bulk solids handling Volume 3, Number 1, March 1983

Bulk Grain Silo Developments in Southern Africa

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Summary

The history of the development of the large diameter free-standing bin silo in South Africa is given explaining the advantages and highlighting some of the problems encountered, the solution of which resulted in the type of grain silo which is now being constructed throughout Southern Africa. Failures which occurred in the early stages are described and discussed. Construction techniques to suit conditions in developing countries are covered. Design standards commonly used for these bins are compared with Codes of Practice. Conclusions based on tests done on a full scale bin are presented which indicate the effect of loading, emptying and temperature on grain pressure in these bins.

1. Introduction

South Africa has in the past 30 years developed a sophisticated industrial infrastructure. From the 1950s this has resulted in a general migration of labour from the rural areas to the towns and cities, thereby leading to a shortage of labour in the rural areas. This, together with a general shortage of bags, resulted in a rapid swing towards the handling of grain in bulk.

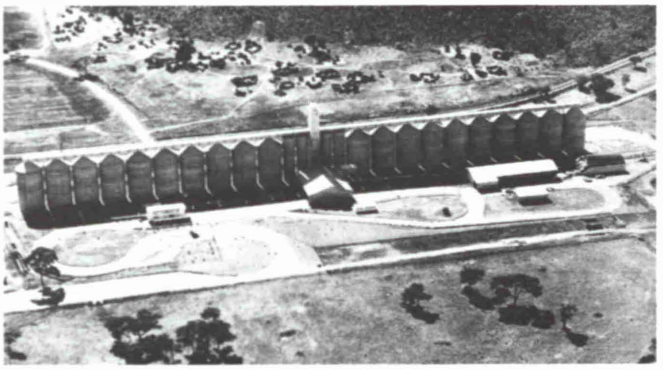
Initially silos were constructed in Southern Africa based on European and American experience but it was found that these were too expensive to build and unnecessarily complicated to operate. The reasons for this were as follows:

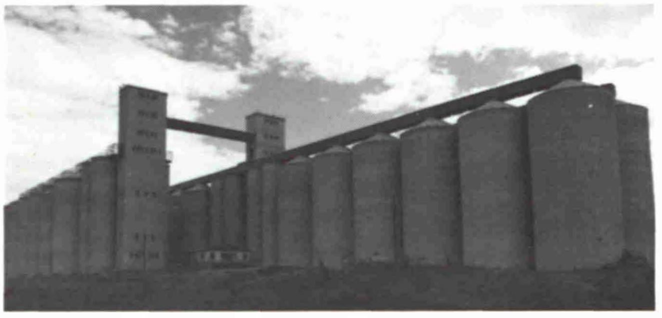
a) Construction required too much plant and skilled labour.
b) The high rate of construction of these structures put a strain on local transport facilities to bring the required volume of material on site to meet the construction programme.
c) As only locally produced grain was stored, large numbers of compartments for different grain types were not in fact required.
d) Operator experience and difficulty of obtaining spare parts proved a problem and sophisticated machinery was soon replaced with simple plant although this was more labour intensive.
e) Electricity costs were high in areas in which grain silos were required and thus operations had to be planned to limit power consumption.

After much discussion with Co-operatives and Contractors, the large diameter free-standing silo bin was developed and found to be the most suitable. In fact, this type of silo has proved to be so successful that it has now been adopted as the basic standard for Southern Africa.

Fig. 1 shows typical rural silos consisting of a number of large diameter free-standing bins.

Fig. 1





2. Design and Construction Aspects

The storage bins themselves constitute the largest portion of the structure and therefore these require the most attention as far as cost saving and ease of construction are concerned. As these are free-standing the relative settlement between bins can take place without causing excessive problems. Foundations usually consist of unreinforced mass concrete spread footings or piers. Piling is only used if founding depths are too great.

Bin floors are usually flat and are constructed above ground level on compacted fill to avoid ingress of moisture. The reclaim conveyor is housed in a narrow reinforced concrete tunnel running the length of the row of bins. This tunnel is constructed in short lengths with flexible joints to eliminate settlement and shrinkage problems.

Bin walls are mostly of reinforced concrete although bins constructed of corrugated and flat steel plates have also been built. Concrete bin walls are constructed by means of a sliding shutter. Bins are constructed one at a time thus ensuring many re-uses of the sliding shutter. The most satisfactory bin roof was found to be a thin conical shell of reinforced concrete cast in situ. Shutters once manufactured can be used many times. Overbin gantries are manufactured from light lattice steel sections spanning from bin roof to bin roof and incorporating suitable movement joints.

The machine tower is generally reinforced concrete, again constructed by means of a sliding shutter. Floors are of concrete cast on permanent galvanised iron shutters and supported on steel beams.

A typical silo layout and flow sheet are shown in Figs. 2 and 3.

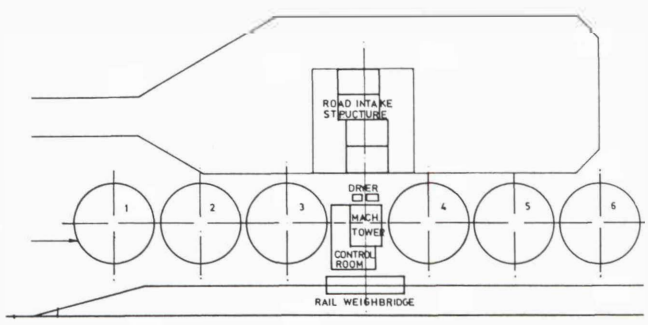
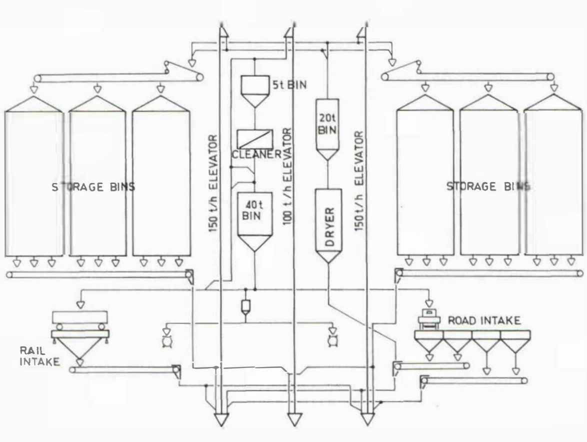


Fig. 2

Fig. 3



3. Design of the Large Diameter Bins

During the last 20 years approximately 300 grain silo projects have been completed. The diameter of the storage bins varied from 10 to 20 m and the heights from 30 to 50 m.

Due to the large number of bins constructed, an economical design was therefore extremely important.

All the design information available in the early 1960s was based on tests of models and on smaller bins less than 6 m in diameter, and it was realised that it would be dangerous to apply test results indiscriminately to the larger diameter bins. It was therefore decided to build a silo of ten bins as an experiment to see how it behaved under load. While this first silo was being constructed the advantage of this type of construction was realised and a decision to build a further three silos was taken. It was shown at the time that this method of construction was some 50 % cheaper than the nested silos being built up to that date.

On filling the first silo which was located at Lichtenburg, the bins cracked when only half full. Work had however already started on the second silo at Wesselsbron, the bins of which had thicker walls with more reinforcement as they were approximately 50 % higher. The client investigated the cracks in the Lichtenburg silo and decided to proceed with the construction of the Wesselsbron silo due to the urgent requirement for storage space. As it was not clear why the first silo had cracked, no change was made in the design of the latter silo and construction proceeded without any change in the reinforcement. Thus the top 15 m of the bin walls had exactly the same reinforcement as the Lichtenburg silo. When the Wesselsbron silo was filled the walls also cracked. After the investigation of the cracking of the bins of the above two silos, the design was revised and the next silo was built at Bothaville. This silo did not crack when filling or emptying.

Details of the bin walls for the above projects are as follows and amounts of ring reinforcement are shown in Fig. 4:

Lichtenburg:	Bin diameter	15.25 m
	Wall thickness	150 mm
	Height of grain when crack was first noticed	8.25 m
Wesselsbron:	Bin diameter	15.25 m
	Wall thickness	175 mm
	Height of grain when crack was first noticed	17.4 m
Bothaville:	Bin diameter	15.25 m
	Wall thickness	200 mm
	Height of grain when crack was first noticed	not applicable

In all cases cracking occurred during filling, starting at the bottom of the bin and extending up as the bins were filled. The cracks were neatly spaced at approximately 0.5 m intervals, were very fine and only a few required sealing to prevent the penetration of water. There was no increase in cracking on loading out of these bins indicating that the emptying pressure was not significantly higher than the filling pressure.

On inspection of these bins, design standards were established which formed the basis for all standard 15.25 m dia. bins designed by the authors' firm of which more than 600 have been constructed. Less than 4 % of these bins have shown any sign of vertical cracking.

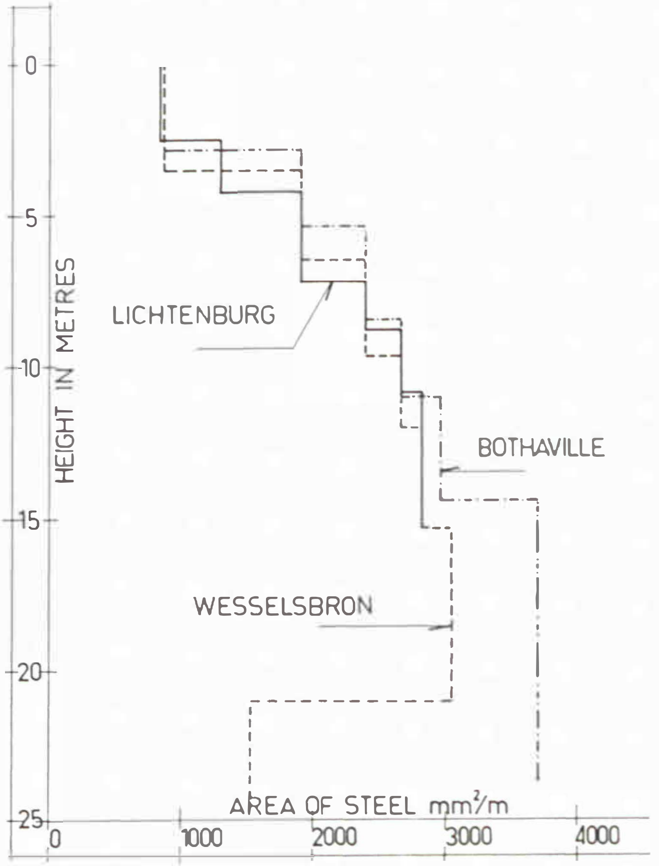


Fig. 4

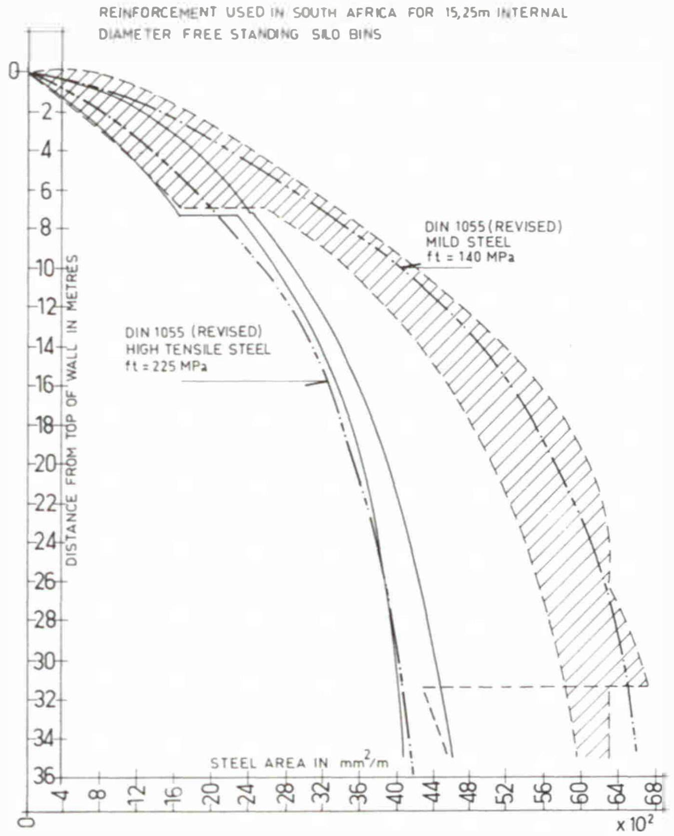


Fig. 5

When the German Code DIN 1055, sheet 6, for design loads in silo bins became available in 1965, the above standard was compared with the code and a close correlation was found. At the time steel stresses were limited to 170 MPa but these were later increased to 230 MPa to come in line with the over-pressure factors subsequently recommended by the German code.

Resulting from the investigation of the cracking of the original bin walls the authors concluded that the minimum thickness of the concrete for a crack-free bin wall should be such that the strain in the reinforced concrete should not be more than 1.6×10^{-4} based on emptying load of the revised DIN 1055.

4. Tests on Full Scale Bins

During 1977 it was decided to untertake load tests on a full scale bin of 32 m height, 15.25 m diameter, which had been constructed at Viljoenskroon. A summary of the test results is shown in Fig. 6.

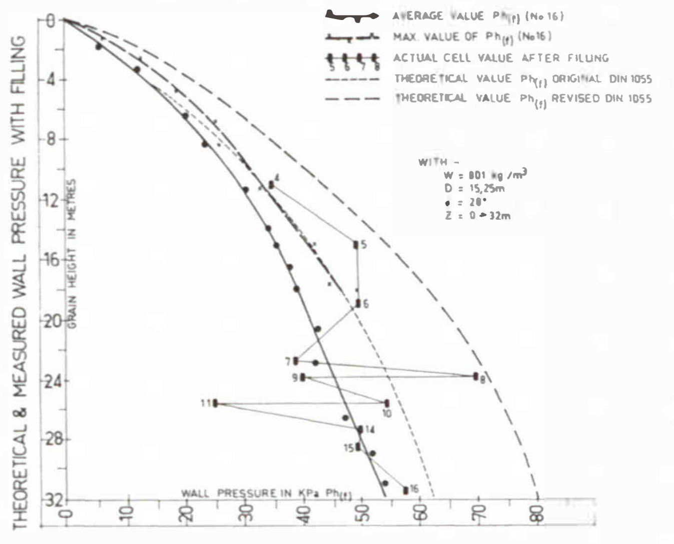


Fig. 6

The bin was filled, after a period partially emptied and filled again and during this period temperature, pressure and strain readings were taken at regular intervals throughout the test period. Results from these tests can be summed up as follows:

a) Due to temperature variations the grain in the bin (in this case corn or maize) is constantly moving and is never static. The top surface of the grain moves up and down and is highest during the hottest time of the day and drops during the night.

b) On filling of the bin the cone surface builds up and collapses causing impact loads on the bin walls; the increase in pressure is not uniform throughout the mass of material but peaks occur at random locations on the bin wall.

c) The average filling pressure correlates closely with the filling pressure given by DIN 1055 sheet 6, 1965, and the maximum allowance for impact forces correlates closely with the filling pressure given by the supplementary notice to DIN 1055, i.e., an increase by a factor of 1.3.

d) Once the bin was filled there was a slow increase in the wall pressure due to the movement of grain as a result of temperature variation. This reached a maximum of approx. 25% more than the filling pressure.

e) On loading out there was no increase in pressure but the pressure stayed constant for a long time before starting to decrease.

f) If the grain is withdrawn until the pressure starts dropping and then filled again, the maximum wall pressure increased by approximately 50% more than the initial filling pressure.

g) Although there was no increase in pressure on emptying, using the emptying pressure according to the supplementary notice to DIN 1055 gives a good correlation of the maximum pressure that can be expected allowing for temperature effects and the effect of partially emptying and filling the bin.

Fig. 5 shows the area of reinforcement provided in South Africa for a standard bin and compares it with DIN 1055. We have further studied the results of silos in Sweden and have come to similar conclusions on certain aspects. We have found that if for the large diameter bins the area of steel in mm^2 per metre height in the bottom portion of the wall divided by the square of the bin diameter in metres is less than 17 there will be a tendency for cracks to appear. These cracks which are usually very fine increase in width with reduction in steel area and occur at approximately 0.5 m centres. We have also concluded that for bins with a diameter larger than 10 m there is a minimum wall thickness for eliminating vertical cracks. With the tension steel calculated based on the DIN 1055 code, the minimum wall thickness in mm divided by the square of the bin diameter in metres should not be less than 0.8 to ensure a crack-free wall.

Although design parameters obtained using the German code give acceptable results, this code ignores the temperature effects which in our opinion is incorrect. Further, the reduction of calculated pressure at the bottom of the wall according to this code is not applicable and can result in the formation of cracks developing in this area.

5. Operation of a Grain Silo

Most silos are usually operated by semi-skilled and unskilled labour and experience has shown that the best method of operation is as follows:

All the grain is weighed on a weighbridge where it is also graded. This eliminates handling equipment and power consumption in the machine tower and allows the intake hoppers to be kept full all the time leading to maximum utilisation of intake facilities. Silos are usually provided with two sets of intake plant to prevent interruption of operation due to plant breakdown.

Intake cleaning is confined to rubble separation and the proper cleaning of grain is done during load out. It is necessary because of the relatively short intake season to provide high capacity intake plant whereas loading out can usually be done at a much slower rate.

Cleaning on loading out therefore requires less cleaner capacity and reduces power demand. Similarly drying of grain, if necessary, is carried out during slack periods, damp grain being temporarily stored in one of the bins. Bins are usually emptied by means of gravity but as the floors are flat the residue has to be moved by hand labour. This can be minimised by providing three outlets to each bin, the bulk of the outloading being through the centre outlet to avoid eccentric loading conditions in the bin. The three outlets have the effect of reducing the angles of repose of the grain to approximately 15° and this reduces the amount to be moved by hand.

The following types of equipment have been found to give the best service. Belt conveyors and bucket elevators for conveying; weighbridges instead of scales for weighing; fumigation by means of liquid sprays or pills instead of gas. The number of dust extraction points is also limited for ease of efficient operation which necessitates good housekeeping. Plant design should allow easy replacement of spare parts by relatively unskilled personnel.

The electrical control panel for housing the starting and interlocking equipment is of module construction so that faulty parts can easily be replaced. A simple mimic diagram of the plant is incorporated in the panel to assist the operator.

6. Conclusion

In conclusion statistics on grain silo projects in South Africa are given:

a)	**Number of Grain Silo Projects**	
	Co-operatives and Agents	235
	Port silos	3
	Milling silos	53
	Other silos	16
	Total	307
b)	**Total storage capacity**	19 million m^3 (543 million bushels)
c)	**Largest Single Project**	193,000 m^3 (5 1/2 million bushels)
d)	**Average construction cost in 1982**	US $ 55 per m^3 (US $ 1.93 per bushel)

Acknowledgements

The authors wish to thank their fellow staff members at Henny & Aalbersberg Inc. Consulting Engineers, Johannesburg, for their valuable assistance in preparing this paper.

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