A STUDY IN WALL PRESSURES IN A FLAT CLEAR-SPAN COTTONSEED STORAGE HOUSE

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Abstract

A study of a clear-span, flat cottonseed storage building was conducted to determine the pressure exerted on the side walls by cottonseed. Pressure on the wall of a scaled emulation chamber was studied to determine whether or not the wall pressure in a cottonseed storage building could be emulated.

Results from these studies indicate that cottonseed exert a pressure on the building as a function of the total depth of the seed. A relationship for wall pressure was established as a function of vertical pressure for the chambers evaluated. The maximum wall pressure in a cottonseed storage building was found to occur at approximately 15 to 20 percent of the total seed depth above the floor. The maximum horizontal pressure observed for the 19 ft eve-height storage building with a 4/12 roof slope and with seed to the 28-30 ft level in the center of the building was 285 lb/ft^2 and occurred at 4.5 ft in 1994. The maximum horizontal pressure observed in 1995 was 166 lbs/ft^2 for a 16 ft depth of seed in a partially filled house (blown against one wall until seed reached the center of the floor), without aeration. The maximum forces occurred about 3-4 ft above the floor level. The first filling of the house was aerated which resulted in about a 25 percent increase in horizontal forces when aeration was being performed. Some increase in wall pressures were observed as the seed pile's lateral depth increased after reaching the final filling depth. This supports the simulation chamber results that house width and length do have an effect on wall loadings.

Introduction

Side and end wall failures of flat cottonseed storage buildings have occurred on several occasions in the recent past. Interest in cottonseed storage particularly at gins in the Mid South and Southeast has increased. These factors coupled with the lack of reliable data for design purposes prompted the authors to seek funding and conduct studies to determine the pressure exerted by cottonseed on a storage building's walls.

Numerous articles dealing with the wall pressure found in various grain storage structures are available (Welch, et. al., Molenda, et.al. Bokhoven, et. al and Mosey, et. al. are only a few).

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1625-1630 (1996)
National Cotton Council, Memphis TN

DeFrancisco, et. al. reported that building wall pressure exerted by cottonseed were different from those exerted by more conventional grains. He determined the angle of internal friction to be approximately 22 degrees as compared to a range of 28 to 36 degrees for grains. DeFrancisco, et.al. also suggested that border effects from the floor resulted in a decrease in the wall pressure near the floor. However, DeFrancisco's study was limited due to the difficulty in making repetitive measurements in an actual cottonseed storage building.

This report summarizes studies conducted at Farrell Gin, Incorporated, Sherrard, MS in 1994 with a 100 ft width x 200 ft length x 19 ft eve-height and at Delta and Pine Land Company, Scott, MS in a 100 ft width x 40 ft length x 20 ft eve-height and two different emulation chambers. These studies were funded in part by Cotton Incorporated, Raleigh, NC.

Materials and Method

Prior to the 1994 ginning season, Farrell Gin, Incorporated constructed a 100 ft wide by 200 ft long x 19 ft eve-height cottonseed storage building. The height to the apex of the building is 35 ft, and the full capacity is about 6,200 tons. Two 3/4 in. plywood panels (2.5 ft wide and 16 ft high) were installed temporarily on the inside of the building against the sidewall purlins. Nine square holes (6.25 x 6.25 in.) were cut to accommodate load cells (Figure 1).

Twenty "S" type load cells, ten of each the 50 lb and 100 lb capacity were purchased and calibrated before they were installed in the plywood panels. The load cells (Figure 2) were mounted using a spacer assembly such that the 6 in. by 6 in. by 1/4 in. thick sensing panels were flush with the "seed" side of the plywood panels in the side wall of the building. Four of the 100 lb capacity load cells were placed at the 3.5, 4.5, 5.5 and 6.5 ft levels above the floor. Periodic measurements were made and an approximate filling depth noted for each set of measurements. Removal, recalibration and rezeroing of these load cells was accomplished following the removal of the 1994 seed crop in April of 1995. Pressure measurements were recorded periodically throughout the filling of the building and for a period of approximately six weeks after the building was filled.

Delta and Pine Land Company (D&PL) constructed seed storage facilities similar to those at Farrell Gin during the summer of 1995. The main differences were that the D&PL facilities were partitioned into 40 ft length x 100 ft width chambers with the walls completely lined with formed steel sheeting. The filling mechanism coupled with the chamber's dimensions, seed lot sizes and management's operating procedures for handling varieties of cottonseed resulted in shallower filling depths, but much more rapid filling and emptying than did the bulk storage at Farrell Gin Company. A 1 ft high concrete retainer wall was poured around the base of all walls such that the metal skin was recessed about 2 inches from the edge of the concrete retainer wall.

Load cells were placed in the 40 ft long and 100 ft wide walls of one chamber as in the Farrell Gin storage facility in early September, 1995 (Figure 3). One 3 ft wide steel building panel from each load cell location was removed from the inside wall sections and replaced with the plywood load cell mounting panels. The edges of the plywood panels were covered by the remaining adjacent steel wall panels. A 6 mil polyethylene plastic film was placed over the load cell plates to prevent any seed from becoming wedged between the load cell plate and the plywood mounting panel. The load cells were connected to a data logger. Data was recorded at 1 minute intervals during the filling process and for 4 to 10 days after filling stopped. Filling cycles were monitored in October and again in December.

A chamber, 2 ft x 4 ft x 8 ft was constructed and instrumented with two load cells in the center of adjacent walls about 4 ft above the floor (Figure 4a). This chamber had no bottom to facilitate unloading the seed after each test had been conducted. The box was reinforced with pine 2 in. x 4 in. on edge horizontally on the exterior. The interior was lined with a 6 mil polyethylene sheeting to prevent seed from wedging into the cracks between the load cell sensing plate and the plywood panel. The chamber was filled with cottonseed (8-10 percent moisture) to a depth of 8 ft. The seed were weighed as they were placed into the chamber. A 2 ft x 4 ft x 3/4 in. plywood panel was placed on top of the seed to serve as a platen for weight to be added to the seed mass.

The lateral pressure and the depth of the platen from the top of the chamber were recorded before 4 front tractor weights (approximately 96 lbs each) were added to the top platen. All the tractor weights were weighed and recorded prior to the start of the test and applied in a given sequence during the test. The lateral pressures were observed and allowed to stabilize (usually about 5 minutes) after each increment of 4 weights was added, and then the data was recorded. The vertical displacement of the platen, the exact increment of weight that was added and each load cell measurement was recorded. A total of approximately 4,000 lbs of weights were added. The chamber was emptied by removing the weights then lifting the chamber off of the compacted seed with a fork lift. Four replications were run in this manner.

Analysis of the load cell data revealed a very different vertical pressure to wall pressure relationship for the two load cells in adjacent walls. A second chamber (Figure 4b), measuring 4 ft wide, 8 ft long, and 8 ft deep was constructed. This chamber was used to determine if the observed differences were in fact related to the lateral depth of seed in front of the load cells. A steel "I Beam" superstructure was constructed around the chamber and a floor placed in the bottom. The 3/4 in. plywood wall panels were reinforced with pine 2 in. x 6 in. girts running in 9 belts on edge around the chamber and further supported by the steel superstructure. One end of the chamber was made removable in order to facilitate unloading. Four, 2 in. x 12 in. hydraulic cylinders were mounted between an "I Beam" reinforced platen and a 5,000 lb capacity load cell mounted on the overhead structure. An AC powered hydraulic pump/valve system was used to supply power to the four hydraulic cylinders connected in parallel.

Four "S" type load cells were calibrated and mounted above each other, spaced vertically 1 ft apart beginning 18 in. above the floor midway in each wall using a steel structure attached to the 2 in. x 6 in. pine reinforcement girts. Four, 100 lb capacity cells were placed in each end wall. Four, 50 lb capacity load cells were placed in each side wall for a total of 16 load cells. Each sensing plate's seed surface was flush with the inside plywood surface. The interior of the chamber was lined with 6 mil polyethylene sheeting as in the first chamber. The seed capacity of the chamber was about 6,000 lb of seed.

Filling of the chamber was accomplished by directing one of the storage building seed pipe discharges into the top of the chamber. This allowed filling with warm, moist seed directly from the ginning process. The platen was then put on top of the seed and the test begun. Increments of vertical pressure were applied by maintaining as near possible a constant pressure with the relief valve in the hydraulic system. Additional increments of vertical pressure were applied by adjusting the hydraulic system's relief valve setting and holding the directional control valve open to the hydraulic cylinder's piston side. Vertical pressure was measured with the four, 5,000 lb capacity cells and recorded.

The seed used in a replication was weighed on platform scales and sampled for moisture content as the chamber was emptied. Seed moisture content ranged between 11 and 14 percent during the 4 replications of the test. New seed were used for each replication. Vertical pressure, wall pressure and platen displacement were measured and recorded for each increment of vertical pressure. The density of the seed for each vertical pressure increment was computed.

Wall pressure exceeded the capacity of the side wall load cells when about 2/3 of the vertical pressure was applied. This necessitated the temporary interruption of the test to permit removal of the 50 lb load cells before applying the final increments of vertical pressure. A total of 16,000 to 20,000 lb vertical force was applied over the 32 ft^2 platen area during each of the 4 replications of the experiment.

Results and Discussion

Farrell Gin Storage (1994). The maximum measured wall pressures in 1994 occurred at Location #1 in the building and was found to be 285 lb/ft^2 at the 4.5 ft level above the floor (Figure 5) when the building was completely full. A shift in the height where the maximum lateral pressure occurred was observed as the building was filled. Similar pressures were measured at Location #2.

Emulation Chamber Results. Average densities of cottonseed determined with the emulation chambers ranged between 23.7 lb/ft^3 for uncompressed seed (8 ft deep) and 27.9 lb/ft^3 at a maximum vertical pressure of 539 lb/ft^2 for the 1993 seed in the 2 ft x 4 ft x 8 ft small chamber (Figure 11). Similar average densities were found for the 1994 seed. The 1994 seed were 3 to 5 percent higher in moisture content and generally less mature than the 1993 seed which probably accounted for the slightly lower initial density in 1994. Some differences in the uncompacted densities probably are due to the different methods of filling the chambers for the two sets of tests.

The relationship of seed density to vertical pressure is of value only if the vertical pressure component can be related to an equivalent seed depth. The total vertical pressure (VP) applied divided by the average seed density (D) should yield the equivalent seed depth (ESD). This relationship:

$$ESD = \frac{VP}{D}$$

where ESD = Equivalent Seed Depth (ft)
VP = Vertical Pressure(lb/ft^2)
D = Seed Density (lb/ft^3)

was used to convert the vertical pressure applied to the seed in the test chambers to a depth of seed in a storage building .

The small chamber test results indicated a linear relationship of vertical pressure to horizontal pressure against the wall (Figure 12). It is apparent that the lateral depth of seed that a load cell/wall was exposed to influenced the horizontal pressure measured by the load cells.

The equations:

$$WF_4 = \underline{23.2} + \underline{.27*}\ VP$$
and
$$WF_2 = \underline{13.2} + \underline{.13*}\ VP$$

where:

WF_4 = Wall pressure on the end wall (lb/ft^2)
WF_2 = Wall pressure on the side wall (lb/ft^2)
were developed and resulted in coefficients of determination (R^2) of .985 and .997 respectively for the end and side wall measurements.

A similar difference was observed between the wall forces measured on the side and end walls of the larger chamber (Figures 7 and 8). The equations developed from this data:

$$WF_4 = \underline{40.9} + \underline{.323}*\ VP \qquad R^2 = .907$$

$$WF_8 = \underline{36.9} + \underline{.441}*\ VP \qquad R^2 = .921$$

where:

WF_4 = Wall pressure in the side walls

WF_8 = Wall pressure in the end walls

Both the slopes for the tests were different. The computed ESD from the chamber data would indicate that a pressure of 550 lb/ft^2 would equal a depth of 25 ft. The corresponding end wall pressure from the chamber would be 279 lb/ft^2. However, the chamber data does not show a decrease in pressure near the floor as does the storage building data. The large chamber end wall equation predicts a wall pressure of 150 lb/ft^2 at a depth of 15 ft. A maximum pressure of 285 lb/ft^2 was measured in the Farrell Gin storage building at a height of 4.5 ft above the floor. This corresponds with a depth of 15 ft from the eve. A pressure of 150 lb/ft^2 was measured at 7.5 ft above the floor. This indicates that the total pressure is not being predicted with the end wall chamber load cells and the resulting equation. It appears that additional pressures are being transferred to the load cells for each additional increment of chamber or building width or seed depth extending above the eve level in the center of the building.

Delta and Pine Land Company Storage (1995). The first filling of the instrumented chamber began October 2, 1995 and was near completion by October 8, 1995 with locally grown seed from two different gins. Seed moistures ranged between 8 and 10 percent (Wb.) with an average moisture in the chamber seed of 8.8 percent. These moistures were lower than those for Farrell Gin in 1994. However, complete records of all Farrell Gin's seed going into storage were not available. Seed were blown against the south wall first and allowed to fill and flow towards the north wall where the bulk head door was located. This resulted in about a 4 day lag in the east wall's load cells responding to seed pressures. The wall forces observed for the south wall reached a maximum of 147 lbs/ft^2 for the load cell located 3.5 ft above the floor level (Figure 6). Forces increased against the wall at the bottom as seed depth increased between the 14.5 ft and 17.66 ft load cells levels. Since the 14.5 ft load cell sensed a near constant force against it during the 96 hour span shown in Figure 6, we have to assume that the final level of 16 ft seed depth was already reached, and the chamber was being filled progressively toward the north wall. Therefore, most if not all of the increase in forces are a result of increasing lateral depth from south to north as was observed in the emulation chamber.

The forces measured on the east wall reached a maximum of 138 lbs/ft^2 for a seed depth against the load cells of 16 ft (Figure 7). The maximum force observed was for the load cell located 1.5 ft above the floor. Periods of filling activity between 0 and 12 hours and again between 16 and 28 hours can be detected in the 64 hour time span shown. Seed depths greater than 16 ft were achieved in the chamber at almost every location. However, due to the east wall load cell panel being located directly under the catwalk in the center of the building (east to west), no seed contacted the 8th load cell. The fact that the load cell closest to the floor sensed the highest pressure seems somewhat puzzling until you apply the 15 to 20 percent of seed depth for maximum force rule- of-thumb and realize that the maximum force should occur between 2 and 3 ft from the floor. The second load cell was above the point where maximum pressure occurred. Following approximately 6 weeks of storage, the seed from this chamber were processed for planting seed and the chamber cleaned for refilling.

Arizona seed were brought in by truck for a partial second filling. Pressures reached 165 lbs/ft^2 on the south wall during the second filling with a corresponding 18 ft depth against the load cells in the south wall (Figure 8). The maximum force was recorded from the 4th load cell on the south wall at a height above the floor of 4.5 ft. Seed reached only the first load cell on the east wall with the toe of the pile extending about 60 ft from the south wall. Some effect of lateral depth appears to be present in this filling as in the first filling as shown by increases in wall pressure with no increase in seed depth after reaching the deepest level above and next to the load cells.

A cyclical effect in wall pressures was noticed when the data was analyzed from the first filling (Figure 9). The low point of each cycle seems to occur in late morning of each day with the high point occurring in late evening. These times correspond fairly close to the times aeration was turned on and off each day. A difference in pressures of about 40 lbs/ft^2 for the load cells nearest the maximum wall pressure (load cells #3 & 4) was observed. Both the south and east wall load cells responded similarly. It seems unlikely that a 4 to 6 inch (H_20) static pressure change on the seed could result in this much wall force change. However, no other explanation can be offered at this time. Wall forces from the second filling did not exhibit a cyclical characteristic even though shown for a period of only 24 hours (Figure 10). No aeration was performed at any time on the seed in the second filling. The raw data from both fillings appears to be without excessive electrical noise or other low frequency variation.

Summary

Results from these studies indicate that pressure on the walls of a cottonseed storage building increase with depth. Maximum pressure was found to occur at 15 to 20 percent of the seed's storage depth above the floor both in 1994 and 1995. The maximum measured wall pressure was 285 lb/ft^2 in 1994 for the Farrell Gin storage building when completely filled, and was found to occur at the 4.5 ft level above the floor. Seed depth was 25 to 28 ft in the center of the building and 19 ft at the eves. A shift in the point of maximum wall pressure was observed in the 1994 study as the storage building was filled.

The emulation chambers can provide insight into the behavior of vertical and lateral pressure in cottonseed. However, these relationships are not yet developed enough to be a reliable predictor of wall loadings. The chamber width between the load cell and the opposite wall was found to influence the wall pressure measured. This suggests that cottonseed storage building width may also affect the magnitude of the pressure against the wall.

Further investigation of the wall pressure in narrower storage buildings is needed to complete the relationship of building width to wall pressure.

Maximum pressure was found to be 147 lbs/ft^2 and 138 lbs/ft^2 for the south and east walls of the Delta and Pine Land storage chamber for the first filling to a depth of 16 ft above the floor and 165 lbs/ft^2 for the south wall for the second filling with a maximum seed depth of 18 ft above the floor. Maximum force was observed at the load cell 3.5 ft above the floor in the first filling on both walls and 4.5 ft above the floor on the partial filling on the south wall. This agrees with the maximum force occurring 15 to 20 percent of the total seed depth above the floor.

Cyclical trends were found in the wall pressures measured in the first filling of the D&PL chamber and are attributed to some phenomenon associated with aeration. Increases in wall pressures with no apparent vertical seed depth increase but with the chamber being filled further from the wall lends some credibility to the belief that building width may also influence wall pressures.

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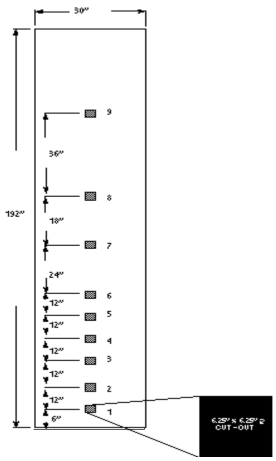

Figure 1. Load Cell Mountings in Farrell Gin Storage Building

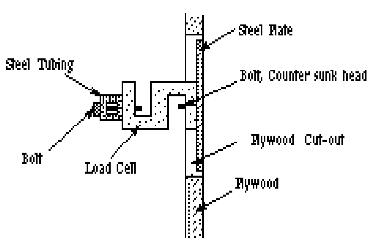

Figure 2. Sensing Plate Assembly

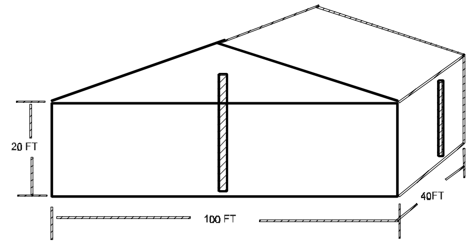

Figure 3. Delta & Pine Land Seed House Load Cells, 1995

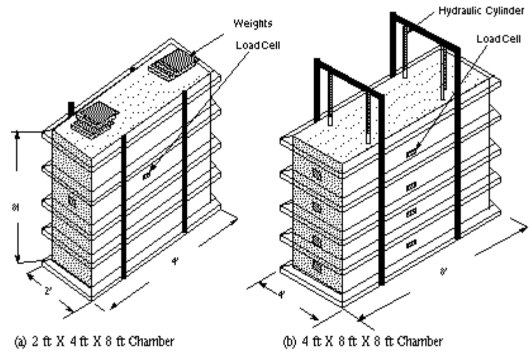

Figure 4. Emulation Chambers Used in the Studies

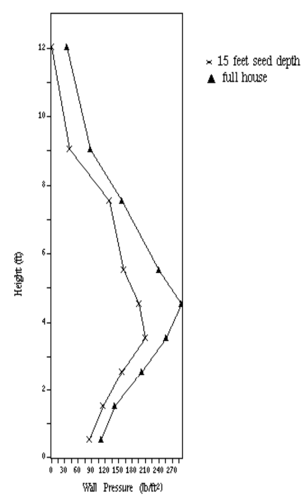

Figure 5. Wall Pressures of Cottonseed Storage Building (1994)

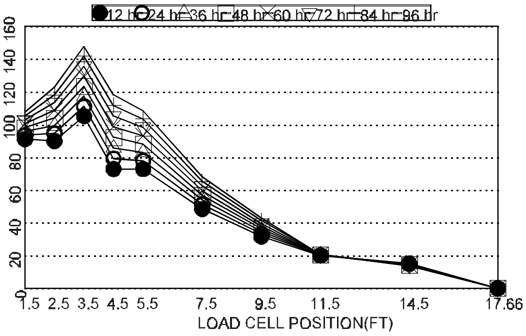

Figure 6. Wall Force, First Filling, 1995 D&PL

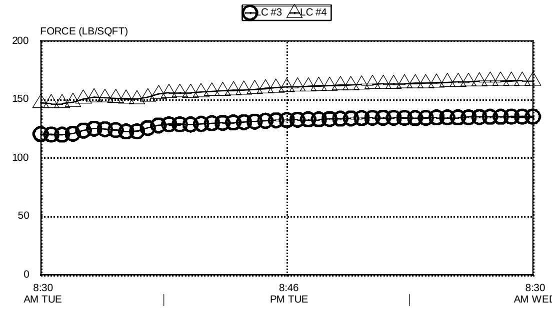

Figure 10. Effect of Aeration on Wall Force, LC #3, LC #4, 2nd Filling, D&PL 1995

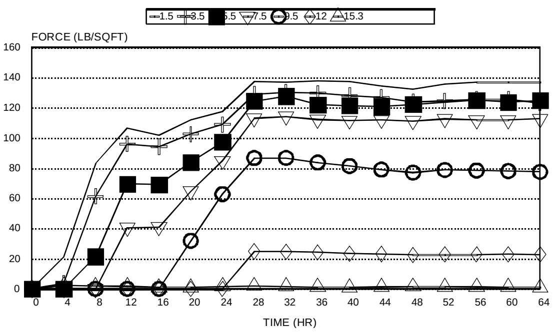

Figure 7. Wall Force Progression During First Filling, East Wall, D&PL 1995

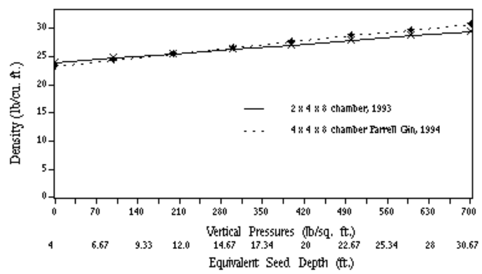

Figure 11. Density of Cottonseed as a Function of Vertical Pressure

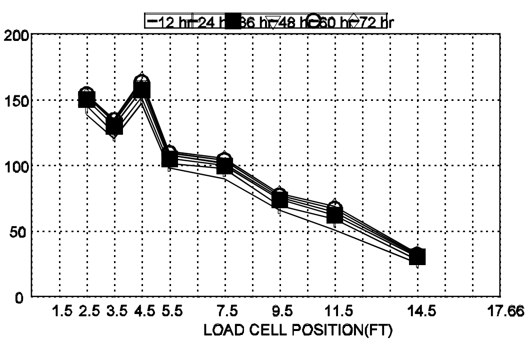

Figure 8. South Wall Force 12 HR Interval, 2nd Filling, D&PL 1995

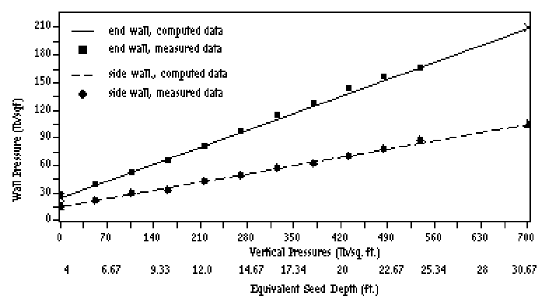

Figure 12. Wall Pressure as a Function of Vertical Pressure in a 2 ft x 4 ft x 8 ft Chamber

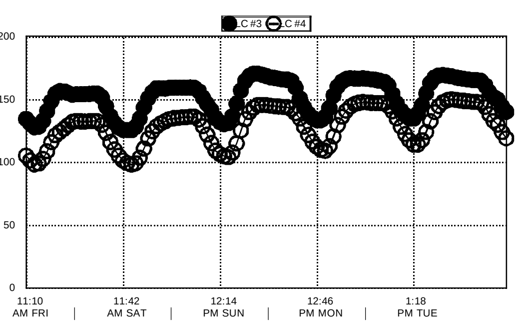

Figure 9. Effect of Aeration on Wall Force, LC #3 & LC #4, 1st Filling, D&PL 1995, South Wall

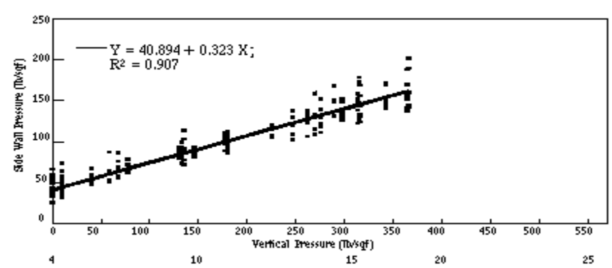

Figure 13. Side Wall Pressure vs Vertical Pressure

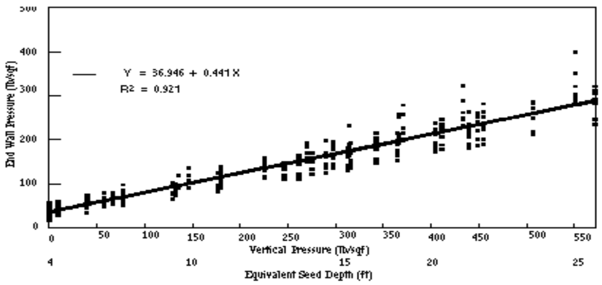

Figure 14. End Wall Pressure vs Vertical Pressure