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Silo structures for silage have been used for grain storage, both wet and dry, for a number of years. Although the first cost of a concrete or steel silo for grain storage is usually somewhat higher than the cost for a comparable volume round metal bin storage, the ease of adding concrete hoppers, the more efficient space utilization of the tall silos, and a structural form considered by many as more permanent, has appealed to many elevator and some farm operators.

As farm operations change from year to year, a number of farmers find themselves with a silo that is not being used for silage. The structure may be too small, in the wrong location, or abandoned as enterprise organization changed. This publication is directed to the possible evaluation and adaptation of such silos for dry shelled corn and/or small grain storage.

General Considerations

There are a number of general considerations that need to be weighed in approaching the evaluation of an existing silo for possible adaptation for dry grain storage. These include:

1. The silo must be in sound structural condition, and hooped or reinforced sufficiently to store dry shelled grain.
2. The silo must have a roof.

3. The silo must have a concrete floor, preferably built to a height above that of the surrounding soil grade around the silo.

4. The walls must be reasonably moisture tight. The doors and walls must be reasonably air tight to permit forced aeration.

5. The silo must have a fill system that will minimize grain damage.

6. The silo must be equipped with an aeration system adequate to condition dry grain.

7. The silo must be equipped with an unload system that will withdraw grain from the bottom center point--side tapping for gravity outflow is only permissible if the manufacturer will so certify.

8. The silo should be in a favorable location for incorporation into a sound and efficient long range grain storage facility.

Structural Condition and Adequacy

A sound structural condition implies that the foundation is intact and level, that the walls are not heavily pitted and cracked such as to render their performance questionable in terms of safety and protection, and the doors are or can be made reasonably air tight. Examine the exterior surface of the silo and try to judge whether walls appear capable of turning water. It may be useful to examine an empty silo during and following a driving rain, to detect possible leaks or wicking of water through the wall due to capillary action.

Evaluate hoop size and spacing in terms of the manufacturers recommendations for grain storage. If the silo is adequately hooped to store grass silage, it may be adequate for grain storage but hoop requirements for dry grain should be evaluated critically. Check the general condition and tension of hoops -- it is very important that they be tensioned snuggly and equally so that each hoop carries its designed share of the load.

On most stave and hoop silos, the intermediate hoops that are spaced at levels that would cross the doors, are attached to headers or spreader bars on each side of the door. These spreader bars transfer the load to short tie rods above and below the door, across the face of the door sills. Examine the spreader bars for any evidence of stress cracks or bending due to excessive load. Be especially aware that added hoops must not be hooked into these same spreader bars, unless the bars and short ties that span the door opening, are specifically designed for this increased load. This judgment must be made by the manufacturer.

Usually, the hoops to be added may be placed at levels that coincide with the door sills, except in very large silos that require considerable addition of hoops. The structural question involved in placing one heavy hoop every 30" to coincide with the door sills, versus two lighter hoops every 15" spacing, concerns whether an individual stave and whatever intermediate hoop support was already present, can support the total load placed against it when the main support is spaced 30" apart. The structural loading involved is not unlike that of placing an individual stave on two saw horses 30" apart, and loading bags of sand or individual bricks on the stave until the applied weight equals that of the grain pressure. If the stave breaks or is dangerously stressed, the solution is to support it at closer intervals. Again, only the manufacturer can adequately evaluate this answer.

If the doors are of no consequence for grain storage unloaded from the bottom, hoops may be run across the door opening. In adding hoops, the new hoops should **never** be run over the top of any sharp edges such as the spreader bars or door frames that might cut the tie like a knife edge, or hold it away from the silo staves for considerable distance on each side of the projection. If the spreader bar does not have opening for passing added rods through the bars, do not drill the spreader bars without concurrence of the manufacturer concerning structural adequacy of the remaining bar section.

See MWPS-l3 for specifications on silo hoop sizes for selected silos.

Extremely tall concrete stave silos over 60' in height may approach or exceed safe limits on the vertical crushing strength of the relatively thin stave wall immediately above the foundation point, when converted to grain storage. Stored grain places a very heavy vertical side wall load on the silo walls. In fact, after the grain depth in the silo reaches roughly 2-1/2 times the diameter of the silo, the weight of additional grain is almost totally supported on the sidewalls, with no added pressure placed on the bin floor in the center of the stored mass. Unless the silo manufacturer has increased the stave thickness in the lower sections of the wall, or otherwise increased their strength in crushing, limits may have to be imposed on the maximum safe fill level. The manufacturer should be consulted for a recommendation and design.

Tile silos with internal reinforcing imbedded in the mortar joints **should not** be considered for grain storage. In fact, any such silos that are old or that have been used for a number of years for silage, whether recent or some years ago, should be viewed with extreme caution concerning structural safety. It is impossible to evaluate the corrosion damage done to the reinforcing rod from silage seepage into the mortar joints. Do not be misled by the excellent condition of the reinforcing rods in the top courses of the silo -- these top courses have never sustained silage action and acid for any appreciable time so will almost always be in good condition. Tile silos that collapse under loads frequently show many reinforcing rods with no fresh break, or rods that have necked down to a pin head or match stem cross-section of remaining metal.

Poured concrete or monolithic silos with internal reinforcing must be evaluated by the builder or manufacturer for adequacy of the reinforcing systems to sustain grain storage pressures. It may be possible to add hoops to old monolithic silos that are in good condition, but the only safe assumption is to disregard the unknown internal reinforcing.

Modern steel silos, both galvanized and glass coated, are virtually always designed for silage and grain storage. Their adaptation is primarily one of installing aeration equipment, modifying unloading if necessary, and making provision for aeration air discharge in the top of normally sealed units.

Older style steel silos, especially those that show severe corrosion in the lower sections and/or those that have not been used for a number of years, should be viewed with extreme caution as safe grain or silage storages. Corrosion on a very thin metal wall can markedly reduce the metal area remaining to sustain the storage load.

Structural Stability During Unloading

Most circular storage structures derive a significant amount of their structural strength and stability from uniform sidewall loading. The uniform wall loading forces the wall into hoop tension--the wall tension or the external hoops keep the wall from bulging outward, and the grain pressure on the inside keeps it from buckling inward. The wall is thereby held essentially vertical and rigid to resist both lateral or outward pressures, and the vertical sidewall loads or pressures discussed earlier with reference to potential wall crushing near the foundation.

Silos must not be side tapped for gravity unloading into a truck or a conveyor hopper, unless the structure is specifically designed for such side withdrawal. Removing grain from one side of the structure immediately reduces the pressure bearing laterally against that sidewall directly above the outlet point, and extending to the top of the grain mass. We sometimes forget that grain in-flows off the top of the grain surface when we withdraw from below, much in the manner of the grain mass turning wrong side out in unloading.

When the sidewall pressure of the grain directly above the outlet diminishes, as grain withdrawal continues, the wall area with the reduced pressure bearing on it tends to collapse inward. At the same time, the pressures acting on a given section "hooped" around the silo continue to push outward with the original force. These forces tend to move the wall section opposite to the withdrawal side, outward, and cause the structure to form a slight out-of-round shape, bulging outward at the back side. This places some of the storage mass on a vertical line outside of the foundation and supporting wall below the bulge -- the structure has now possibly received permanent damage in shape and is in some danger of collapse from the eccentric loads of the stored mass.

As side withdrawal continues, the draw-down of grain on the top surface of the grain mass above the withdrawal point continues until the top surface slopes at the angle of repose for the grain -- typically 26 - 28° above horizontal. This surface slope of roughly 27° is essentially a 1:2 ratio -- thus in a 24' diameter silo, the wall opposite to the withdrawal side may have 12' of added grain depth bearing against it. If the grain is in any manner out of condition, the angle of repose may be much steeper with even higher resultant unbalance.

The grain stacked high against one wall of a circular wall section has no grain on the balance of the exposed wall surface to push outward to stabilize the wall. In thin wall structures, the building will surely develop a serious out-of-round form and is in extreme danger of collapse. On low structures such as round metal bins, the structure may slide horizontally on the foundation, to relieve the high wall pressures on the loaded side. In tall structures such as silos, the combination of relieved sidewall pressure on the withdrawal side coupled with stacked grain high on the opposite side may cause complete structural collapse.

Unloading from the bottom, center is usually an absolute necessity in upright circular grain storage structures, especially in **thin** wall units. The unloading is usually via an auger, which is inserted into a tube attached to a center hopper. Auger equipment designed for round metal bins is usually directly applicable. See MWPS-13, **Planning Grain-Feed Handling** for schematic drawings of unload auger adaptations for silos and round ear corn cribs. Several of these illustrations feature combination unload conveyor/aeration floor section installed in the original unloader trench.

Floor Installation

Most concrete silos have only an earth floor that is usually below the level of the surrounding grade outside the silo. This floor level must usually be raised 8" to 16" above the outside grade, to facilitate the installation of the unloading and aeration equipment. It is most desirable not to have the discharge of the unload auger installed "with its nose in the ground." If you have to dig a hole to get the transfer auger under the discharge of the under-floor auger, the hole and hopper will usually be full of water. The water will frequently be frozen in freezing weather.

The earth floor pit is usually filled with pea gravel or wetted, compacted sand. A vapor barrier of 4 - 6 mil polyethylene plastic is placed over the fill and a 6" concrete floor poured over the surface. No reinforcing is necessary in the floor, but many builders prefer to install a 6" x 6" welded wire mesh to keep the cracks that form from opening.

If the unload conveyor tube, center hopper and floor channel for a partial aeration floor system is to be formed in the concrete floor, these forms must be staked down rigidly to keep them from floating out of the concrete during pouring. Most metal bin builders have partial aeration floor kits, plus the unload system kits. They also have installation experience that may prove valuable.

Forming hopper floors in farm-type silage silos is not generally recommended. Again, the farmer must rely on the manufacturer for the final judgment and design certification. Installing hoppers that extend above the ground can add severe pressures on the lower sidewall supporting the above ground section of the hopper. Too, the hopper below grade will present serious ground water seepage problems in most areas of Indiana that grow heavy corn yields. And finally, hoppered floors are much more difficult on which to install the necessary aeration system.

Water Proofing Concrete Silo Walls

Most concrete silo walls are reasonably water resistant and usually do not require special treatment. Most operators try the silo the first year without any application of special moisture barriers. The exception would be any circumstance in which observation, experience, or judgment based on visual inspection during and following a driving rain, indicate that water entry is an apparent problem.

Moisture sealing is usually accomplished by spraying the outside surface with a silicone-type moisture sealant. Most of these materials are completely clear and do not discolor the concrete in any way. There are probably moisture barrier materials available that will apply a surface color at the same time the sealant is sprayed -- check with farm supply and paint representatives.

Door seals for dry grain storage are not critical except as they may affect aeration air leakage or leakage of fumigant materials. It is usually better to rework the door seals than to try and install a plastic or paper curtain down the inside of the silo wall over the door openings. These curtains must creep as the grain settles in the initial fill. They present problems of keeping grain from lodging behind them during filling and they tend to flow out of the silo with the grain as unloading proceeds, with resultant grain flow and equipment jamming problems.

Conveying Dry Grain Into Silos

Most silos are at least 40' high, with numerous units of 50 - 60' height and many large diameter structures of recent years measuring 70 - 80' heights and more. These fill heights essentially eliminate any consideration of inclined conveyor filling, either in portable or permanent form -- the fill heights render such equipment systems unworkable and unsafe. Vertical elevator systems appear to be the only workable solution available at the present time.

Blower systems of elevating dry grain are not acceptable for grain to be marketed. Even though the blower is run at minimum speed, the amount of grain cracking is high. A very limited number of farmers use a blower to elevate dry grain for livestock feed, into silos. Most materials must be about 1 - 2% more dry to store in a ground state, compared to their safe moisture as whole grain. This could mean 12 - 13% moisture content for long range storage.

Dry corn blown into the silo should also probably be cool before it is placed in the structure, if at all possible. With the large amount of fines present in the grain as it is blown upward and dropped onto the grain mass, it is impossible to aerate the grain. This means stored grain should go into the silo at 50°F. or below, preferably 35 - 40°F. This either means cooling the grain in another storage or Dryeration bin essentially to night-time temperatures in the fall before placement in the silo, or running the dryer delivery from the night hours to the silo storage.

Any spontaneous heating that may develop in the silo from concentrations of fines, incompletely dried grain, or moisture movement due to air circulation from convection is probably impossible to correct. Storage of dry corn cracked from blower impact in elevating is therefore not recommended as a proven practice. We do know that a very limited number of farmers commonly practice such storage and handling, some successfully for as long as 10 years or more. But with corn values in the range of $2 - 2.50/cubic foot, problems that may develop have to be viewed with extreme caution.

Bucket elevator systems are the most likely conveyor method for satisfactory performance on commercial grain. The problem is that such conveying systems require high initial investments. As such, they must be used efficiently on reasonably large volumes to be justified. This means that it is highly desirable to have the silo or silos located such that the leg required for their special fill height requirements, can also be used for the balance of the grain receiving/handling/drying/storage/processing/marketing needs.

A very limited number of farmers have installed a very small bucket elevator as a special fill conveyor at a silo, and used gravity flow wagons to meter the grain into the intake. Such a system, which may use a bucket elevator with a capacity as low as 300 - 500 bushels per hour, requires that the gravity wagon be moved to the silo and left while elevating proceeds automatically. The advantages are a lowered equipment first cost. The disadvantages involve the continual shuttling of transport vehicles to and from the silo, plus the requirement for special vehicles to gravity feed the small intake. Bear in mind that the grain may have to be hauled back to the grain center for processing.

A number of aspects of bucket elevator conveying systems is presented in MWPS-13, cited earlier.

Impact damage to grain dropped into a tall silo can create added fines that affect storage and market options. Research studies have demonstrated that impact damage in yellow corn approaches a critical point when grain velocities reach that equivalent to 40' of free fall. Obviously, grain dropped into a 60' high silo, from a gravity spout that started possibly 10-20' above the silo, may result in significant increases in fines in the grain.

There is little that can currently be done to reduce impact damage in grain drops into tall structures. Bean ladders have been used in the edible bean and seed grain industry for a number of years, to safely let down high value materials with minimum damage. Such use has not generally been economical with commercial corn. The current route to reduced fines probably lies more in reducing stress cracks in grain drying drying and cooling, to reduce susceptibility to impact breakage. The use of slower drying procedures, especially when drying through the critical 19% - 14% moisture range on corn, plus the possible incorporation of Dryeration cooling, will do much to reduce stress crack formation.

Vertical auger systems of handling dry grain into tall silos does not generally appear to be a very workable or economical system. Performance rates are quite low, of the magnitude of 1000 bushels per hour or less, unless the auger system is at least "8" or 10" or larger. Larger augers mean greater initial costs and increased horsepower. Wear out and maintenance on auger systems is considerably higher than that for high speed belt bucket elevator systems. Vertical auger units are generally not acceptable for use for wet grain receiving, or as a complete conveyor system for the entire receiving/drying/storage/processing/marketing facility.

The special handling equipment requirements, in the final analysis, probably do more to force the issue concerning whether or not to adapt an existing silo for dry grain storage, than does any other single factor. The one exception may be the more basic question of present silo location, in relation to the long range grain facility and processing needs.

Aeration Systems

Aeration systems are essential in grain storages of 2-3000 bushels or more to control the temperature of the grain. If the grain is placed in the storage in early October, the temperatures of the grain into storage can easily be 70-90°F. or higher (a high speed batch or continuous flow dryer cannot usually cool grain below 10°F. above the outside air temperature). Since grain is a good insulator, the temperature in the center of the mass will probably not change more than about 1°F. per month, as the grain around the outside wall of the silo cools down with declining winter temperatures.

In a short period of time, the grain along the outer wall will be 10° - 40° F. below that of the center of the grain mass. This temperature difference, which would exist across a 12' distance in a 24' diameter structure, will bring about convection air circulation within the grain mass -- cold air along the wall is heavier and sinks toward the floor. The warm air mass in the center is relatively much warmer than the surrounding air outside-the bin, and hence is more buoyant -- it rises toward the upper grain surface, much as a hot- air balloon flies.

This convection air circulation within the grain-mass transports grain moisture with it, collecting moisture as the air is warmed, and dropping it in the form of condensate as it strikes the cold upper bin surface. The process is called moisture migration it usually becomes significant whenever the grain temperature is 10°F. or more above that of the outside day/night air-temperatures. The solution is a control led airflow imposed on the grain mass, which we call aeration.

It is beyond the scope of this paper to outline a complete discussion of aeration system planning, operation, and management.

Silo-type grain storage structures should usually not be designed for appreciable grain drying in the storage. The grain depths are too great to permit normal farm drying air flow rates. It will usually not be practical to supply more than 1/2 cfm/bu to grain depths over 40 - 50'. More practical aeration flow rates range from 1/10th to 1/20th cfm/bu minimum, to possibly 1/5th or 1/4th cfm/bu as an upper value. The latter may permit receiving grain of 15-1/2 to 16% moisture, and~performing some drying during the storage period. Elevator operators may run higher storage moisture contents with these same air flow rates, but realize that they usually have multiple structures and temperature sensing to alert them to storage problems and permit rotation of troublesome grain.

Aeration system design is very critical. Once the amount of grain to be dried is defined in a given size structure, the entire aeration system is dictated and defined. There is a particular amount of air flow that must be supplied for a particular moisture content to be placed in the structure This air flow level requires a specific minimum amount of perforated metal to introduce the air into the grain. Too, the size of the air duct required to convey the air into the bin and under the perforated metal is also fixed.

The point is that the aeration system design is not something to be taken lightly--it is a very specific set of specifications that must be incorporated into the silo conversion, if the total performance is to be reliable.

Long Range Facility Plan

The development of a sound and efficient long range plan for the complete- grain receiving, drying, handling, storage and processing or marketing facility - -is probably the most important consideration of all. If the existing silo structure or structures does not fit into this long range plan, incorporating options for growth alternatives, it probably is not worth adaptation.

Recognize that the silo is probably already some number of years old. Consideration of facility life beyond 20-25 years is risky and usually economically unwise. The point is that 20-25 years is a **long** time -- easily half or more of the productive years for most of us. Most of the technologies for which we buy and construct farm buildings tend to last more like 5 - 10 years or less. This means that the technology cycles at least twice during the 20-25 year life. To consider a useful life of 30-40 years tends to completely disregard obsolescence and change as an economical factor in farm production.

In the final analysis, the silo has to be in a reasonably good location relative to the efficiency of the long range facility plan, to warrant much investment in adaptation and use. If a special conveyor system can be installed for use with a remote silo, in a manner that will not restrict the timely conduct of grain harvest and storage during the 20-25 critical operating days available in which to complete harvest, it must be given consideration. But if the combination of all of the factors outlined above, that must be carried out to adapt and use an existing silo, add up to an inefficient or costly short range plan that gets worse in performance over time, alternate uses for the structure must be evaluated. Its use as a high moisture corn storage for livestock feeding is an obvious option.

It may be useful to view the development of a grain handling facility on the basis of reminding yourself that some day, you will be 10 years older and possibly 20 years more tired! The alternatives you want may look a whale of a lot different to you when you are 50 than they did when you were 35 or 40 years old. But the silo you adapt or build today or the new bin you build tomorrow will still probably be with you 10 to 20 years from now. What you do with your current new investment will, in a large measure, determine your future options for efficient, economical growth and performance.

REFERENCES

MWPS-13, Planning Grain-Feed Handling

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