Four steps to keep your concrete silo standing tall

Craig Thompson  WL Port-Land Systems, Inc.

This article explains how to design, build, use, and maintain a concrete silo to help ensure that it will stand up to your storage requirements and function reliably for the long term.

When you own and operate a concrete silo, it’s natural to be concerned about maintaining its structural integrity. After all, you need to protect this major investment. In the following sections, we’ll help you meet this goal by looking at the four steps in achieving concrete silo structural integrity: design, construction, use, and maintenance. The information can help you gain a better understanding of each step, see where the responsibility for each step lies, and learn if you can do more to keep your silo standing tall.

1 Design

As the silo owner, you’ll share responsibility for designing the silo with a structural (or design) engineer and a construction contractor. The structural engineer — who may be employed by a silo supplier, an independent engineering consulting firm with bulk solids handling expertise, or a design-build company — must be licensed in the state where your silo will be constructed. The construction contractor — who may be independent or work for a design-build company — should have experience in concrete silo construction. You, the structural engineer, and the contractor each have important roles during the silo design phase. This phase includes establishing the silo’s structural design criteria, determining the silo’s function, and configuring the silo.

Establishing structural design criteria. The structural design criteria for your concrete silo focus on the silo’s foundation type and components. While the structural engineer will make most of the decisions about these criteria, you should also contribute to and review the criteria before the silo design is final.

This process involves an important preliminary step: contracting an independent geotechnical firm to perform a soil analysis at your site and provide a report based on the analysis. The most important information in this report includes the soil’s allowable bearing pressures, pile bearing capacities (if the foundation requires pilings), and expected soil settlement based on the silo’s expected dead and live loads. The structural engineer will use the report’s recommendations to develop criteria for selecting the silo’s foundation type and components. Failing to base these criteria on an expert soil analysis can cause major problems over the silo’s lifespan, including silo wall cracks and detachment of equipment mounted on the silo wall and roof.

Determining how the silo will function. By clarifying exactly how the silo will function, you can make sure that the finished structure will be strong enough to handle your requirements and meet your needs over its lifespan. Consider what materials the silo will handle and each material’s flow behavior, whether the silo will provide short- or long-term storage, and whether it will require frequent filling and discharging. Also think about how these functions may change as your plant’s needs evolve.

Then discuss these details with your structural engineer. This will help the engineer choose silo construction materials and methods and silo components so the structure can not only meet your current needs but accommodate your future needs without requiring costly modifications or repairs.
Configuring the silo. The final design step, working with the structural engineer to configure the silo, includes choosing such elements as the silo dimensions, the type and capacity of filling and discharging components, the floor or hopper, and — if you need multiple silos — determining how they’ll be arranged.

While no single silo configuration is right or wrong, certain design elements — such as the silo diameter and height — will affect your silo’s structural integrity and service life. Being aware of these effects will help you design the silo to accommodate them. For instance, the concrete wall of a large-diameter silo will stretch more than the wall of a smaller-diameter silo. The stretching can enlarge the silo’s perimeter by as much as several inches and, because of concrete’s poor tensile properties, can crack the wall. The same properties cause inelastic shortening of a tall concrete silo’s wall, causing it to shrink slightly because the wall is subject to higher compressive loads than the wall in a shorter silo.

Your silo’s discharge design will also affect the structure’s strength. Using a concentric (center bottom) discharge is always preferable to prevent damaging stresses on the silo wall during discharge. If your application requires an eccentric (noncentered bottom) discharge or a sidewall discharge (a discharge through one side of the silo), you must design the silo to handle the stresses induced by such a discharge. Otherwise, material flowing through the eccentric discharge will stretch and distort the wall from round to egg-shaped, while flow through the sidewall discharge will impose extreme stresses on the wall area near the discharge and damage it. Even when you’ve designed the silo for an eccentric or sidewall discharge, such a discharge will shorten the silo’s lifespan.

Eccentric filling can also create extreme stresses on the silo wall. While eccentric filling isn’t as damaging as eccentric discharging, designing the silo for concentric filling will help maintain the silo’s strength.

Depending on your requirements, you can configure the silo bottom in different ways, but a flat floor or a steel hopper are the most typical. In a silo with a flat floor, the floor can be self-supported by concrete columns or a steel support structure; in a silo with a hopper, the hopper will be supported by anchors embedded in the concrete silo wall. How well you design the floor’s support structure or hopper’s wall anchors will influence the silo’s structural integrity. With a hopper, you’ll also need to consider what stresses on the anchors and the hopper’s steel wall will result from the hopper wall angle, which is selected based on the materials the hopper will handle. Make sure that you design the anchors and hopper wall to handle these stresses.

Deciding to connect multiple silos in a cluster to save space or minimize conveying distances will also affect the silos’ structural integrity. For instance, four silos can be connected in two rows of two, or six silos can be connected in two rows of three. Connecting silos in this way can cause structural problems down the road, including silo wall distortion and large wall cracks, because the silos can’t expand freely where they connect with other silos. While you can mitigate these problems by following sound silo design principles and carefully choosing the placement of steel reinforcement bar (rebar) in the walls, a silo built as part of a group will always have a shorter lifespan than an individual silo of the same design.

2 Construction

Your concrete silo’s construction phase can be hectic and confusing, with a compressed schedule, long workdays, and tight quarters making everyone tense. Nonetheless, it’s important to verify the quality of the construction materials and monitor construction methods and quality during this phase to prevent structural integrity problems both during building and once the silo is operating.

Verifying material quality. During the building phase, the quality of construction materials is your primary concern. The structural engineer specified the right construction materials during the design stage, but now you need to
make sure that the materials delivered to your site match these design specs and meet your quality standards.

The concrete’s compressive strength, the aggregate size, and the rebar size and grade are most important:

- The concrete’s compressive strength determines how much compression the concrete can take without crushing. This affects the concrete’s durability.
- The aggregate mixed into the concrete must have a small enough particle size to fit between adjacent rebar and prevent air pockets from forming in the wall; such air pockets can eventually lead to spalling (flaking or pitting).
- The rebar size and strength affect how much hoop tension (the stress exerted circumferentially on the silo wall, also called hoop stress) the silo can resist to prevent the wall from blowing out.

For checking the concrete quality, you’ll need to perform a slump test and cylinder test. The slump test essentially gauges each batch’s consistency and workability by measuring how much the fresh concrete slumps, or collapses, right after being formed into a cone shape (described in ASTM C143: Standard Test Method for Slump of Hydraulic-Cement Concrete). The cylinder test verifies the concrete’s compressive strength by measuring how much force is required to break test cylinders made with the concrete after they’ve hardened (described in ASTM C39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens).³

If the concrete, aggregate, or rebar delivered to your site doesn’t match your design specs, immediately bring it to the structural engineer’s attention so, if necessary, you can reject the material at the job site.

Monitoring construction methods and quality. Where the rebar is placed in the silo wall during construction also affects the structure’s integrity. The rebar’s clear cover — that is, how close the rebar is to the wall’s inner and outer faces — will determine how well the rebar is protected from weather and corrosion and how well it can maintain the wall strength specified by your structural engineer. As the silo is constructed, ensure that workers place the rebar within the tolerances in your structural engineer’s design documents and those specified by the American Concrete Institute.³

3 Use

Operating your concrete silo properly will maintain its structural integrity and lengthen its service life. With planning and good judgment, you can ensure that the silo functions within the limits of your design criteria. This means using the silo to store only the materials it was designed to handle, testing each received material before it’s loaded into the silo to ensure that its flow characteristics meet your specs, and taking similar precautions.

But even when you use the silo according to your design criteria, your plant’s storage needs can change over the silo’s lifespan. If your silo will be used for storing a new material not on the original design list, be extremely cautious: First consult the original structural engineer or another structural engineer to determine whether the silo can safely handle the new material. The engineer may indicate that the silo can easily be used for the new material. Or the engineer may recommend against using the silo for the material or allow it to handle the material as long as you
modify the silo and operate it within the limits of the new design criteria. In the latter case, make sure that you get the engineer’s written recommendations to protect your company from liability for worker injuries, silo failure, and other problems.

Some typical changes that allow a concrete silo to handle a new material are limiting the stored material’s height in the silo, changing from an eccentric fill or discharge to a concentric fill or discharge, or changing the silo bottom from a hopper to a flat floor. As the modifications are made, you’ll need to pay close attention to many details to prevent compromising the silo’s structural integrity. This includes making sure that connections between the existing silo wall and equipment such as ladders, walkways, roof bridges, and floor beams are appropriately designed; depending on the wall condition, the structural engineer may need to recommend alternative connections. Be aware that the silo changes will probably be made while the rest of your plant is operating, complicating their logistics and increasing costs, and you won’t be able to use the silo during this time.

4 Maintenance

Properly maintaining your concrete silo will protect your investment by extending the silo’s lifespan and ensuring that it operates safely for decades to come. Your silo maintenance program should include the following components:

Performing inspections and cleaning. Periodically inspecting the silo wall interior and exterior, roof, and discharge area will help you confirm that the silo is structurally sound and functioning as you intended.

When inspecting the wall interior, look for unusual cracks, especially near hopper anchors; unusual cracks include vertical cracks that can be seen from 10 feet away and horizontal cracks of any size, especially those between the hopper’s top and the top of the stored material. Also look for material buildup, loose concrete, exposed rebar, and moisture intrusion. On the exterior wall, look for unusual cracks, spalling, exposed rebar, and wall bulging or other distortion. When you find a crack, document your observations: measure and record the crack’s width, height above grade, and orientation; list the date it was originally noticed; and describe any deterioration that has occurred since the crack was last documented.

Inspect the roof for unusual cracks. Also check that the roof is draining properly and that no leaked material from equipment joints or spouts has accumulated on it. In the discharge area (including the silo’s flat floor or hopper and discharge equipment), look for problems like irregularities in the hopper structure and its wall anchors, wall cracks, weld cracks, and any vertical deflection of the floor or hopper and discharge equipment.

Cleaning your silo at least once a year will also keep it in good working order and maintain its strength. Cleaning’s primary goal is to prevent material buildup on the interior wall. Moisture tends to accumulate in certain stored materials over time, causing them to stick to the wall in the form of large chunks. The buildup can cause flow problems, accelerate corrosion of exposed steel in rebar and silo components, and induce bending moments in the silo wall. With annual or more frequent silo cleaning, you can eliminate this buildup, reducing wall deterioration and extending your silo’s service life.

Checking for flow. Confirming that material is exiting the silo as you intended will also keep your silo in good condition. Looking through an access port in the roof is typically the only way you can confirm that material is flowing properly without bridging or building up. Bridging and buildup can cause the material to flow eccentrically, which can lead to bulges in the silo wall and cause the hopper to pull away from the wall anchors, or the bridging or buildup can collapse and drop suddenly off the wall, creating a large impact load on the hopper (if your silo is so equipped) and discharge equipment. To eliminate bridging and buildup, you’ll need to clean out the silo. But if the silo’s design is preventing material from discharging as you intended or the flow problems have damaged the silo, consult your structural engineer to determine how to modify the silo to achieve the desired discharge.

Checking for moisture intrusion and corrosion. This is a quick and easy maintenance step. As previously discussed, you need to check for moisture intrusion as part of the general silo wall inspection as you look for material buildup on the interior wall, especially near the hopper’s wall anchors. But an easier way to spot moisture is to regularly sample your stored material and measure its moisture content. Even easier, you can install a moisture sensor on the silo roof to detect moisture in the stored material; setting up the sensor for electronic monitoring will allow it to alert you when the material’s moisture level varies from the desired range.

Checking the concrete silo for corrosion takes a bit more effort because, unless your silo is equipped with a hopper, little of the steel it contains will be exposed and available for inspection. For this reason, you should rely on your inspections of the interior and exterior silo wall to determine if corrosion is a problem. It can be more appropriate to have the original structural engineer (or another structural engineer) or a silo inspection company inspect the silo for corrosion.
Making minor repairs. No matter how well your maintenance program works, the concrete silo’s condition will degrade over time. When maintenance inspections yield evidence of these problems, you need to make repairs as soon as possible. Sealing a small crack now instead of waiting until it widens or propagates further along the wall not only saves money but extends your silo’s service life.

Many of the repairs will be minor, requiring relatively little in labor and materials. For instance, a wall crack wider than \( \frac{1}{16} \) inch should be sealed to prevent moisture from contacting the embedded rebar or stored material, and this can often be done with pressure grouting. This grouting method requires minimal labor, although the labor cost will depend on the crack’s location, since accessing cracks high along the wall requires workers to erect and work from scaffolding or other equipment. Also note that making any repair inside the silo will require a confined-space entry permit and following confined-space entry procedures.\(^3\)

Making a major repair, such as fixing a large crack, damaged hopper anchors, or exposed rebar, is costly, so you may need to perform a cost-benefit analysis before proceeding. This is all the more reason you should regularly inspect your concrete silo and make timely small repairs.

References

1. Available at www.astm.org.
2. Find more information on American Concrete Institute (ACI) specifications at www.concrete.org.
3. For more information on the permit and procedures, go to www.osha.gov/SLTC/confinedspaces/.

For further reading

Find more information on concrete silos and other storage vessels in articles listed under “Storage” in Powder and Bulk Engineering’s article index in the December 2013 issue and the Article Archive at PBE’s website, www.powderbulk.com. (All articles listed in the archive are available for free download to registered users.) You can also find books and webinars on this topic in the website Store.

Craig Thompson, PE, SE, is a structural engineer at WL Port-Land Systems, Inc. (412-344-1408, cthompson@wlport-land.com). He holds a BS in civil engineering from Penn State University, University Park, Penn., and an MS in civil engineering from the University of Illinois at Urbana-Champaign.

WL Port-Land Systems, Inc.
Pittsburgh, PA
412-344-1408
www.wlport-land.com