

replaces OMAFRA Factsheet #08-057 of the same name

Deterioration of Concrete Tower Silos

D. Ward P.Eng.

INTRODUCTION

Many of Ontario's older concrete tower silos are still in use today — despite possible danger to humans and animals, as well as loss of the stored product. Farmers continue to fill these older structures, often without considering the deterioration that may have occurred due to age, weathering and the effects of silage acid attack. In recent years, the incidence of collapse of these structures has increased.

The collapse of a tower silo can have serious consequences. In Ontario, farm owners and workers have died as a result of a silo collapse. The silos have fallen onto adjacent barns, injuring or killing animals, destroying property and ruining any silage or grain stored there. Figure 1 shows the impact a silo collapse can have on surrounding buildings.



Figure 1. A collapsing silo can be lethal and cause significant damage when falling onto another structure. (Photo Credit: Thomas P. Rylett Ltd., Consulting Structural Engineer)

SILAGE ACID

Most deterioration of conventional concrete tower silos is caused by the attack of silage acids. When moist plant material is put into a silo it goes through the ensiling process that produces silage acids, mainly lactic and acetic acids. When these acids touch the concrete silo walls, they react with the Portland cement matrix that binds the aggregates together. As the structure ages, there is a gradual decline in strength.

The same acids also corrode silo hoops, reinforcing steel or hardware associated with the silo. Without proper maintenance and repair, this can ultimately lead to silo failure. Figure 2 shows the effect of placing material in the silo that is too wet.



Figure 2. Filling a silo with haylage or corn silage that has higher than normal moisture content, will lead to seepage of corrosive liquids that weakens and damages a silo. (Photo Credit: Thomas P. Rylett Ltd, Consulting Structural Engineer)

Silage acids cause deterioration to both concrete cast-in-place (poured) silos and pre-cast, stave silos. The rate and severity of this deterioration depends on:

- the size of the silo
- the moisture content of the ensiled material
- the amount of protection given to the concrete on a continuous basis.

Silage pressure plays a large part in determining the rate and extent of acid deterioration. In any silo the highest pressure is at the bottom. Taller silos produce higher pressures. This creates increased squeezing on the ensiled mass, which creates even more free liquid and seepage. These acid-laced silage juices are then forced into the tiny pores in the concrete. As a result, larger silos often suffer more acid deterioration than smaller silos. Ensiling higher moisture material leads to more fermentation and a higher level of acid production. This, in turn, results in accelerated concrete deterioration.

Material placed into a tower silo creates vertical and horizontal loads or pressures. Acid attack eventually reduces the ability of the structure to carry these loads.

Pre-cast Stave Silos

The corrosive action of silage acids reduces the ability of stave walls to carry the vertical friction load imposed by the contained silage. As the effective thickness of concrete resisting the vertical load is reduced, the strength of the inner surface of the silo wall decreases. Since stave silo walls have relatively thin sections to start with, any corrosion will cause a significant reduction in the wall strength.

The effect of acid deterioration is compounded in that it attacks the bottom of the silo wall, which is also the part of the wall that carries the greatest amount of the vertical load. In a normal, top-unloading tower silo, approximately 50 percent of the contained weight of silage is transmitted to the footings through the walls due to the friction effect. Thus, at some point in time, the cross-section of effective concrete can be decreased to the point where it will no longer be able to carry the compressive load and the silo wall will begin to crush. Figure 3 shows this mechanism of failure.

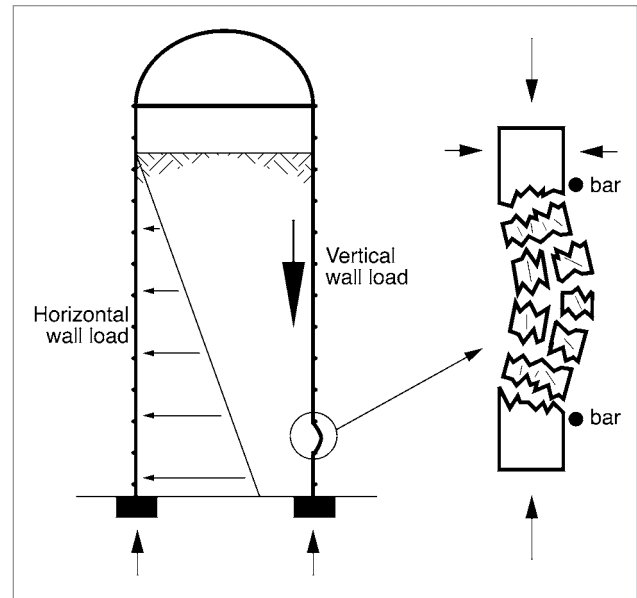


Figure 3. Silage acids can decrease the strength of a stave silo wall to the point where the vertical wall load will cause the wall to fail by crushing.

Stave silo builders usually use the same thickness of staves for all sizes of structures. Although there is a safety factor built into a wall to accommodate the vertical friction load, a larger silo has a lower factor of safety, and this can be reduced to the point of failure by acid deterioration.

Cast-in-Place (CIP) Silos

Acid deterioration is also a serious problem with CIP silos. Although there is more mass in a CIP wall, which is typically 150 mm (6 in.) thick, the concrete in this type of wall is often not as strong or dense as in pre-cast staves. It is not as resistant to acid attack.

The horizontal strength of a CIP silo wall is due to the reinforcing bars that are located close to the centre of the wall. If silage acids penetrate the concrete cover, the reinforcing bars corrode, reducing the effective cross-sectional area of steel. This reduces its strength.

Equally important is the reinforcing bars that encircle the silo are comprised of sections joined only by the concrete that surrounds the lapped ends. So the strength of this steel ring depends entirely on the bond strength of the surrounding concrete. Once silage acids penetrate the concrete around the steel much of the bond strength is lost.

The result? At some point in time the silo wall will not be able to carry the imposed horizontal load and the silo will collapse.

PREVENTION OF SILO DETERIORATION

1. Construction

To prevent, or at least reduce the severity, of silage acid action, you can:

- Build or buy a quality silo, where the walls are made of high quality concrete. Strong, dense concrete provides good acid resistance.
- Protect the silo walls by preventing silage acids from coming into contact with the concrete.
- Apply a suitable acid resistant coating to the bottom $\frac{1}{4}$ to $\frac{1}{2}$ of the inside wall surface of the new silo prior to use.
- Renew this coating as required to maintain a barrier.

2. Management

(a) Moisture control

- Reduce deterioration caused by silage acid by harvesting crops at a moisture content low enough that seepage will not occur.
- Ideally, whole-plant silages should contain enough moisture for good fermentation, yet dry enough to avoid free liquid being squeezed out.
- Use a moisture tester to determine when material is at the proper moisture level for storage.
- Table 1 shows the recommended maximum moisture content in whole-plant silages at time of harvest to avoid seepage problems with various sizes of silos.

Table 1. Maximum Moisture Content To Prevent Seepage – Whole-plant Silages in Tower Silos

Silo Size m (ft.)	Maximum Moisture Content (%)
4.9 (16) x 18.3 (60)	68
5.5 (18) x 19.8 (65)	67
6.1 (20) x 21.3 (70)	66
7.3 (24) x 25.9 (85)	63
9.1 (30) x 33.5 (110)	59

(b) Wall exposure

- If possible, remove all silage from the silo once a year. This reduces the time the bottom of the silo wall will be in contact with wet silage.
- It is structurally beneficial to allow the inner silo wall surface to dry out between fillings.

SIGNS OF DETERIORATION

Distress

The only warning sign of impending failure of a silo is cracking in the concrete. At least annually, scan the entire outside of the silo to determine if new cracks have developed. Use binoculars to do a cursory inspection.

If a silo shows signs of distress, contact a professional engineer before emptying the silo.

The consequences of a structural failure are severe and can be life threatening. Emptying a silo can cause a significant increase in the loads applied to the structure. If a failure is about to happen, unloading the silo can cause an instantaneous structural failure. If you suspect that your silo has structural problems, do not fill or empty it before having a professional engineer on-site to evaluate the situation.

Convert to Dry Storage

It might seem logical to take older, concrete silos and use them for dry grain storage. Do not undertake this without professional advice. Silos designed for whole plant silage or haylage must have additional reinforcement to convert to dry grain. This is usually in the form of steel hoops at vertical intervals on the outside of the silo. Contact an engineer to design this increased reinforcing.

Do not convert a silo to dry storage without contacting a professional engineer.

This Factsheet was updated by John Johnson, P.Eng., and reviewed by Dan Ward, P.Eng., poultry & other livestock housing & equipment, OMAFRA.