* shows a compacted slab with the detachable portion of the mold removed; two exposed edges of each slab were identified with numbers to maintain a reference corner for testing.

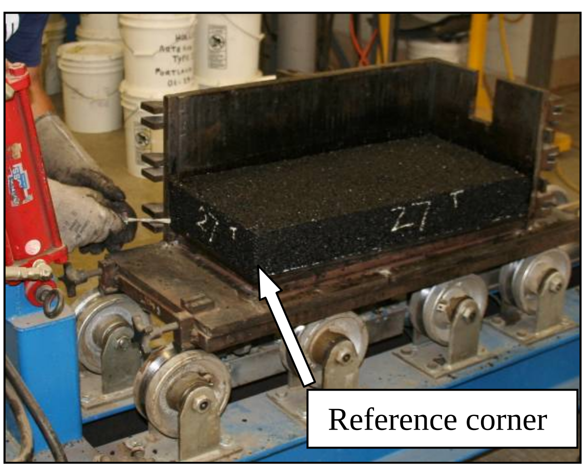
The compacted slab and the solid bottom plate it rests on are carefully slid onto a hydraulic lift cart; care must be taken not to damage the corners of the compacted slab. The slab is flipped over and the release paper removed from the bottom before it cools completely. The slab and bottom plate are placed on two sawhorses, a second plate is set on top, and two operators can carefully flip the entire assembly. The slab must remain flat and fully supported until completely cool.

(a) Loading Mix into LAC Compaction Mold

(b) Leveling of Mix in LAC

(c) Lowering Compaction Plates onto Mix

(d) LAC Ready for Compaction



(e) Compacted Slab

(f) Disassembled LAC Detail

Figure 2.2 Slab Compaction Process

III. Maintenance

Periodic maintenance of the *LAC* is straightforward and consists of cleaning the inside of the compaction mold, draining accumulated water from the air system, greasing bearings, and checking oil level in the hydraulic system; Figure 3.1 shows layout of maintenance locations. Periodic cleaning of the compaction mold surfaces in contact with asphalt mixture will prevent sticking; WD-40 or other solvent works well, especially while the metal is still hot. Water accumulates within the air system and should be removed regularly; this can be done by opening the drain plug at the bottom of the surge tank and by purging the moisture trap of the *LAC* air regulator (A in Figure 3.1). The desiccant in the air drying rack should be dried or replaced frequently as well. Each of the rolling guides has two grease fittings and each bearing supporting the roller has a grease fitting that should be lubricated from time to time. There are 22 grease fittings in all (B in Figure 3.1). The hydraulic system operates on hydraulic oil and the reservoir should be maintained to within 2.5 cm (1 inch) of the fill port located on the top of the hydraulic system reservoir (C in Figure 3.1).

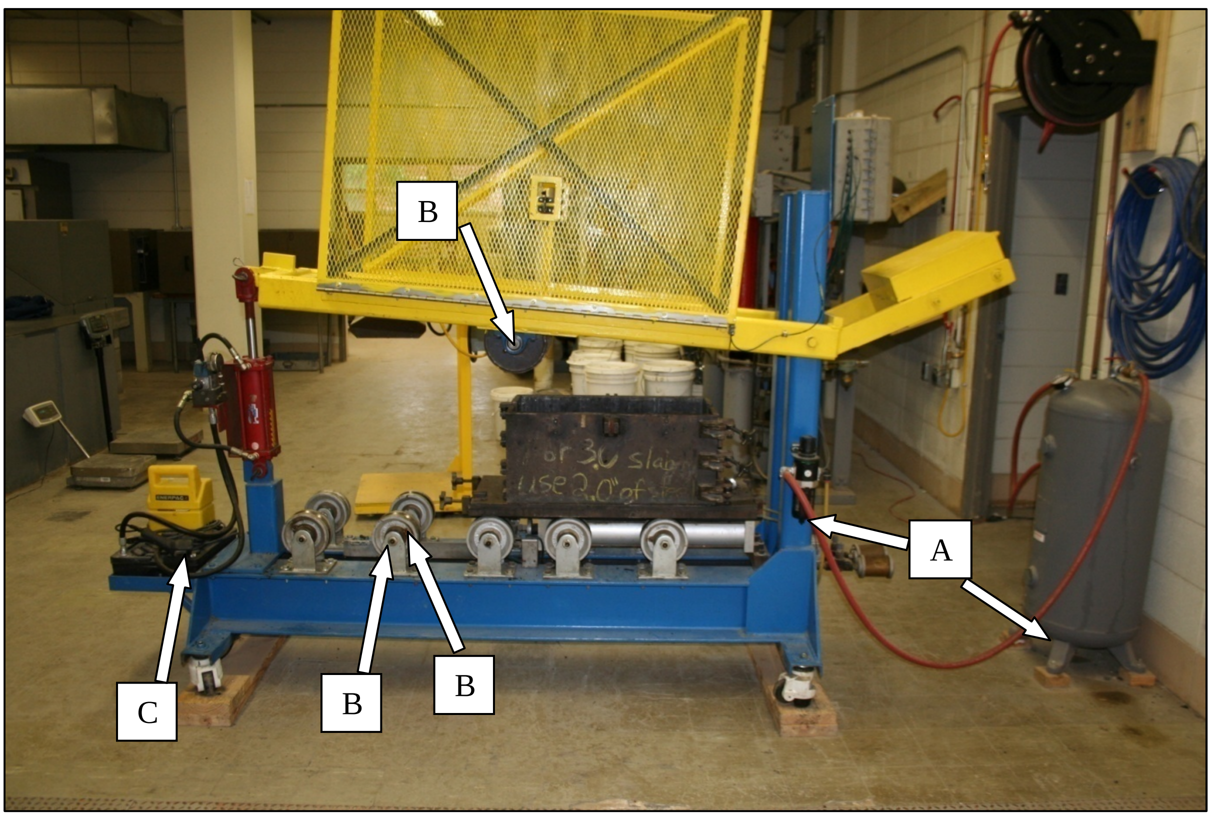
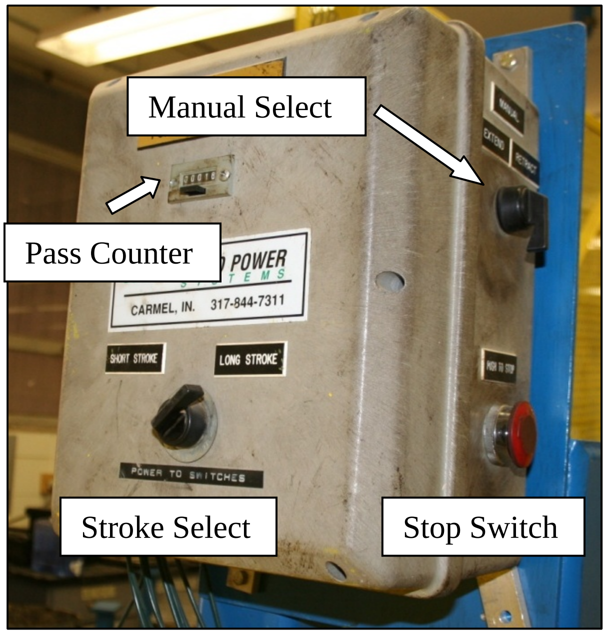


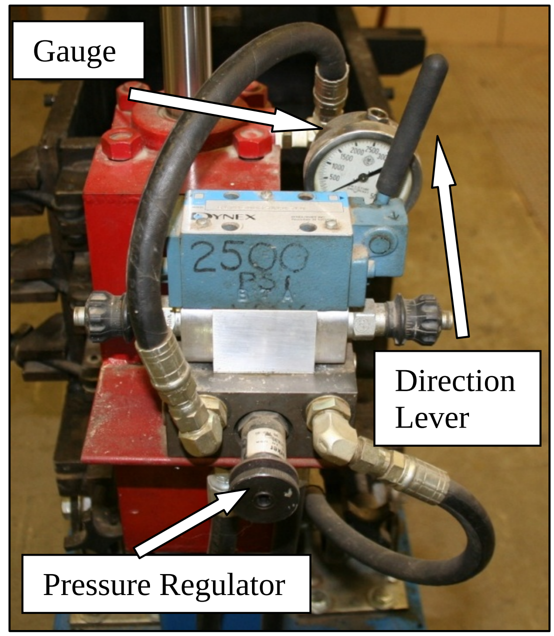
Figure 3.1 Maintenance Locations

IV. Control Systems Diagrams

The air cylinder that moves the compaction mold is controlled by an air logic system. The safety interlocks and pass counter are a part of the air logic system. Figure 4.1*a* shows the physical interface to the air logic control system. Figure 4.1*b* shows the hydraulic ram system controls. Figure 4.2 is a profile of the *LAC*. Figure 4.3 is a schematic diagram of the air logic control system.



a) Air Logic System Control Box



b) Hydraulic Cylinder System Controls

Figure 4.1 *LAC* Control Systems

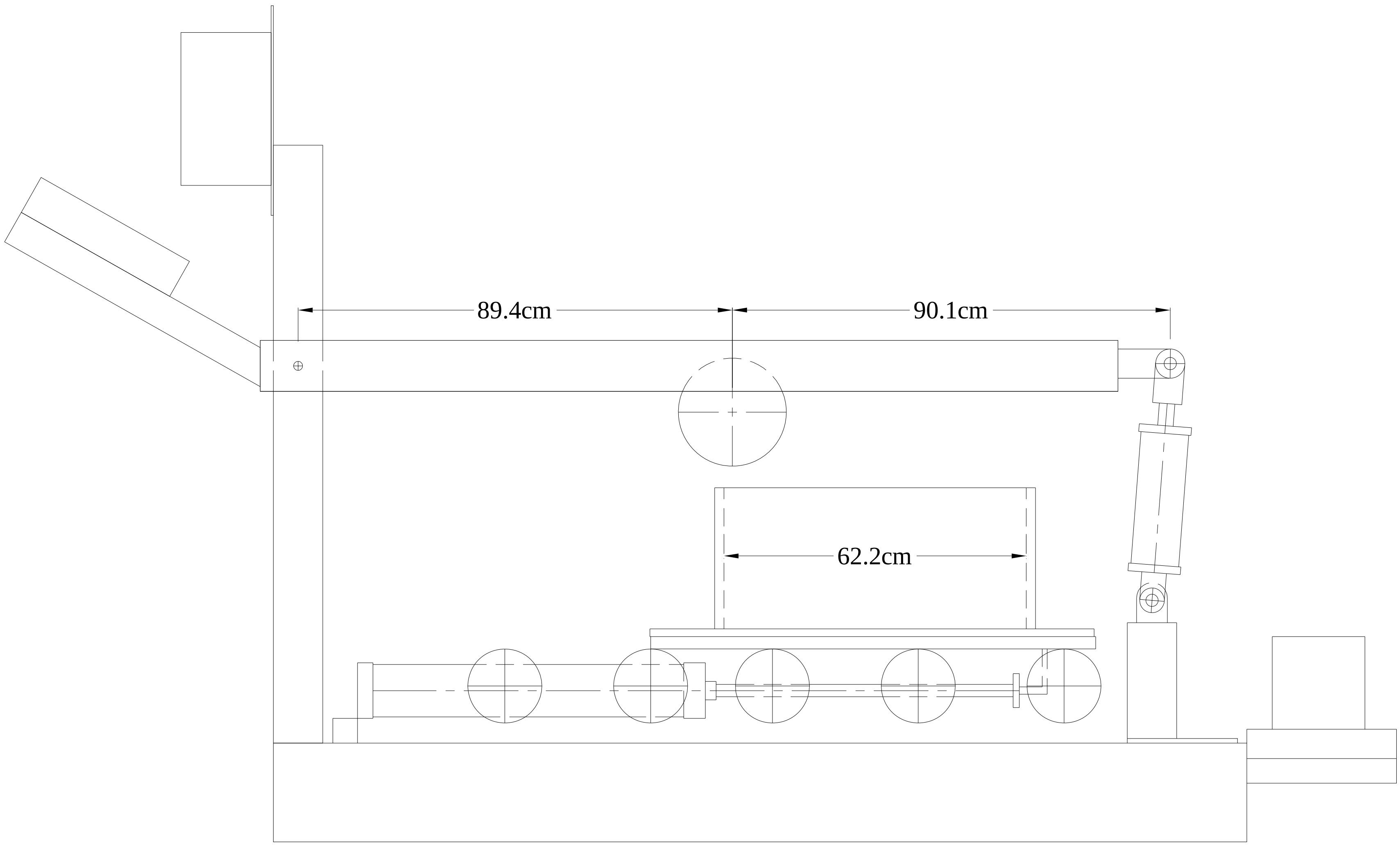
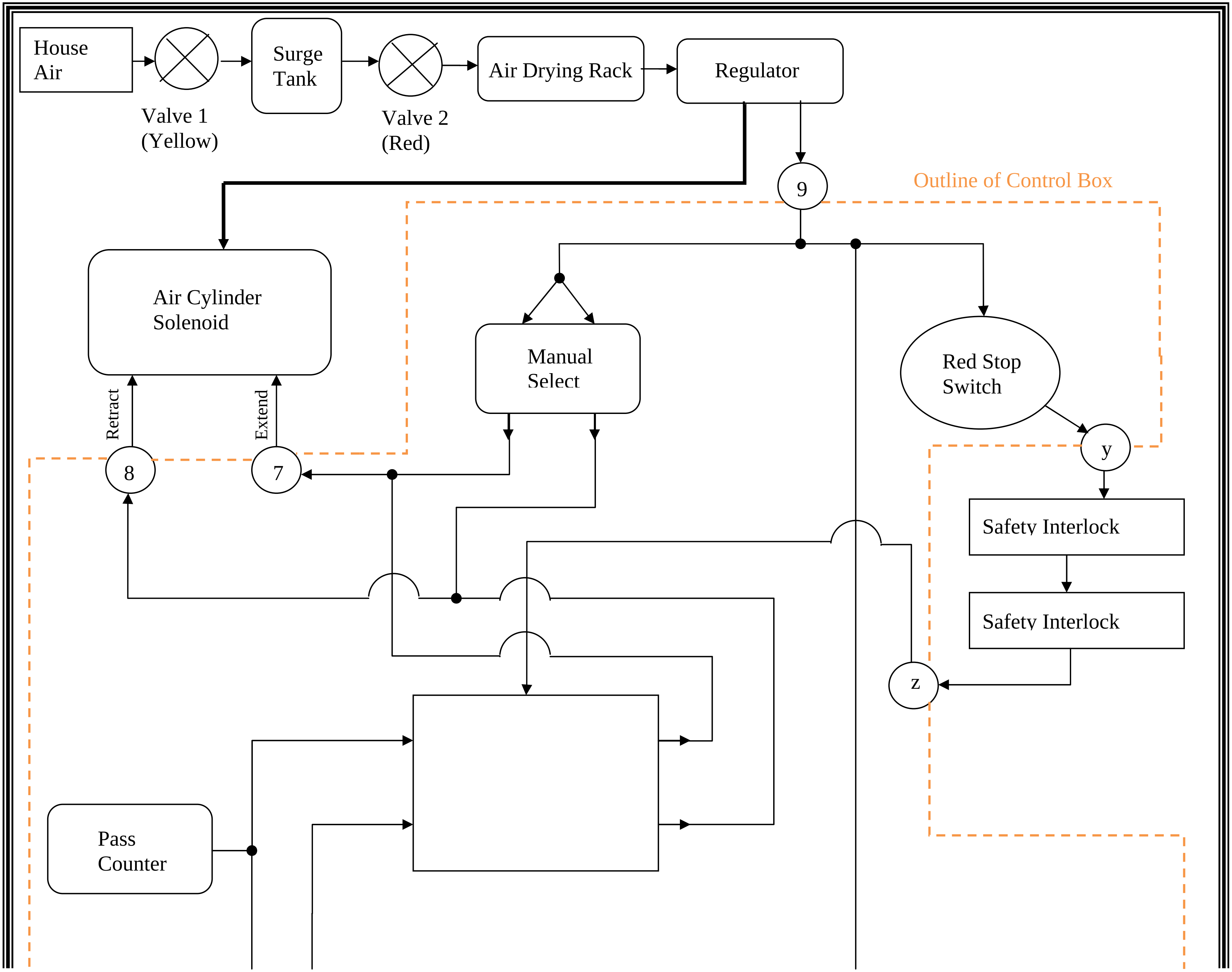


Figure 4.2 ***LAC*** **Profile Diagram**


House Air
Valve 1 (Yellow)
Surge Tank
Valve 2 (Red)
Air Drying Rack
Regulator
9
Outline of Control Box
Air Cylinder Solenoid
Manual Select
Red Stop Switch
Retract
Extend
8
7
y
Safety Interlock
Safety Interlock
z
Pass Counter

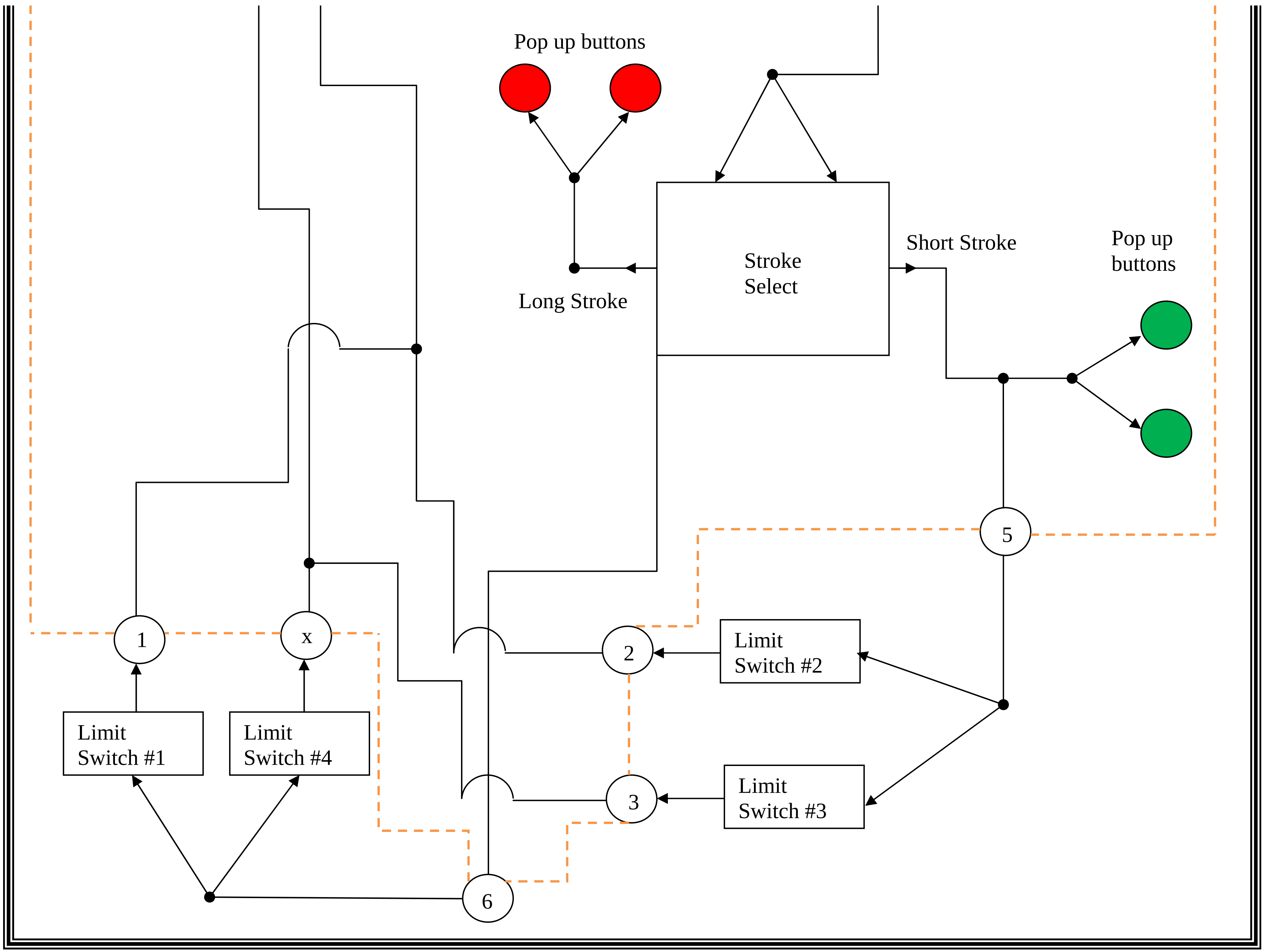


Figure 4.3 Air Logic Control System Schematic

V. Troubleshooting

Description	Probable Cause	Solution
Compaction mold will not move	Air system	Check that all valves are open and system is pressurized
		Check that both air interlock switches are fully depressed
		Depress then release the red stop switch
		Verify that all air switches are fully switched to a position
Compaction plates will not fit into mold	Too many compaction plates	Remove a plate: no more than 46 full size plates initially
	Compaction plate edges rounded over	Grind edges smooth or replace compaction plates
Slabs have upturned, poorly compacted ends	Not enough compaction plates	Count plates: need 47 plates that provide a snug fit
	Mold not completing full travel underneath roller	Check that long stroke is selected on air system
		Temporarily reduce hydraulic system pressure during compaction
		Adjust the air limit switches position as necessary

VI. Appendix 1: Material Quantities and Bulk Density Corrections

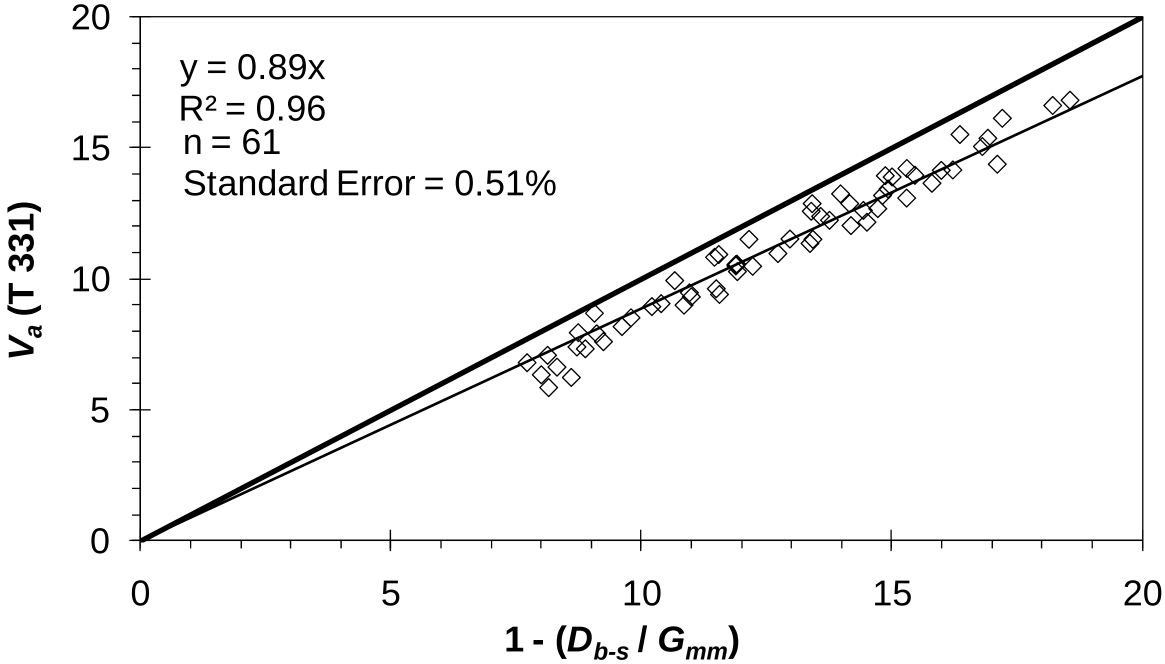
To achieve a target slab thickness range and approximate final air void level the mass of asphalt mix needed is estimated based on the volume of the compaction mold and the target slab thickness. Calculation of batch quantities for desired air void levels is performed by inserting desired air voids, V_a, and sample thickness, d, into the following equations. G_{mm} must be known for the mixture. Mix mass is of total mix not just aggregate. Units are V_a (%), Mix mass (g), d (cm), and P_b (%).

$$G_{mb} = G_{mm}\left(1 - \frac{V_a}{100}\right)$$

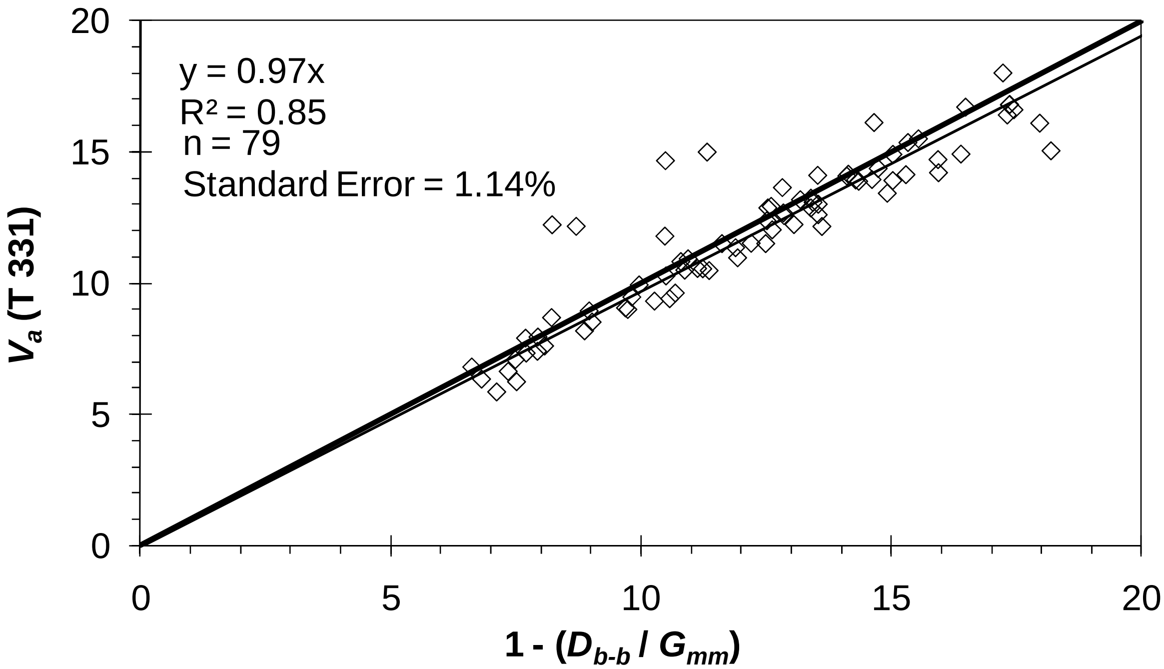
$$\text{Mix mass} = G_{mb} 1828 d$$

$$\text{Aggregate mass} = \text{Mix mass}\left(100 - P_b\right)$$

Measurement of the final bulk density and air void level can be done several different ways including measured slab properties, batched mixture quantities, and G_{mb} measurements of cores sawn from slabs. The *AASHTO T 331* G_{mb} (i.e. CoreLOK) measurements of sawn cores are considered to be the correct values. Note high air voids often negate *AASHTO T 166* G_{mb}, but this method can be used if appropriate. The horizontal plane area of slabs is a constant 1828 cm^2, therefore only thickness and mass values are required for bulk density measurement of compacted slabs. The average of six thickness measurements distributed around the perimeter of slabs has been found sufficient. Mass measurements of compacted slabs are only useful if the compacted slab does not have missing corners or poorly compacted areas. Density calculated with these measured slab properties ($D_{b\text{-}s}$) is used to calculate an approximate air voids level for the slab. A relationship between this air void measurement and the correct *AASHTO T 331* values is presented in Figure 6.1*a*. When compacted slab mass measurements are not usable the batch target mass can be substituted and used in conjunction with average thickness measurements to calculate a bulk density ($D_{b\text{-}b}$); however this relationship is not as accurate as evidenced by the lower R^2 value and higher standard error. As of January 2010, further investigation and analysis of slab air voids variability is ongoing but final results are not available at this time.



a) Air Voids Measured by Slab Properties Compared to Core Density Measurements



b) Air Voids Measured by Slab Batch Quantities Compared Core Density Measurements

Figure 6.1 Slab V_a Measurement Comparisons

VII. Appendix 2: Compactive Effort and Compaction Parameters

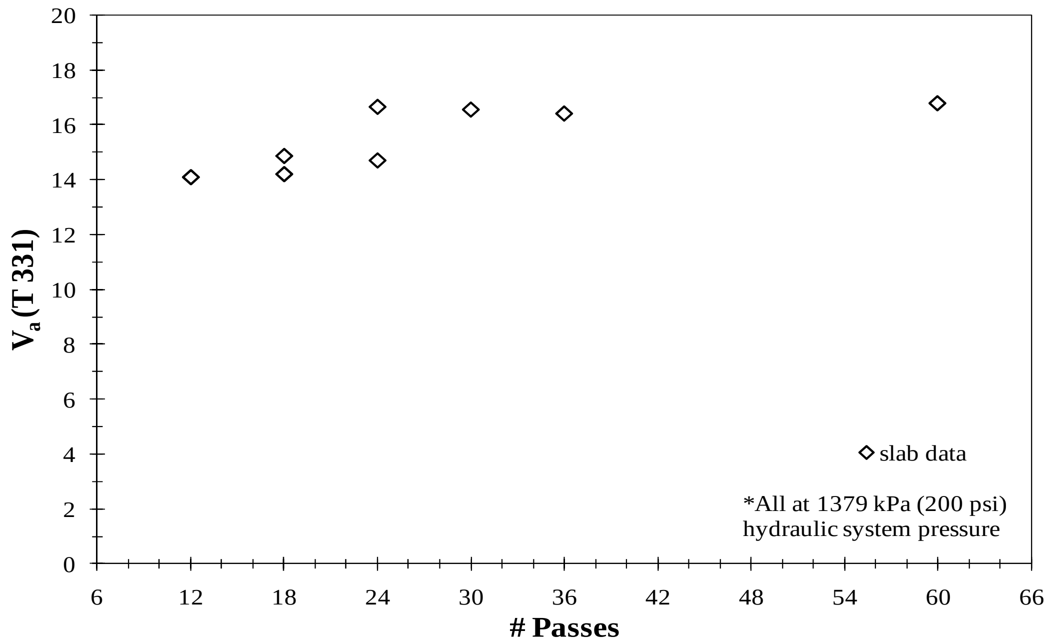
The design of the *LAC* is to simulate the compactive action of a static steel wheel roller. Based on the *LAC* geometry (Figures 2.1 and 4.2) and hydraulic cylinder internal dimensions, Table 6.1 provides estimated *LAC* estimated compactive efforts in force per unit width for various hydraulic system pressures. The hydraulic cylinder system pressure is measured by a gauge (Figure 4.1*b*) and can be set by adjusting the hydraulic cylinder system pressure regulator during the compaction process before the first compaction pass. The original goal was to directly simulate the field compactive effort of a static steel wheel roller; however use of a reasonable field value did not provide adequate laboratory compaction in some instances.

Table 7.1 Estimated *LAC* Compactive Effort

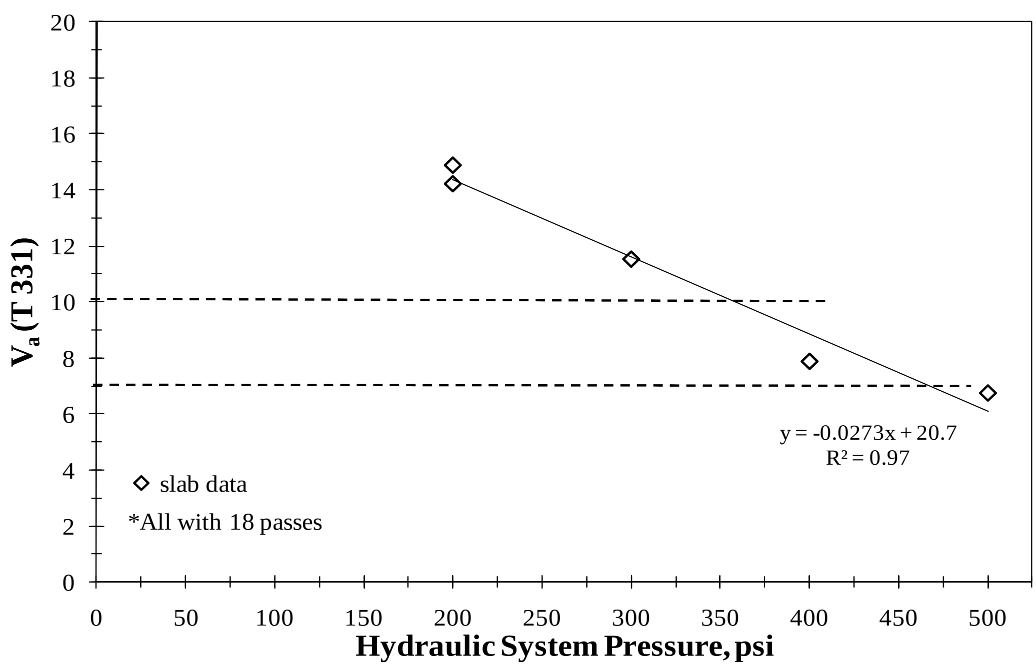
Hydraulic System Pressure kPa (psi)	Hydraulic Ram Force[1] N (lbf)	Reaction Force at Roller N (lbf)	Estimated Compactive Effort N / cm (lbf / inch) width
1379 (200)	7477 (1679)	15020 (3375)	514 (294)
1551 (225)	8404 (1889)	16898 (3797)	578 (330)
1724 (250)	9338 (2098)	18776 (4219)	643 (367)
1896 (275)	10272 (2308)	20653 (4641)	707 (404)
2069 (300)	11206 (2518)	22531 (5063)	771 (440)
2241 (325)	12140 (2728)	24408 (5485)	836 (477)
2413 (350)	13074 (2938)	26286 (5907)	900 (514)
2586 (375)	14007 (3148)	28163 (6329)	964 (550)
2758 (400)	14941 (3358)	30041 (6751)	1028 (587)
2930 (425)	15875 (3567)	31918 (7173)	1093 (624)
3103 (450)	16809 (3777)	33796 (7595)	1157 (660)
3448 (500)	18677 (4197)	37551 (8438)	1286 (734)

1) Hydraulic cylinder rod is 1.25 inch in diameter and the cylinder bore is 3.5 inch in diameter. During compaction (cylinder rod retraction) the effective area of the hydraulic cylinder is 8.3939 inch^2.

Results of nominal 7.6 cm (3 inch) target thickness slabs compacted at 1379 kPa (200 psi) hydraulic system pressure with varying number of compaction passes are presented in Figure 7.1*a*; the goal was to approximately simulate a reasonable field compactive effort. Increasing the total number of passes applied at the low compactive effort did not significantly affect resulting air voids; a value of 18 total passes was selected for subsequent work. Figure 7.1*b* presents the results of slabs of the same mixture compacted with 18 compaction passes and varying hydraulic system pressure; increasing hydraulic system pressure decreases resulting air voids. The mixture used for all slab data presented in Figure 7.1 was a MDOT high design traffic level (HT) 12.5 mm NMAS gradation composed of 63% angular crushed gravel and 15% limestone. PG 67-22 binder was substituted for the original design PG 76-22 and the standard 90 min MDOT short term aging protocol was utilized; the target compaction temperature range was 146 – 152 C (295 – 305 F). The compaction parameters of 18 passes and 2413 kPa (350 psi) hydraulic cylinder system pressure have been used successfully for several different mixture types.



a) Slab Data for Constant Hydraulic System Pressure and Varying Compaction Passes



b) Slab Data for Constant Compaction Passes and Varying Hydraulic System Pressure

Figure 7.1 Slab Data for *LAC* Compactive Effort Determination