DEVELOPMENT OF EMERGENCY STRUCTURES FOR GRAIN STORAGE

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Received 9 November 1977

Muir, W.E., A. Kumar, B.M. Fraser, and **M.G. Britton**. 1978. Development of emergency structures for grain storage. Can. Agric. Eng. 20: 30-33.

Emergency structures consisting of 36-m³ containers fabricated from cross-laminated polyethylene and circular support-walls of wire mesh were developed and tested. The emergency structure that was developed was portable and could be erected by two men on an unprepared site in about 1 h. The quality of wheat stored for 9 mo in five different emergency bins and in two control bins (a plywood bin and a steel bin) remained constant. The mean difference (expressed in percent of initial mass) between the mass of dry matter stored in the emergency bins and the mass removed was -2.0% with a range of -0.8 to -4.3%. The mean difference for the two control bins was -1.2%.

INTRODUCTION

The amount of grain a farmer must store on the farm varies from year to year with variations in seeded area, crop yield and market demand. A farmer normally has permanent storage space to meet his average or slightly above average requirement. Most farmers temporarily store surplus grain (i.e. the amount of grain above their available storage space) in emergency structures or in open piles. Because most of these emergency storages do not adequately preserve the grain (Muir et al. 1973), a better designed emergency structure is needed.

A project was initiated to design, fabricate and test inexpensive storage structures that would store grain for 6 - 12 mo with a limited amount of grain deterioration. In addition, under emergency conditions it should be possible for one or two men to erect the structure on an unprepared site in a few hours.

Figure 1. Control bins and emergency bins under test in fall 1975.

PREVIOUS WORK

In earlier development work at the University of Manitoba, Gamby (1974) considered a number of design concepts and materials. He concluded that a container, capacity 35 - 70 m³, fabricated from special polyethylene sheets with or without a rigid supporting framework, was the most practicable. Gamby fabricated and carried out a 5-mo storage test on three cylindrical bins with cone tops, 4.9 m diam, 1.5 m side wall height and 35° roof angle. The plastic container was fabricated from 0.08-mm thick, cross-laminated polyethylene white sheeting. Wall sheets were fastened to the roof and floor sheets with Poly-Fastener®, a polythene channel and strip that snap together over the sheets. (The mention of trade products does not imply that they are endorsed or recommended by the University of Manitoba over other similar products not mentioned.) Other joints in the wall and conical roof were made with adhesive tape. The polyethylene bin walls were encircled and supported with 1.5 X 15.3-m wire mesh, (3.25-mm diam horizontal and vertical wires spaced 150 mm X 150 mm apart). The wire mesh ends were fastened together by overlapping the wire ends and twist-tying them.

The bins were inflated with a fan during filling. It was difficult to maintain the bin shape under wind loads, to determine the center of the bin and to position the auger so that the bins were filled centrally. Because one of the main problems with the polyethylene bins now in use was the tearing of the roof sheet in the wind (Muir et al. 1973), the roof cone was designed with an angle greater than the angle of repose of the grain so that the grain would force out against the roof. But inflation and filling had to be stopped before the upper one-half to one-third of the roof was filled completely. During the September to January test period, the roof fluttered in the wind and pinholes developed in the sheeting. Over the short storage period, no differences in moisture content of the grain at the peak were evident among the bins with vents in the apex of the roof cone and the bin with no vent. Moisture entered the bins through the Poly-Fastener® joints between the roof and wall and through holes in the floor sheets. A layer of grain up to 25 mm thick was spoiled in many areas on the bin floors. Temperature measurements indicated that these areas began to spoil within 2 - 3 wk of filling the bins in September.

MATERIALS AND METHODS

Based on the results of Gamby (1974) and preliminary testing during the summer 1975, five designs of bins were chosen for testing (Fig. 1). The main departure from the bins of Gamby was to eliminate the need for inflation by attaching the roofs to the bins after the bins were filled. A power source for the fan would not always be available and Gamby had been unable to completely fill the bins to load the roofs and prevent them from fluttering in the wind. Instead in these tests the roofs, which were fabricated in the shape of a cone with the slope equal to the angle of repose of the grain, were fastened to the walls after the bins were filled (Fig. 2). In one bin, the roof was further restrained by fish netting tied over the roof.

A number of design variables (Table I) were studied in the five emergency bins having 36-m³ capacity, 5.2-m diam and 1.4-m sidewall height. Four bins consisted of a container fabricated from cross-laminated polyethylene sheets supported by steel mesh walls. The wall of the fifth bin was fabricated from polyolefin woven fabric, which had a design strength greater than the estimated load imposed by the grain. During filling, the wall was held by six wooden posts equally spaced around the bin wall. Each post was held in the vertical position by a guy rope running from the top of the post to

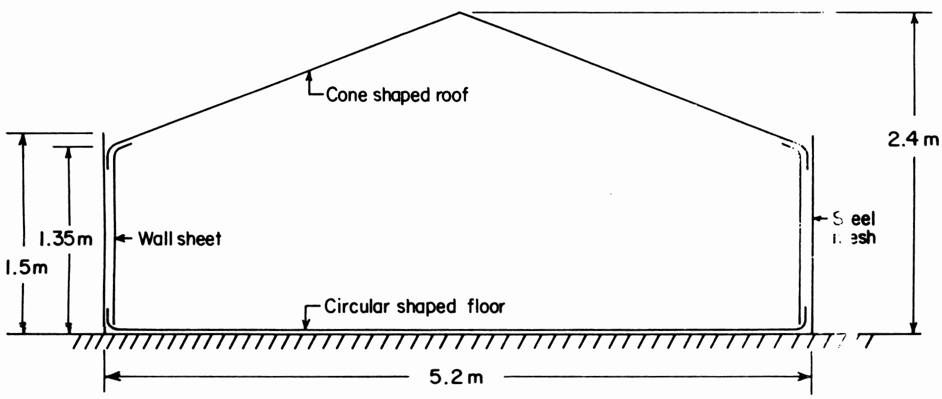

Figure 2. Vertical cross section along a diameter of an emergency bin with a steel mesh supporting wall.

TABLE I. DESIGN VARIABLES STUDIED IN EMERGENCY STRUCTURES FOR STORING GRAIN

Wall support:	Steel mesh and temporary wooden posts
Material type:	Cross-laminated polyethylene and polyolefin woven fabric
Material color:	Black and white
Material thickness:	0.08 mm and 0.10 mm
Flooring:	Single sheet of cross-laminated polyethylene with and without an extra sheet of 0.15-mm clear polyethylene
Joint fastener:	5-cm wide adhesive tape, 10-cm wide adhesive tape and Poly-Fastener®
Roof restraining system:	Adhesive tape, grommets and nylon fish netting (string spacing 8 cm X 8 cm), rubber tires
Roof vent:	25-cm diam cardboard tube covered with a steel pail, 77-cm diam polyethylene cap over a 25-cm diam hole in apex and no vent

a peg driven into the ground about 2 m out from the bin wall.

Two control bins, a steel bin, 60-m^3 capacity and a plywood bin, 52-m^3 capacity, were also studied. Both control bins had wooden floors on sills, 120 mm high. An extra steel ring was installed in the steel bin to give more head room for sampling the grain.

In late September 1975, each bin was filled with 27 t of freshly harvested wheat except for the bin without the steel mesh. The wall in this bin could not be held in position and only 18 t of wheat could be stored in the bin. The bins were unloaded in June 1976.

Throughout the test period, temperatures were measured with 0.8-mm diam copper-constantan thermocouples at 13 locations in each emergency bin and at 15 locations (two extra locations on the roofs) in each control bin. To determine the short-term effect of solar radiation, the roof and wall temperatures of each bin were recorded hourly on 27 May 1976.

When filling and emptying the bins, grain samples were taken from each truck load and from 13 locations in each bin for determination of moisture content using a Halross Model 919 electrical-capacitance meter. On 22 March 1976 and 29 April 1976, samples were taken from along the central axis of each bin. The Canadian Grain Commission determined official grade and dockage for four composite samples for each bin. Selected samples were also analyzed by the Canadian Grain Commission for milling and baking quality.

The mass of grain loaded into and removed from each bin was measured using the truck scale in a nearby primary elevator. After taking into account the amount of grain removed from each bin for samples and the change in mean moisture content during the storage period, the amount of grain not returned to the elevator was calculated. The amount of discarded, spoiled grain was not measured directly because of its high and variable moisture content.

Tests to compare the tensile strengths of the sheeting and joints when subjected to weathering were conducted in the laboratory with a crude loading apparatus. Three replications of each sample were run. Both black and white cross-laminated polyethylene sheets with and without joints made with 5-cm and 10-cm adhesive tape were tested in the laboratory before and after being exposed to outside winter weather for 10, 22, 44 and 76 days. To determine the effect of low temperature on tensile strength, white sheets with a 10-cm tape joint and black sheets without joints were tested at an ambient temperature of -22° C. Tensile tests were also run on samples cut from two of the test bins at the termination of the storage period.

RESULTS

General Assessment

Loss in grade and quality

During the 9-mo storage period, the official grade of the stored grain did not change in any of the bins (three bins contained No. 1 and four bins contained No. 2 Canada Western Red Spring wheat). Milling and baking tests indicated that the wheat underwent changes that are expected to occur normally during storage of freshly harvested wheat. Some spoiled grain at the apex and on the floor of some bins had to be discarded because of spoilage. The main spoilage was on the floor because melted snow water flowed into the bin through holes in the wall gnawed by mice. In three cross-laminated polyethylene bins and in the polyolefin bin, snow piled over the bins and mice lived around the bins under the snow. In the other polyethylene bin, the snow blew away from the bin and there appeared to be no problem with mice. The mean difference (expressed in percent of initial mass) between the mass of dry matter received and the mass returned to the elevator from the emergency bins was -2.0% with a range of -0.8 to -4.3%. The mean difference for the two control bins was -1.2%.

Moisture content

The mean moisture contents (excluding the moisture contents of the spoiled grain that was discarded) of the emergency bins increased from 14.0% in September 1975 to 14.6% in June 1976, i.e. an increase of 0.6% + 0.3%. The increases in the two control bins were 1.2% in the plywood bin and 0.7% in the steel bin.

Temperature

The temperatures of the centers and bottoms (Fig. 3) of the control bins cooled more rapidly than those of the emergency bins because air could blow under the control bins. The initiation of spoilage at the bottom of the mouse-damaged bins was evident by the sharp increase in grain temperature in April (Fig. 3).

Design Variables

Wall support

The wire mesh was necessary to maintain the shape and wall height of the bins during filling. The steel mesh provided adequate strength for the 36-m^3 capacity bins. The same wire mesh was also found to have adequate strength for a 70-m^3, 7.1-m diam bin in a single short-term structural test in

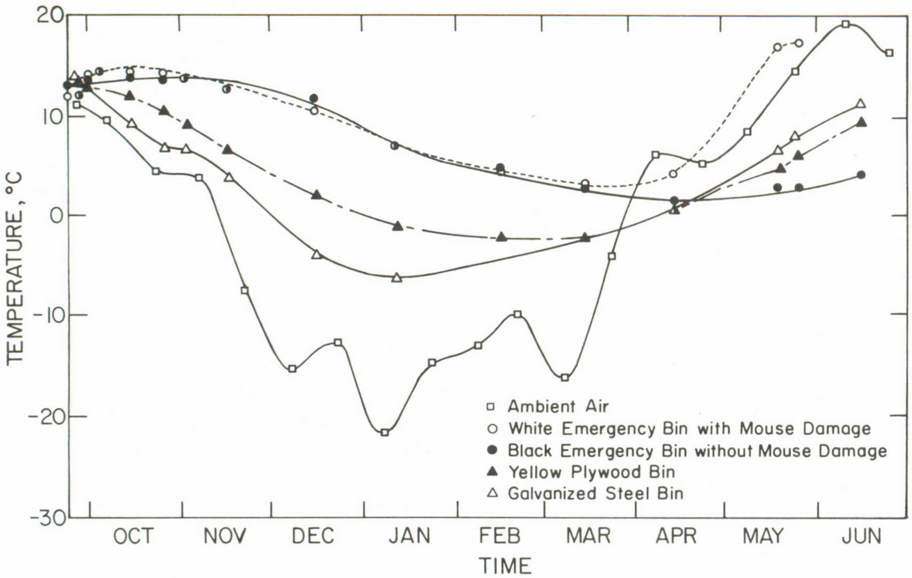

Figure 3. Temperatures at bottom-center of four test bins during 1975-1976.

the summer of 1976. Also, in a short-term summer test it was found that a 36-m³, 5.2-m diam bin could be filled eccentrically, 1.0 m off-center without failure of the wire mesh walls. But such an off-center cone top would make it exceedingly difficult to put on the roof sheet satisfactorily.

Material type

The polyolefin woven fabric did not break under the grain loads but because of its high elongation and the difficulty of holding up the walls during filling, the bin slumped down and could be filled to only two-thirds design capacity. Elongation continued for some time after filling was stopped.

The cross-laminated polyethylene appeared to perform satisfactorily but as previously mentioned, it can be readily damaged by mice.

Material color

In the tensile strength tests, the white cross-laminated polyethylene was initially about 30% stronger than the black material. After 76 days of winter weathering the strengths of both materials reduced by about 10%. The tensile strength of both white and black material measured at -20° C was about 20% higher than that measured at 20° C. The strength of the black and white roof and wall sheets from the test bins did not decrease over the storage period, while the white floor sheet reduced in strength by about 20%. There appeared to be considerably fewer pinholes in the white roof sheets than in the black roof sheets. Hourly measurements of the inside roof temperature indicated that the black roof sheeting could be as much as 10° C higher than the white sheeting under direct solar radiation.

Material thickness:

There were no obvious differences in the performance of cross-laminated polyethylene sheets of different thicknesses used in the emergency bins.

Flooring

There were a few holes in the flooring other than those caused by mice but because water entered the bins through mouse holes it was impossible to determine any differences between the two designs of flooring (Table I). It would appear that the single sheet was sufficient because hot spots did not develop in the fall and winter in any of the bins. In the bin with no mouse damage the spoilage on the floor was insignificant.

Joint fastener

The adhesive tape deteriorated fairly rapidly when exposed to the combination of solar radiation and dynamic stress. All the joints between the roof and wall had to be refastened in March with tape. Only one of the joints running down the cone roof had to be refastened, and this was on a bin where the roof sheet was fluttering in the wind. The 5-cm wide tape deteriorated more rapidly than the 10-cm wide tape. The adhesive tape loosened from the polyolefin woven fabric within a few days.

In the tensile strength tests black sheets of cross-laminated polyethylene joined by 10 - cm wide adhesive tape had the same initial strength as sheets without joints, while joined white sheets had about 15% lower strength than sheets without joints. Taped joints in white material lost about 20% of their strength after 10 days of weathering and then remained constant for the remainder of the 76-day test period. Samples of exposed taped joints between the floor and wall from the test bins exhibited about 35% lower strength than new joints. Taped joints that had the tape on the inside of the bin lost only 10% of their strength.

The Poly-Fastener® did not deteriorate during the storage period but appeared to allow water to enter through the joint. It is more difficult to apply than adhesive tape and because of its stiffness prevents folding a prefabricated bin compactly.

Roof restraining system

None of the roofs fluttered excessively in the wind. Although some pinholes did develop in the roof sheets, they appeared to have had no effect on grain quality. The different restraining systems seemed to have no effect on the number of pinholes that developed.

When only adhesive tape is used to restrain the roof and fasten it to the walls, the tape must be replaced during the winter or weights, such as old rubber tires, must be thrown onto the roof. Tying the roof sheet to the steel mesh with grommets and string seemed to be fairly satisfactory but one-third of the grommets broke during the storage period. Fish netting tied to the wire mesh kept the roof from fluttering and the netting did not deteriorate during the test period. The fish netting, which is probably more expensive than other restraining methods, can become tangled when placing it on the bin.

Roof vent

Snow blew into the control bins and accumulated in 1-m diam piles on the grain peaks. Presumably, snow also blew into the two emergency bins with vents but this could not be determined because of the need to avoid disturbance of the shape of the cone that would have resulted in the inspection process. Spring sampling on 22 March 1976 indicated that the moisture contents at the peaks of the two bins with vents increased to 17.0% from an initial moisture content of 13.7%. The grain at the peak in the bin with the cardboard tube vent did not dry before June when the bin was emptied. In the bin with the polyethylene cap, the grain dried to 13.8% moisture content by unloading time. In the remaining three emergency bins, which were without vents, the average moisture content at the peaks increased to 15.1% by 22 March 1976 and then decreased to 13.4% when unloaded. The moisture contents at the peaks increased to 22.3% in the plywood bin and 24.3% in the steel bin when sampled on 22 March 1976. However, by 23 June 1976 the grain had dried to 13.6% and 13.2% in the plywood and steel bins, respectively. The moisture contents 200 mm below the peak increased during the storage period to an average for all seven bins of 16.1 + 1.0%. The highest values at this location at unloading were 17.2% in the plywood bin and 17.7% in the steel bin. There were also some small isolated spots of high moisture grain on the floor of the steel bin which appeared to be due to melted snow water running down through the grain to the floor.

Filling and emptying bins

Unloading grain from any of the emergency bins can be hard work and can be dangerous. The end of the auger is lifted over the top of the wire mesh and shoved into the grain. At the beginning of unloading some augers can tip forward if the end is not pushed further into the grain as the grain is augered out. Once the auger has been pushed down to the floor it will not tip.

During both loading and emptying the emergency bins, there can be a problem with wind. When the bin is empty it must be restrained in the wind by placing heavy objects such as old tires inside the bin. If this is not done the plastic will balloon out and can blow away.

DISCUSSION

The effectiveness of a structure for storing grain under temperate climatic conditions is mainly dependent on its ability to prevent precipitation (snow and rain) entering the grain and to prevent moisture accumulating in the stored grain. The main problem with emergency bins fabricated from cross-laminated polyethylene appears to be puncturing of the polyethylene by mice or other damage to the bottom of the bin. Moisture migration and accumulation due to temperature gradients in the grain bulk do not appear to be a problem when storing dry grain for less than 1 yr.

The prevention of damage by mice or other rodents to the bottom of the bin is nearly impossible. Proper rodent control measures such as keeping the area around the bin clear of rodent harborages can be fairly effective but probably can never be perfectly successful. The bins were located within 25 m of a granary heavily infested with mice. The mice lived around the bins that had snow blown over them. The bin that was more in the open and around which less snow collected had no mouse damage. The direct grain loss due to the mice was small but the grain loss resulting indirectly from mouse damage was due to water entering through the mouse holes.

It would appear that the best method of reducing grain loss would be to erect the bins in a well drained location away from places where snow collects. This would also reduce the possibility of water entering through other openings in the bottom which could be caused by many other possible agents such as protruding objects on the ground, cuts by shoes during erection or small holes in the manufactured sheets.

Although the mean moisture content of all the grain bulks increased during the storage period, there was a greater increase in moisture content at the peaks of the bulks. In the emergency bins with vents and in the control bins, the increases at the peaks were probably due to entrance of snow and rain. In the other bins, the increase was probably due to moisture migrating in the natural convection air currents in the bulks. It was initially believed (Muir et al. 1973) that this moisture migration would cause spoilage at the peak of the emergency bins because it would not be able to escape through the plastic top as presumably can occur in steel or wooden bins. Therefore, two emergency bins were tested with vents. Neither the vents on the emergency bins nor the vents in the control bins were able to keep out snow. A bin ventilator that keeps out driving snow is nearly impossible to envisage (Kelly et al. 1942).

The unvented bins did have some moisture accumulation at the peak during the winter but with hot spring weather it apparently was driven back into the grain bulk. It appears that more grain could be damaged by the entrance of snow through a vent than by moisture migration and accumulation in an unvented bin. This is specially true for emergency bins which frequently are emptied during winter or early spring. If grain is stored at higher moisture content or for longer periods of time, the moisture accumulation in the polyethylene bins may become greater and thereby some grain spoilage may result (Muir et al. 1977). But for an emergency bin used for temporary storage, it seems unnecessary to incur the cost of developing and manufacturing a snow-tight vent.

SUMMARY

The research indicated that emergency bins can maintain as well as steel or plywood bins the commercial quality or official grade of stored wheat for 9 mo. The amount of spoiled grain will vary according to a number of factors of which the most important are the management practices. The amount of grain spoiled in emergency bins can be high when the bins are located in poorly drained locations and mice or other agents cause holes in the bins. But the tests also showed that spoilage can occur in permanent storage structures. By taking some precautionary measures, the spoilage in both emergency bins and permanent bins can be minimized.

Although now somewhat out of date, Kumar (1976) showed that, based on estimated 1976 costs, emergency structures of this type could be an economical alternative for storing grain surpluses that occur one out of three years. If the emergency bins are repaired and safely stored for use in a second year the economics for using them for the temporary storage of grain becomes quite favorable.

ACKNOWLEDGMENTS

We thank the National Research Council of Canada for financial assistance. We thank the following for their assistance: Canadian Wheat Board, Manitoba Pool Elevators, Canadian Grain Commission, G.H. Kabernick, Forever Industries (1971) Limited, Sto-Cote Products Inc. and Westeel-Rosco Ltd.

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