Overall considerations/benefits of metallic silos

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Abstract: Metallic silos are probably the most common shell structures designed specifically for the storage of large quantities of free flowing cereals, ranging from small 'on-farm' silos for the agricultural market, up to large scale industrial/commercial storage silos that are suited to a large number of different applications. The key design factor is usually the definition of the silo capacity which is based on the planned application of the silo. Thanks to the simple basic design, manufacture and erection principles, metallic silos are standardized, with the result that cost-effective structures can be realized in a relatively short timescale. Furthermore, the basic material used in the construction, that is, high quality galvanized steel, allows the structures to be relatively light, with the results that there are realistic transportation costs to site as well as a low-maintenance requirement. The aim of this paper is to focus the attention on the overall benefits of metallic silos; made possible thanks to FRAME's experience gained in its 25 years of in-field activity.

CE Database subject headings: Metallic silos; Shell structures; Storage facilities;

Why consider bulk storage?

- There is an opportunity to generate improved margins due to the ability to purchase cereals on the futures markets which could provide significant cost savings.
- It's possible to maintain the quality of the stored cereals & minimise the risk of losses more easily, which could also have an impact on margins
- In the case of imported cereals, there is the possibility to negotiate more favourable shipping rates with higher tonnages being transported.
- Possibility of long term storage provides security of supply.

Benefits of metallic silos

Metallic silos are best suited to the storage of bulk grain compared to other storage methods such as warehouse storage, concrete silos etc. The main reasons are:

- Cost savings. The overall level of capital investment is lower. Relative simple design rules for standard projects that lead to a wide range of standardized products that function extremely well and cost-effectively provided the conditions remain those anticipated in design. Of course, actual costs are dependent upon the total storage capacity & other variables such as the capacity & required 'flexibility' of the mechanical handling system. To give an example of typical costs; for a 24,000 tonne capacity silo, based on 4 no. 6,000 tonne silos with 200 t/h reception, including weighing, cleaning facilities etc & 100 t/h reclaim equipment, would cost around Euro €63.00-Euro €70.00/tonne, excluding electrical wiring, erection & civil works.

Fig. 1: 24.000 T Plant in Dar Es Salaam, Tanzania

- There are a wide range of standard silo capacities & dimensions available to suit both the specific site dimensions as well as individual cell capacity to accommodate varying grain standards.
- There is a relatively short timescale for the completion of the project from initial conception.
- Silos can be built by unskilled labour, under expert supervision.
- Many metallic steel silo manufacturers such as FRAME who have been awarded ISO 9001 Quality Assurance Certification, follow strict quality control procedures during the complete manufacturing process, whereas the quality of slip form silos is subject to variations such as the weather conditions, possible differences in the cement used and curing time.
- Necessary catwalks over the silos can be supported from the silo walls (see Fig. 2) & centre cap under most circumstances, meaning individual support towers are not required, saving costs.

Fig. 2: Detail of catwalks directly supported over silos

- There would be a reduction in labour costs with the incorporation of fully mechanised loading/reclaim systems which can be automated if required.
- There is the ability to maintain the quality of the stored product over long storage periods with the provision of aeration, fumigation, temperature sensing & even chilling systems within the silos.

Specific considerations in the silo capacity selection process

Before approaching the silo manufacturer for detailed proposals, consideration should be given to factors such as:

- The total storage capacity required relative to the daily milling capacity. Typically, if there is a local supply chain through farmer's co-operatives, the required storage capacity would be approximately one month; where there are unreliable logistical connections, the suggested storage capacity would be at least two months. For imported wheat, where there is a direct link from the vessel to the mill, a storage capacity based on the size of the vessel, plus 20%, should be considered.
- Consider that, based on the ongoing operation of the plant, with filling, discharging, cleaning, pest control etc, the actual utilisation of the silo is around 70%-80% of the nominal capacity.
- The individual silo capacities required; these are based on factors such as the monthly consumption (see Fig. 3) & number of cereal qualities. In the case of imported cereals, the individual hold capacity of the vessel should also be carefully taken into consideration.

Fig. 3: Site area analysis for existing plant expansion

- Also critical is confirmation of the area of the site which is available on which the silos can be erected, taking into account the question of truck movements & what additional facilities, such as sampling, cleaning, weighing etc are required in addition to the silos themselves, have to be incorporated into the project (see Fig. 3).
- Decide on the capacity of the reception/intake required as the weight & dimension of the silo loading conveyors could have an effect on the silo catwalk specification.

Design considerations of metallic silos

- Currently, there are no.3 main basic design standards for metallic silos used for cereal storage in our industry.
  - ASAE/ANSI EP433 (R2011)
  - DIN 1055 Part 6 1987
  - Eurocode EN 1991-4 (2006)

  As there are no specific requirements for individual countries in Sub-Saharan Africa, the normal design standard used is ASAE/ANSI.
- In addition to the basic design standards, the 'constitution' of the silo, that is the thicknesses of the vertical wall stiffeners, sidewall & roof sheets, the punching pattern of the sidewall sheets etc, are determined by a number of other local factors which have an effect on the final silo design which should be carefully considered, these include:
  - The bulk density of the cereals to be stored
  - Seismic acceleration.
  - Windspeed.
  - The number of fill/empty cycles per year.
  - Special conditions such as high filling/discharge rates, physical dimensions of the machines loading the silos, (note, where high capacity machines are involved, careful consideration has to be given to the dimensions & weight of the conveyor drives).
  - Possible incorporation of 'gravity sidewall discharge' facility
  - And in some countries, although not in this region, snow load!
- In order to determine the most cost effective silo model for the required storage capacity, as previously stated, the site area available should be determined so the appropriate model of silo with a height & diameter suitable for the area can be selected; this decision will have a considerable influence on the price of the silo. It should be noted that there have been significant advances in both improved steel properties/quality as well as silo component design in recent years, particularly with respect to stiffeners, use of wind rings etc, enabling manufacturers to offer metallic silos at heights that could not be produced previously, with the result metallic silos can be erected on sites where previously it would not have been possible, however, based purely on the basic silo cost, a silo with a height similar to the diameter is considered the most cost effective solution.

  In addition, using their in-house developed Finite Element Analysis Models, FRAME can rapidly respond with the constitution, which influences the total weight & therefore cost of the silo, as well as generating the base loads, so that, once soil tests have been taken & analysed, a suitably qualified Civil Engineer prepare a basic base design for the Civil Contactor, the cost of the civil works can be a very important consideration in the overall silo project.

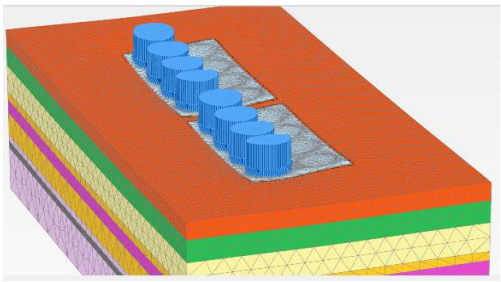

Fig. 4: FEM analysis of soil deformations under full silo weight

As can be seen from Fig. 5, Fig. 6 & Fig. 7 it is possible to simulate various different load distributions such as: snow, wind, product, seismic and side draw on different key components within the silo structure and roof from our computer program. The results of this analysis in term of stresses are taken into account for the design of the cylinder and the roof while the results in terms of deformations are considered to check the safety of all the equipments linked to the silo. Even in case of soil/foundation settlement (carefully evaluated with computer analysis by third parties like in Fig. 4) the in-house FEM is then able to capture the base settlements of the silo and to analyse its behaviour under such deformations.

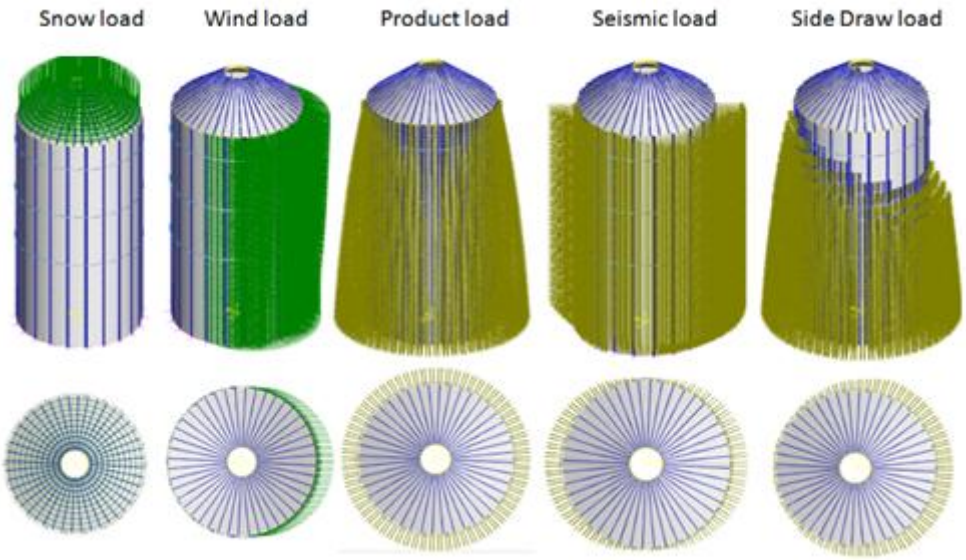

Fig. 5: Simulation of different loads distribution in FEM software

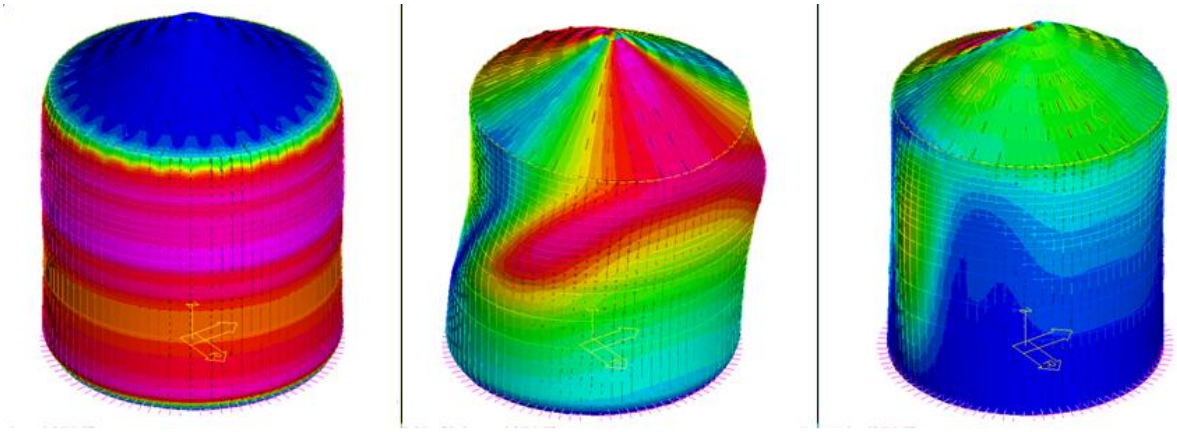

Fig. 6: Cylinder deformation for different loads distribution
(from the left: Symmetrical product load, Side Draw Load, Wind Load)

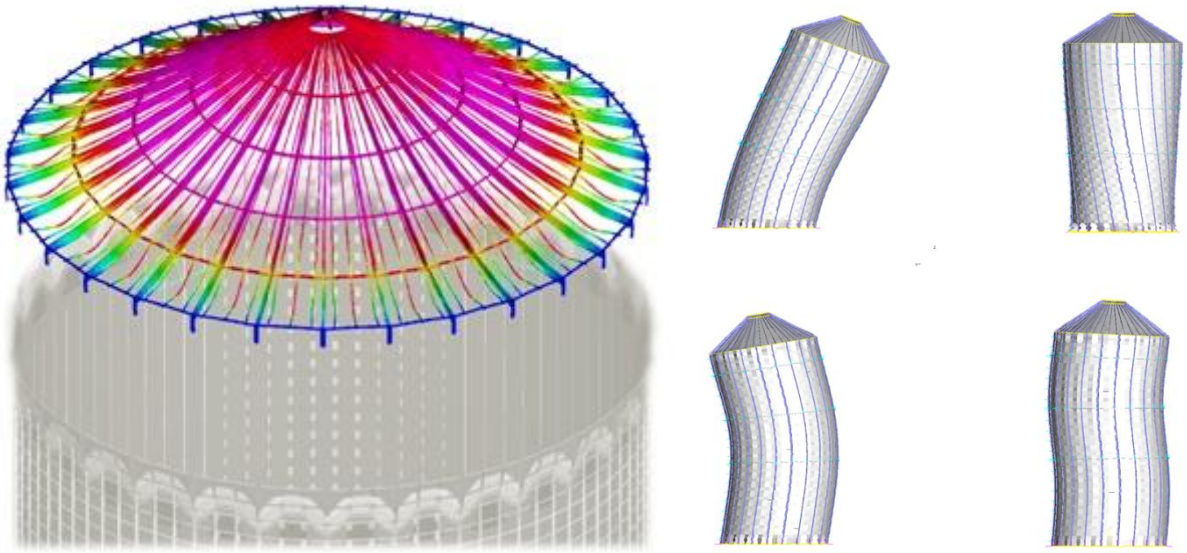

Fig. 7: Roof deformation & Slender silos seismic mode shapes

- Civil costs have a significant influence on costs, & will vary according to the diameter & height of the silos. For interest, civil works would account for a similar cost to the silos, assuming there is no piling required, if however piling was required, the cost would increase, it is therefore vital that soil tests are carried out early in the process.

Other factors affecting the silo specification requiring consideration

In addition to the design considerations of the silo, careful thought should also be given the material quality & specification offered.

This will include:

- Galvanising specification.

Along with most European manufacturers, FRAME offer 450 grammes/m2 (both sides) sidewall & roof sheet galvanising, as can be seen from this slide 450 grammes/m2 offers considerably more protection compared to the 275 (G90) grammes or 350 (G110) grammes offered by many manufacturers, in fact, in this particular region, 600 grammes galvanising is now frequently requested.

For further interest, we would also refer to Fig. 9, which indicates the anticipated period before maintenance is required of various galvanising finishes, depending on the local environmental condition C1-C5.

		TYPE OF COATING	MASS OF THE COATING on 2 sides [g / m²]	THICKNESS on 1 side [µm]
UNI EN 10346	Continuously hot-dip coated steel flat products	Z 275	275	19,3 min.
		Z 450	450	31,7 min.
		Z 600	600	42,2 min.
EN ISO 1461	Hot dip galvanized coatings on fabricated iron and steel articles t = thickness of steel sheet	1,5 < t < 3	650 min. 790 average	45 min. 55 average
		3 < t < 6	790 min. 1010 average	55 min. 70 average

Fig. 8: Coating Mass vs Thickness

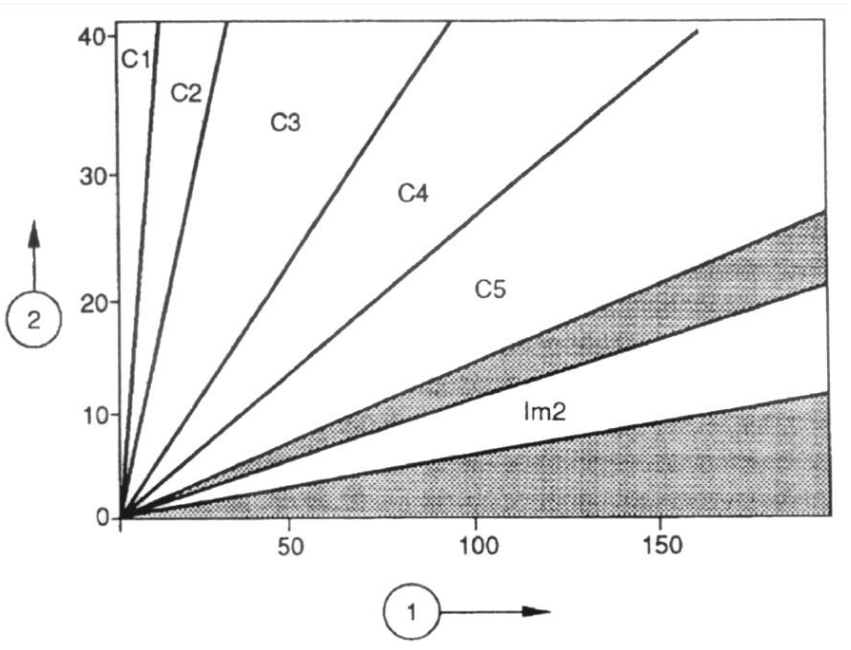

Fig. 9: Typical lives to first maintenance of zinc coatings in different categories of environment based on typical corrosion rates.

① coating thickness, in micrometres
② coating life to first maintenance, in years

- Further considerations should also be made in respect of the corrosion resistance of the fixings etc, as an illustration, FRAME use spun galvanised nuts & bolts, many others use simple electro plated fixings, in addition, to provide additional protection to other components such as door assemblies

should be 'hot dipped galvanised' after manufacture, silos where the use of 'cold galvanising' finish is used on welded assemblies should be discounted

- Insist on knowing the grade of steel being used, typically, for the sidewall & roof sheets as well as vertical stiffeners, this should be a minimum S350GD+Z material.
- Check what quality control management procedures & certification are followed by the manufacturer, as an example, FRAME silos can be delivered with CE Certification 1090-1 standard as required to meet the latest European Directive 89/106/CEE, in addition, ISO 9001:2008 & 3834-2 Quality Management Certification covers quality procedures, whereas EN ISO 3834 refers to the quality of welding procedures adopted in the manufacturing process.

ISO 9001
CERT. N. 6980/0

Quality Assurance Certification for the design, production and installation of grain storage silos, ensuring that the highest standards are maintained through all stages of the project.

ISO 3834-2
CERT. N. 6979/0

EN ISO 3834 deals with quality in welding, the standard defines quality requirements for welding both in workshops and on site and demonstrate the manufacturer's capability to produce welded construction in accordance with specified criteria.

UNI EN 1090-1
N. 0425-CPR-2724

Under the latest EU requirements, any series manufactured structural metal components either manufactured or imported into the EU must comply with the CE marking requirements, in fact it will be a criminal offence to supply structural steel work within the EU unless it conforms to this standard & carries the legitimate CE mark.

- Accessories:
  - The silo should, in our view, incorporate an efficient aeration system, we would suggest an air volume around 7m3/h/tonne is specified, together with grids that are easily removed, & are not corrugated, together with a PC based temperature indication system, allowing monitoring of the temperature of the grain within each silo via sensors, fixed to cables that can be removed even when the silo is full. If ambient temperatures dictate, the use of a fumigation system, as well as chillers can be considered.
  - Careful consideration should be given to the inclusion of level & other safety switches within the scope of supply

Fig. 10: Aeration Tunnel at silo bottom

Operation & general maintenance of the silo

Finally, we should briefly consider the general maintenance & operation of a silo, we will specifically consider the silo & associated accessories, rather than the complete installation with the mechanical handling equipment.

- Operation:
  - In order to ensure the quality of the stored grain over a period of several months, it should be cleaned before being loaded into the silos, in addition, the moisture content etc of each load should be checked & recorded. Guidelines for the safe storage temperature and moisture for cereals are u
  - It is assumed that the correct procedures 'First filling procedures' have been followed correctly, & the sweep auger positioned correctly so the loading of the silo can commence.

- The aeration system should be started & operated in accordance with as the manual, & the temperatures checked regularly.
- The silo should be filled to the high level indicator.
- The readings of the temperature indication system should be monitored at regular intervals, & the aeration system used in accordance with the instructions.
- For discharging the silo, care should be taken that the silo is discharged from the centre outlet only, consider incorporating limit switches to ensure the intermediate outlets CANNOT be opened until the angle of repose has been reached, they can then be opened, & finally the sweep auger can be used for the final clean up.
- Ensure after any inspection into the silo via the eaves manhole, this is closed.

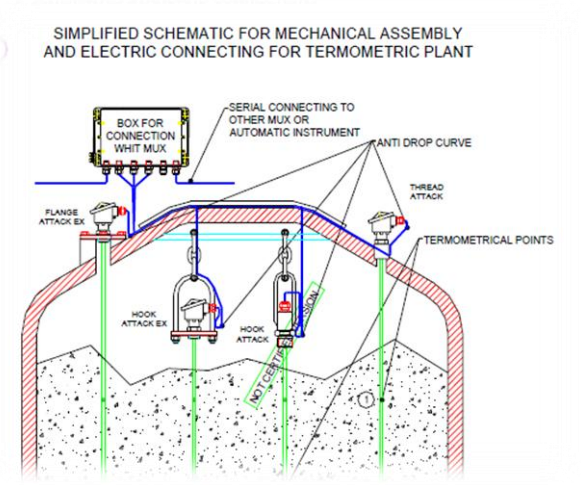

Fig. 11: Schematic of temperature sensing system

- General maintenance, unfortunately a lack of time prevents us from covering all aspects of the maintenance procedures that should be carried out, however, we can provide detail some important points:
  - Ensure the silo is cleaned thoroughly between each fill & empty cycle
  - Lift the aeration grids & clean underneath to ensure there is a clear passage for airflow
  - Make visual inspection around the silo base to ensure that ingress of water is not possible through cracks in the concrete, & inspect around sidewall access doors etc at intervals.

Future Scenarios

Over the many years, silo design has continually evolved from the early days of un-stiffened on-farm silos to meet the challenge of self-propelled combine harvesters in the 1950's & the consequential requirements of the bulk handling & storage of cereals with a few hundred tonnes capacity with virtually no industry standards to meet the challenges today of much higher capacity silos as well as much stricter design standards.

Metallic silo manufacturers such as FRAME have a policy of continuous improvement.

As an example, the re-design of the FRAME vertical stiffener has resulted in the ability to not only offer higher silos but also to reduce the number of stiffeners on certain models of silo resulting in lower capital cost & erection time; then there are investigations into the use of higher grades of steel, with the subsequent reduction in the weight of the silo as well as the design of higher capacity silos.

In addition to silo design, are continuously investigated possible improvements in manufacturing methods & administrative procedures such as producing 'on-line' quotations & the preparation of 3D layouts to provide the client with a faster service.