Causes of silo failures

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In percentage terms, silo structures collapse three times more often than bridges or any other type of civil structure and this phenomena occurs worldwide. Even very sophisticated buildings like soccer stadiums, bridges and sky scrappers are safer buildings than silos! What are the causes of the silo failures and who is underestimating the complexities of silos? Martin Wuerth of Wuerth Consulting Engineers discusses the causes of silo failures all over the world and the reasons why mankind and the cement industry are not able to learn from past experiences.

Take a look on a web log page about silo design and check out a few questions and it is likely that as a client you would have some concerns about having a new silo being built. You find that there are many young or inexperienced engineers that are designing silo structures for the first time, sitting in offices scattered all over the world without any support from their company and having little idea how to convert what the silo codes require.

Where are the experienced silo designers and where are the design checkers who understand silo structure?

It really seems, that turnkey contractors, civil contractors, design companies and of course, the clients themselves, are not conscious of what they are doing if they are not choosing an experienced team for these silo projects and don't allow checks from a third-party consultant!

Silo structures are often underestimated, leading to silo collapse

Silo structures are really underestimated by several parties. I don't know if it is cost pressure or because decisions are based on the missing knowledge of the people involved. The reason why knowhow about silo design is not very widespread is simple – the silo design market is small compared to other design markets, therefore universities often do not offer silo design courses. Why is this required? There are design codes for silo loads, additional knowhow is surely not necessary.

As a designer knows, a design code only shows *what* has to be considered for a structure, a code never tells you *how* to do it. An example, from the field of earthquake engineering, would be when the design code shows which kind of earthquake proofing is needed. If you have to do a displacement-based seismic assessment, the code will not show you how to do this. The code simply tells a person when to do it. You need at least two additional books that will guide you exactly, step by step, how to do this assessment. But as a beginner in each field you have no idea, how the result should look and you have to accept what the calculation is giving you. This is of course not serious enough for a large building and should at least then be checked further by a third party.

Dead load, snow-, dust- and bulk material load, extraction and eccentric extraction load, earthquake load, wind loads, loads based on settlement and temperature loads are the main load cases for a silo structure. All these load cases are given in codes but if you compare only the load case bulk material load you can see the difference between the different codes in Figures 1 and 2.

Compared to other codes, the DIN 1055/6 (now EC1, 2, 3 each part 4) gives horizontal loads in the middle field and vertical loads at the low end. The big gap between the different codes is not surprising when you see how divided the opinions of worldwide experts are about extraction and eccentric extractions loads.

As soon as an inexperienced silo designer comes to the load cases' temperature (hot bulk material or climate temperature differences) or buckling resistance of concrete and steel shells under consideration of the inside pressure, it will be not possible for them to design the silo in a safe way without additional information.

The above picture of a collapsed steel silo structure (2009) has been recalculated in Figure 3. The red parts had a material utilisation of 100 per cent and the dark

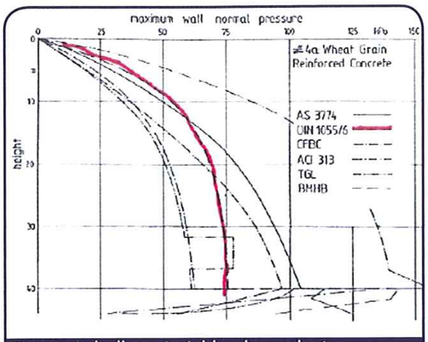


Figure 1: bulk material load – code 1

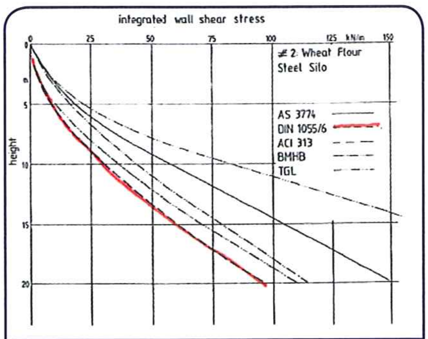


Figure 2: bulk material load – code 2

red parts a utilisation of up to 400 per cent! It was not really obvious what calculations the designer had made, yet the client built more than 10 silos with this design.

Main reasons for design failures are:

- no quality assurance programme for operation, safety and maintenance
- no qualified designer
- no checking engineer

Erection failures

As usual in large cement plant projects a main civil and steel contractor is responsible for the erection of the plant buildings. The contractors were chosen based on their low price offer and high performance capacity but not based on their qualification and experience in erecting silos and storage facilities. For the silo and storage part, which takes approximately 15-20 per cent of the whole civil costs of a plant, it is normal for a formwork sub-supplier to be hired for the sophisticated silo formwork tasks.

So far, in all silo reinforcement tasks Wuerth Consulting Engineers were involved in, the formwork itself was never the cause of failure. Any failures were largely attributed to the insufficient preparation by the contractors. To supply, erect and check reinforcement, prestressing, concrete and electrical power 24 hours a day is really a challenge for all involved staff.

The problems with steel silos are mostly based on geometrical deviations and not suitable welding and cooling equipment. Sometimes the steel supplier has problems to fulfill the quality standards of the material given by the codes or the coating is not as originally ordered.

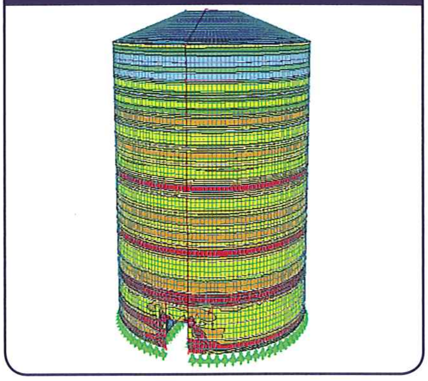
The consultant or owner on the other side sends supervisors to the construction site to make sure that the contractor delivers the correct quality at the proper time to the right price. But it is often the case that no supervisor on the site is experienced in supervising erection procedures for steel or concrete silos. This fact often results, in a few years later, in an additional investment in the silo facilities to reinforce them.

The supervisor on site needs a quality assurance programme made by the designer to fulfill all the checks that have to be carried out on site and know what to do if the result is not satisfied. If the supervisor has no such guideline, and merely makes a visual check of 'good looking', this is not sufficient.

Main reasons for erection failures are:

- no quality assurance programme for fabrication and erection of silo structures
- no qualified manpower on site
- no suitable equipment
- no sufficient material logistic for night shifts
- no qualified supervisor on site
- no supervisor on site during night shifts

Figure 3: recalculation of the collapsed silo shows that the original silo suffered from a too heavy material utilisation (red and dark read areas) near the bottom



Conclusion

Silos and storage buildings are the most underestimated buildings in a cement plant. There is only one way to cut down your future investment in such facilities: choosing experienced designers, checking engineers, supervisors and contractors. At least two of these four parties must be experts in the field of silos, otherwise you are playing Russian roulette.

Most silo failures have occurred in large investment projects with turnkey contracts where the focus of the involved people is more on the time schedule than on the quality of the single facilities.

If the owner doesn't want to lose the value of the long-term silo investment he must secure it at the very beginning of the planning procedure by pulling the right levers and choosing the right partners: confidence is good, control is better. ■


Insufficient concrete quality


Insufficient rebar cover and concrete quality


Unqualified reinforcement concept