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WALL LOADS CAUSED BY FLUMES IN A MODEL GRAIN BIN*

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A b s t r a c t. Wall flumes are vertical conduits attached to the walls of grain bins through which grain can flow. Flumes are thought to encourage funnel flow throughout the height of the bin while reducing the dynamic loads and moments associated with plug flow and side unloading. Discharge outlets from the flume can be placed at any location along the vertical line of the flume. Tests were performed with soft red winter wheat in a smooth-walled, model grain bin 2.44 m in diameter and 7.44 m tall, constructed of galvanized steel. Tests were conducted both with and without the flume. During unloading, the wall flume created an "artificial" funnel flow regime within all parts of the bin which produced wall loads smaller than those measured during filling, other than at the onset of discharge in which a small load spike was observed. However, in unloading through the flume unbalanced wall loads were observed around the circumference of the bin, which produced overturning moments in the plug flow zone. Tests were conducted in which flow was transferred from the wall flume to the center discharge gate. This "switch" in the discharge position created wall loads significantly larger than those measured during filling at the flume location where the switch occurred. Operator caution should be used in performing these types of flow "switches" within bins when using wall flumes.

K e y w o r d s: grain bin, pressures, wall flumes

INTRODUCTION

Grain storage bins are generally designed as thin-walled cylindrical shells. They are typically loaded and unloaded along the line of their central axis. These geometric considerations and operational practices effectively optimize the bin design.

Two generalized flow patterns occur when discharging grain from storage bins; plug flow and funnel flow. Plug flow generally occurs in tall bins with a height-to-diameter (H/d) ratio greater than 1.5 to 2.0. In plug flow, the entire mass of grain flows at approximately the same speed down the bin walls. During plug flow the grain flowing down the bin wall creates pressures on the walls of the bin larger than those observed during filling. These pressures are commonly called overpressures. Funnel flow generally occurs in a bin below an H/d of 1.5 to 2.0 and exhibits a last-in, first-out flow phenomenon. During this type of unloading, a flow funnel forms inside a column of grain surrounded by static or non-flowing grain, with the topmost grain flowing through the funnel first. This process continues until the last grain to leave the bin is that in the bottom of the bin. During funnel flow, the unloading pressures in the bin are the same as those measured during filling.

Discharging of grain through the side of a bin can simplify grain movement within a grain storage installation. However, unloading grain

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through eccentrically located orifices in the bin floor or bin wall imposes unbalanced loads (overpressures) on the storage structure which are larger than those in center unloaded bins. In addition, this type flow regime creates overturning moments in the bin because of the non-symmetric distribution of loads.

Overpressures created during center discharge, off-center discharge or sidewall unloading of a bin can be reduced by antidynamic tubes or flumes attached to the bin wall. Antidynamic tubes [3] are vertical conduits, generally located in the center of the bin, with the bottom of the tube placed directly over the discharge orifice in the bin floor. Similarly, flumes are vertical conduits attached to the bin wall through which grain can flow. Discharge outlets from the flume can be placed in the floor or the bin wall at any location along its vertical line. Both devices are thought to facilitate and encourage funnel flow throughout the entire height of the bin, thereby reducing the dynamic loads and moments associated with plug flow and sidewall unloading. The research reported in this paper was conducted to determine the bin loads caused by unloading of a test bin through a flume. The results will be compared to the loads for the same test bin for center and off-center unloading.

MATERIALS AND METHODS

Wall and floor loads were measured during the loading and unloading of a test bin with and without a test flume attached to the wall. The test bin was cylindrical with smooth-walls and a flat-floor. The test bin was 2.44 m in diameter and 7.3 m high. The cylindrical wall of the bin and the flat floor were each supported independently on three load cells to isolate wall and floor loads. Loads cells supporting the wall cylinder and the bottom were spaced at an angular distance of 120 degrees around the circumference of the bin. Three orifice locations were used in the experiments: 1) at the center of the floor, 2) at a distance of 2/3 the radius from the center, and 3) located adjacent to the wall through the flume. Figure 1 shows the locations of the discharge gate and the load cells associated with the wall cylinder. During testing the bin was centrically filled at a flow rate of 16.7 m^3/h. Grain was discharged from the bin through discharge orifices which were 89 mm in diameter and produced a discharge flow from the test bin of 14.5 m^3/h.

The irregular shaped flume sections used in the experiment are shown in Fig. 2. They were bolted to the bin wall along a vertical axis with a spacing of 25 cm on-center to a height of 6.5 m. The flume sections were a 1/4 scale model

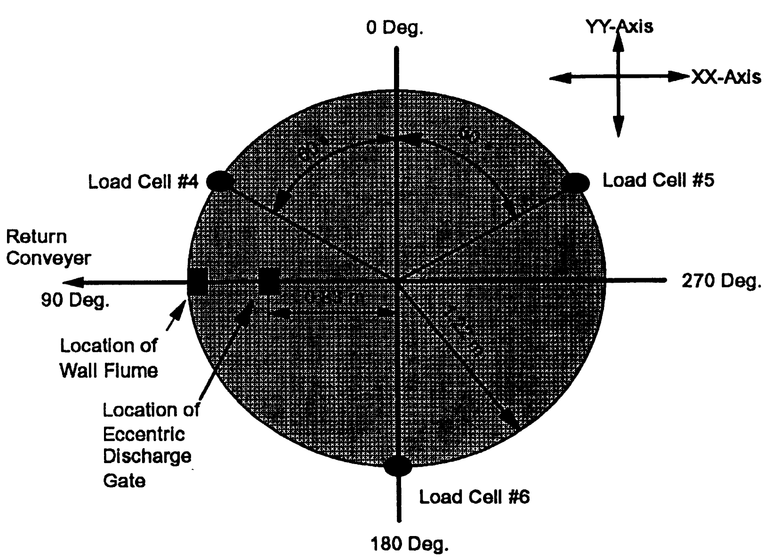


Fig. 1. Schematic diagram of the bin bottom unloading system and support load cells.

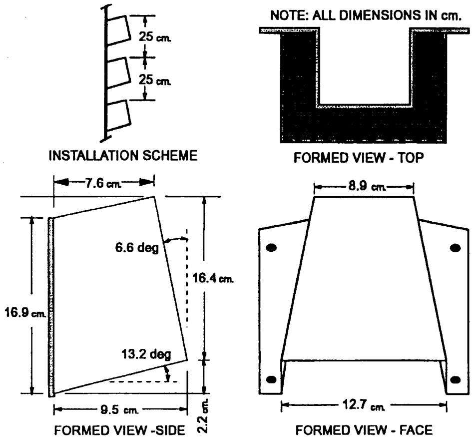


Fig. 2. Diagram of the wall flume unloading system.

of a commercially available flume. Tests were conducted in the model bin in which grain was discharged through the flume at different heights along the wall section.

Soft red winter wheat at a moisture content of 12% moisture content (wb) and an uncompacted bulk density of 760 kg/m^3 was used in all tests. During each test the bin was initially filled with grain and then allowed to equilibrate during a holding period of 0.5 h. The wall and floor loads were measured during loading, detention and discharge using a data acquisition system at 1 min intervals until discharge was completed.

RESULTS

The Total Wall Loads (TWL) shown in Fig. 3 were measured during: 1) center loading of the bin, 2) center unloading of the bin, and 3) unloading through a discharge orifice at the bottom of the flume. The TWL were calculated by summing the vertical loads measured by the three different load cells which supported the wall. When filled to a grain height of approximately 6.7 m approximately 25% of the total weight caused by the grain was carried by the walls and approximately 75% was carried by the floor. During center unloading, overpressures (loads greater than the filling loads) were observed during much of the plug-flow region of the bin. Fully developed plug flow was observed in this bin at a height-to-diameter (H/d) ratio greater than 1.6. In this bin, overpressures occurred between an H/d of approximately 1.8 and 2.7 for the center unloading condition.

EP433 [1] suggests that "wall flumes are used to encourage funnel flow into the uppermost opening in the flume at which grain is present". The TWL for unloading through the bottom of the wall flume are shown in Fig. 3. Based on these results, it appears that the sidewall flume negates most but not all of the overpressures which occur in bins during plug flow unloading. Small overpressures (Discharge Load/Filling Load) of 1.08 were observed

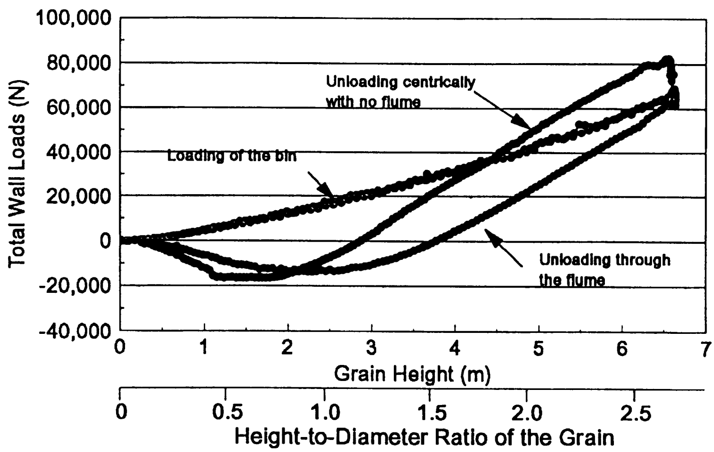


Fig. 3. Total wall loads during loading and unloading of the model bin.

during the first two minutes after the onset of discharge. The wall flumes were observed to create an "artificial" funnel flow pattern within the bin. However, at the onset of discharge the funnel flow discharge pattern had not yet formed within the bin, therefore, grain flow during this initial period is both down and towards the openings in the flume, which would cause some grain to flow along the bin walls creating small overpressures. Once the funnel flow pattern was formed, overpressures were no longer observed. Similar small overpressures were observed by Thompson [4] during the initial discharge period when unloading a bin through an antidynamic tube. However, once the flow pattern was established overpressures were not observed.

The TWL measured during: 1) center loading of the bin, 2) eccentric unloading of the bin, and 3) unloading through the bottom of the wall flume for grain heights between 5.5 and 6.7 m represented in Fig. 4. This represents the final stages of loading and the onset of discharge. The small overpressure which occurred at the onset of discharge, when unloading through the flume, shows up much more clearly in this figure. However, these overpressures occurred only over the initial phases of discharge. For eccentric unloading, an overpressure (Discharge Load/Filling Load) of 1.42 was observed at the onset of discharge, which was greater than that observed during center unloading. Pieper [2] and Thompson *et al.* [5] both proposed that the most nonuniform pressure distribution in a bin was caused by unloading through a semi-eccentric discharge orifice such as the one used in these experiments.

The vertical wall loads (VWL) measured by each load cell for both centric unloading and unloading through the flume at the bottom of the bin are shown in Fig. 5. Each line represents the VWL supported by a single load cell during each test. Theoretically, the loads within a center unloaded bin, should be symmetric and therefore, each load cell should have measured the same VWL at all grain heights. However, because of small imperfections in either the walls of the bin, or in the loading frame in which the bin wall was erected, some variation in the measured loads occurred around the bin. This unbalanced loading resulted in overturning moments of approximately 2000 N-m in the plug-flow region of the bin. When unloading through the flume each of the load cell readings was much less than that observed when unloading centrically, however, a greater variation in the VWL between each load cell was observed when unloading through the flume. This unbalanced loading around the circumference of the bin created an overturning moment which must be carried by the structure during unloading. When unloading through the flume overturning moments of approximately 5000 N-m were observed over the normal plug-flow region of the bin.

The loads measured by each load cell for eccentric unloading and unloading through the wall flume at the bottom of the bin are shown in Fig. 5. Not only does the eccentric unloading produce larger overpressures, but also the largest variation in wall loads among the three load cells. This variation produced overturning moments in excess of 30000 N-m over the normal plug-flow region of the bin.

Tests were also conducted in which the bin was unloaded through the wall flume at other discharge points along the vertical axis of the wall. The TWL measured during unloading of the flume through discharge points located at an H/d ratio of 1.6 and 1.05 in the bin, respectively are presented in Fig. 6. In this figure the initial depth of grain at which unloading began was also varied to determine if this had an effect on the TWL. It appears that regardless of the discharge location, the flume appears to negate any overpressures which occurred during unloading. However, in using a discharge point along the wall, once the depth of grain gets below the level of the discharge outlet in the flume, grain discharge will stop. Discharge through the flume would also stop if the flume was blocked by trash or foreign material within the grain. To unload additional grain from the bin management decisions by the operator must be made to decide if grain will be discharged from lower gates within the wall flume system,

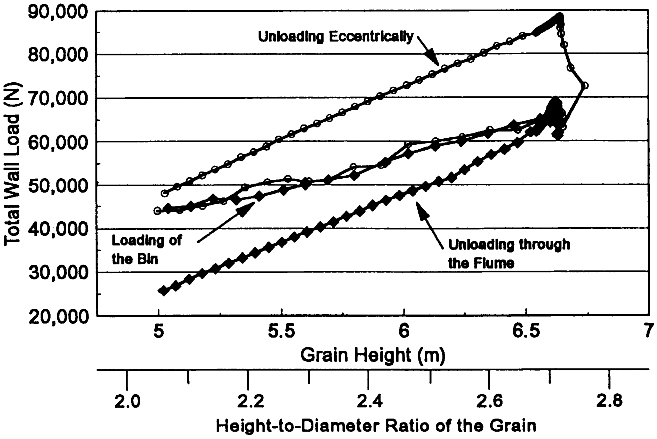
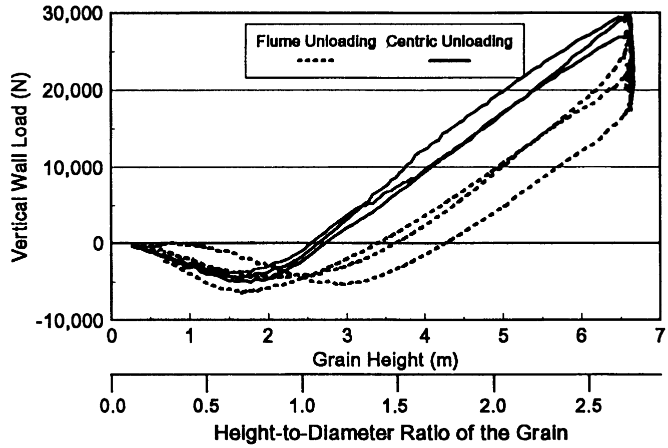


Fig. 4. Total wall loads during the onset of discharge through an eccentric discharge location and discharge through the wall flume.



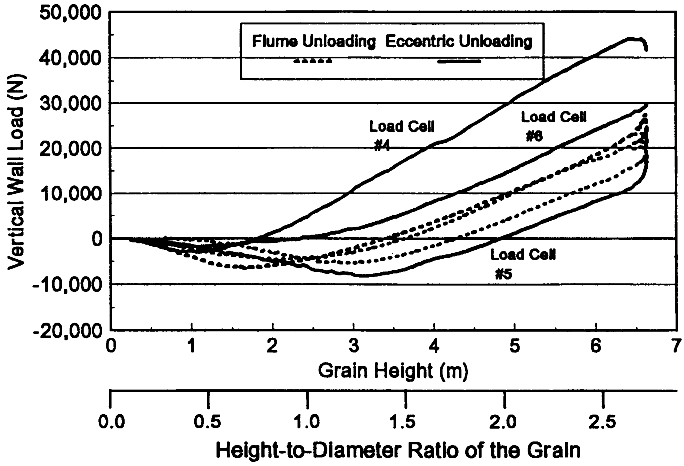


Fig. 5. Vertical wall loads measured by each load cell during centric and a eccentric unloading and unloading through the wall flume.

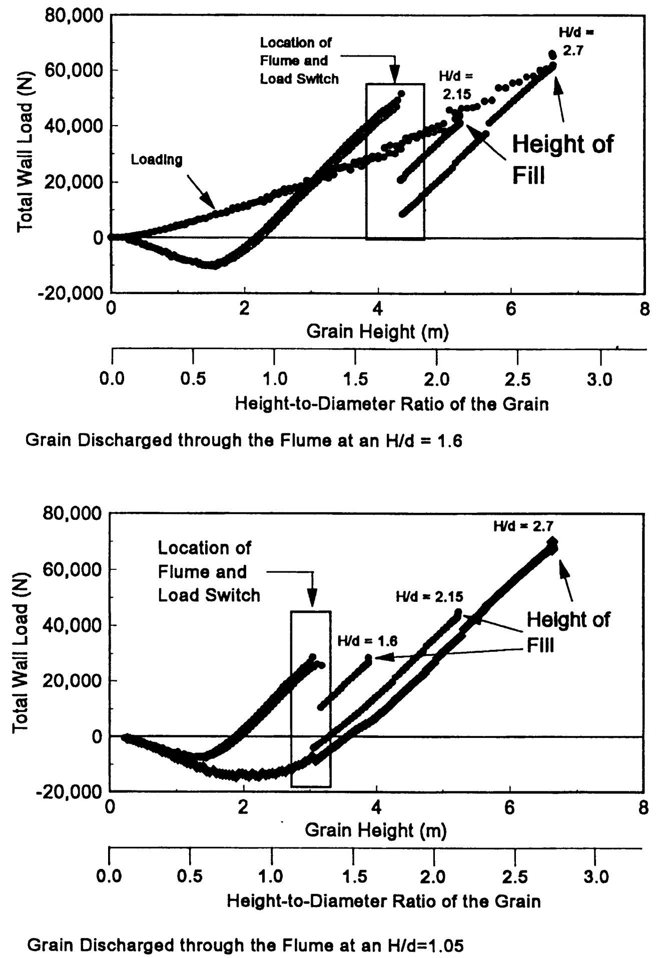


Fig. 6. Total wall loads during unloading through the wall flume at an H/d of 1.6 and 1.05.

or from other discharge gates in the floor of the bin. During these tests, once grain flow ceased through the flume, the remaining grain in the bin was unloaded using the center discharge gate. In switching from the flume discharge gate to the center discharge gate a change in the flow regime occurred, which created a change in the pressure fields within the bin. This can be observed in looking at the unloading curve in the bin. When the grain discharge was switched to the center gate, an increase in the TWL was observed. For one unloading condition the wall loads increased from 8600 N up to 52000 N when switched, creating an overpressure of 1.52 at that location. When unloading through the flume at an H/d of 1.05 similar large switch pressures were observed at that location where overpressures of 1.44 were observed when discharge was switched to the center discharge gate. These switch pressures were prevalent at an H/d of 2.15, 1.6 and 1.05. At an H/d discharge point of 0.5 very little change was noticed in switching back and forth between the two discharge outlets. This was probably the result of there being so little grain in the bin at that point, and a natural funnel flow discharge condition existing in the bin at that point. To offset these switch pressures, additional discharge should have been through the lower gates within the flume system rather than through the center discharge gate. This indicates that proper management must be used when unloading using a flume/gate unloading system, and that switching by the operator between discharge gates in the flume and bin floor within a bin complex should be done with some care.

CONCLUSIONS

The overpressures and overturning moments produced during eccentric unloading were much larger than either centric unloading or unloading through the flume. If side unloading of a bin is needed, unloading through a flume might cause fewer structural loading problems than through an eccentric orifice. Wall flumes appeared to negate any overpressures created during discharge when unloading through any of the gates within the wall flume system. However, unloading through wall flumes did create overturning moments in the bin which must be carried by the structure. The overturning moments produced when unloading through a wall flume were 6 times smaller than those measured during eccentric discharge. Operator caution should be used when switching back and forth between gates within the wall flume and other discharge locations within the bin. This is because change in discharge location creates a change in the pressure and flow regime which causes overpressures on the bin wall.

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