Review of Remote Silo Monitoring

RMC UK Cement

By Steven Grublys

Summary

The installation of equipment to provide test sites to allow for a better understanding of remote silo monitoring and the required equipment is complete. The test sites are at Russell Roof Tiles in Burton on Trent with two silos at 35t & 75t and at Eternit with one 370t silo

The level measuring equipment trailed was

Load cells	@ Russells
Strain gauges	@ Eternit
Wire Guided Radar	@ Eternit
Ultrasonic	@ Eternit

The load cells at Russells have proved to be very accurate after a degree of setting up. Due to the very high cost of load cells for monitoring silo installations the Russells silos will continue to be monitored but load cells will not be considered further.

The comparison of the strain gauges, wire guided radar and ultrasonic run at Eternit has revealed some interesting results. This has shown that a more detailed review is required before any silo is equipped for remote monitoring.

The results have shown that in the case of the Eternit 370t silo there is evidence of extreme funnel flow; that is the centre column of material is extracted before the sides follow. There is also evidence of product fall in as a result of the funnel flow.

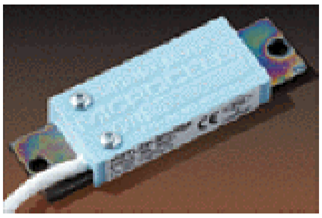
In considering the installation of remote monitoring equipment there are a number of key items to be reviewed: silo size, construction, flow characteristics within the silo, silo support structure are the key items to consider.

Remote silo monitoring is achievable but there are a number of considerations which affect the decision as to which level monitoring system is to be used.

Equipment

<u>Minsterport Strain Gauges</u>

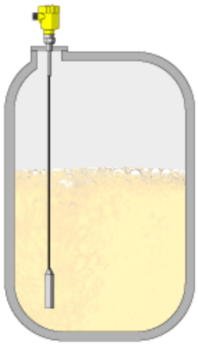
The strain gauge is a bolt on piece of equipment which measures the strain set up in the silo support structure due to the load imposed by the product in the silo. The unit works by being bolted to the support frame, as product is added the legs compress and so does the gauge this compression is called strain. Typically four units are used to measure the strain in each of the four legs, the readings are summed in a processing box and the result is shown as a mass reading on the front of the display.



To set up the level measurement the silo has to be emptied to make the empty set point and filled to capacity to make the full set point. Once completed the system displays the actual mass of product in the silo

<u>Vega Wire Guided Radar</u>

The wire guided radar consists of a signal generator with a cable or rod dangling below. The unit is fitted to a screable socket welded to the top of the silo. High frequency microwave impulses are coupled to this cable or rod and guided along the probe. The impulses are reflected by the product surface and received by the processing electronics. A microcontroller identifies these level echoes measured, evaluates them and converts them into a level information.



Due to this measuring principle, the comprehensive adjustment with the product is no longer necessary. The instruments are adjusted to the ordered electrode length. The adjustable cable and rod versions are suitable for individual adaptation to the local conditions. Just by entering the vessel dimensions, a level-proportional signal can be displayed. An adjustment with emptied and filled vessel is no longer necessary

Vega Ultra sonic
The unit consists of a transducer fitted to a flange welded to the top of the silo to be measured. The transducer emits short ultrasonic pulses between 10 kHz and 70 kHz. These pulses are reflected by the product surface and received again by the transducer. They spread with sound velocity and the time from emission to receipt of the signals is proportional to the level in the vessel.

Latest microprocessor technology and proven software select the level echo from a number of false reflections and measure it exactly.

Just by entering the vessel dimensions, a level-proportional signal can be displayed. An adjustment with emptied and filled vessel is no longer necessary!

Installations
Two sites are in place, these are;
- Russell Roof Tiles in Burton on Trent
- Eternit at Meldreth nr Cambridge.

The method of level measurement used at these sites is different but the system to monitor these level systems and display over the Internet is the same. The detail of the silos and systems installed at the sites is as follows.
The system to capture the readings from the level measurement devices and transmit these to a site to be displayed on the Internet was determined in a separate study, and the Dedicated VMI equipment and web system was chosen

Russell Roof Tiles
There are two silos on the site, one of 80 tonnes and one of 40 tonnes. Each of the silos have been fitted with a load cell system from Novatech. These display the weight of the product in the silo at the filling point and in the control room. The signals from the load cells are taken to a Dedicated VMI remote terminal unit (RTU). This RTU captures the readings at a predetermined frequency, currently every hour, and stores them for transmitting, also hourly, to the Dedicated VMI offices for automatic web site update.

Eternit
There is one 370tonne silo currently monitored on the site, plus another 250tonne silo which may be connected in the future. In the early stages of the remote silo monitoring project, agreement was reached with Eternit to use their silo as a test unit to evaluate the available level

measurement systems. As a result three different types of level measurement equipment have been installed and are monitored, these are

- Strain Guages from Minsterport
- Wire Guided Radar from Vega
- Ultrasonic from Vega

The signals from the three systems are taken to a Dedicated VMI remote terminal unit (RTU). The three systems have been installed to gain experience of the different level measurement systems available. With this experience a better understanding of the problems of level measurement can be developed, with the effect of gaining a level of confidence in the different types of equipment and to make recommendations on equipment to be installed and accuracy available.

In addition to the three systems above, Eternit have their own level measurement system consisting of load cells. The installation is somewhat questionable due to the build up of material around the load cells, these have not been connected into the Dedicated VMI RTU.

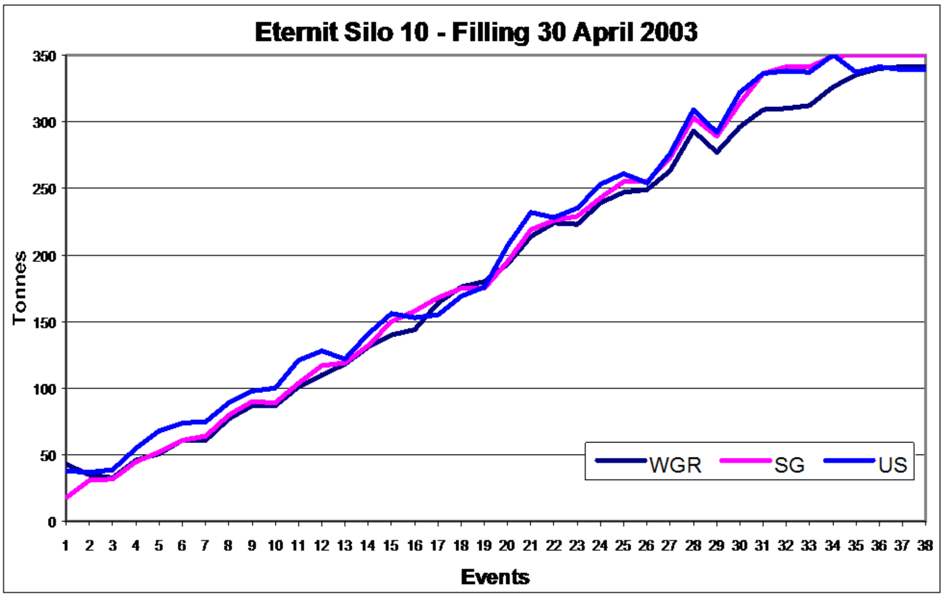
Ongoing Monitoring

The Russell's site has proved to be a success and the process of monitoring has been handed over to the Shipping office in a move to allow them to monitor and supply cement to the customer.

The Eternit site continues to provide data. Some interesting evidence of the difference between the three different types on level measuring systems has been obtained. As a result a second calibration process was conducted.

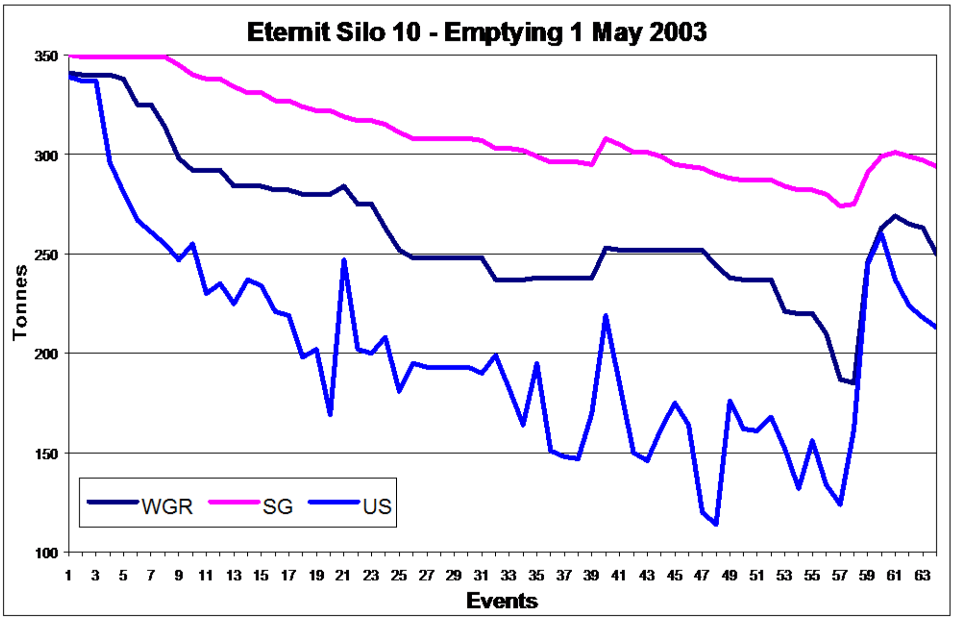
Eternit Recalibration

With the agreement of Eternit, the silo was emptied to the point where nothing more could be extracted, this was then the practical empty point. All of the four level measuring systems were zeroed at this point. The silo was then filled by pumping cement from road tankers into the silo, this continued until the silo was practically full. Reports from Eternit gave the "empty" point as 60tonnes and the full point at 350tonnes, The practical empty point was found to be 30tonnes. On filling the process was stopped at 370tonnes, this was 2m from the top of the silo.
During the filling process all three level measuring systems were relatively close, see graph below; (the 350 maximum is due to the upper setting on the Dedicated VMI equipment, this has been lifted to 370tonnes) WGR = Wire Guided Radar, SG = Strain Gauges, US = Ultrasonic



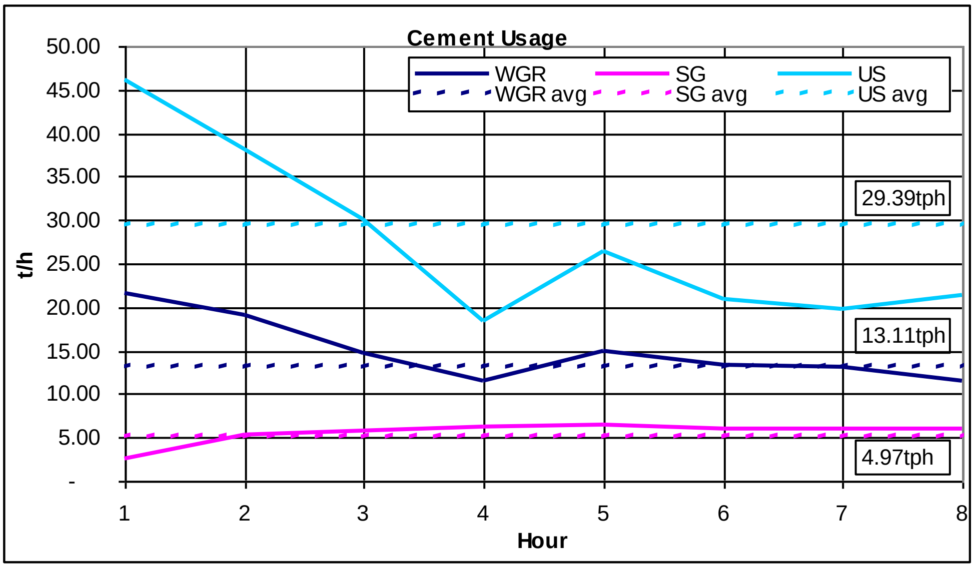
The recording of the filling process showed that the systems report relatively accurately compared to each other while the silo is being filled. The next part of the process was to monitor the emptying cycle from the full point to a lower level. This was completed the next day when Eternit put the silo back into production.

The readings from the emptying cycle can be seen below.



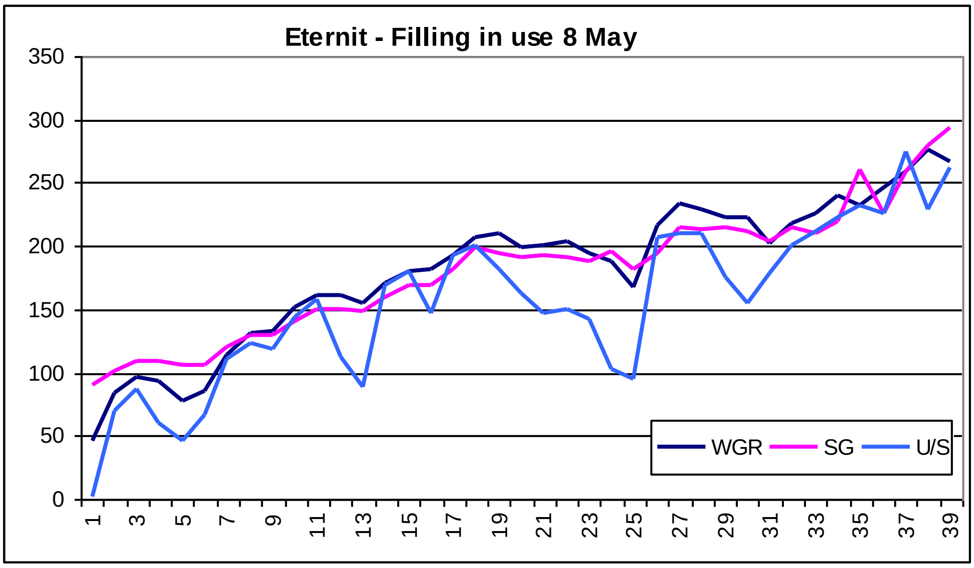
From this graph it can be seen that at the start there is a step change between the Strain Gauge system and both the Wire Guided Radar and the Ultrasonic. This is evidence of a certain amount of settlement of the cement in the silo. From that point on, the three traces take very different paths.

In order to establish what is happening inside the silo, a closer investigation of the figures obtained is required.



Eternit production rates run at a maximum of 8.4t/hr for the first line and 3.6t/hr for the other, giving a total of 12t/hr with both lines at maximum. Actual usage figures for the period are expected from Eternit.

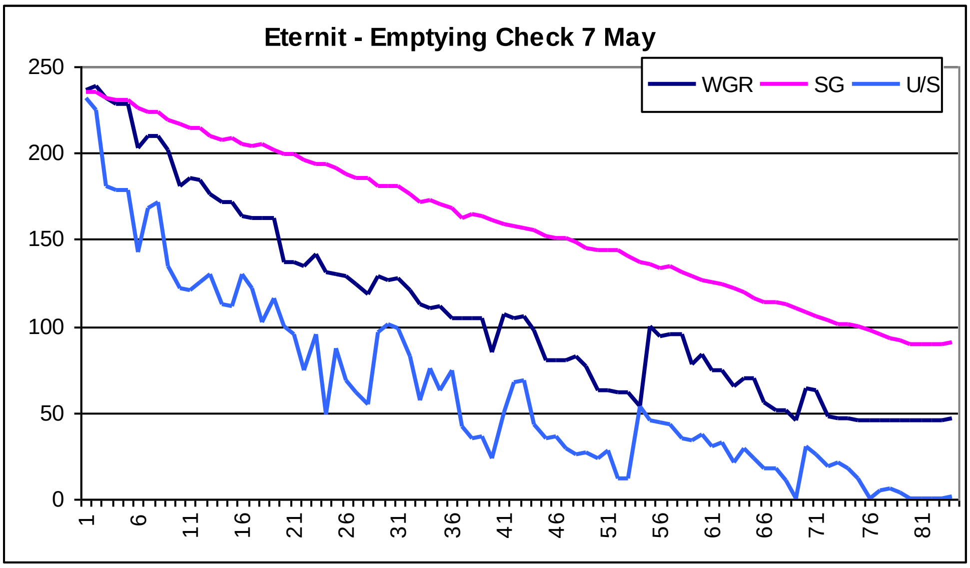
Monitoring the effect of the filling cycle following an empty cycle shows the following



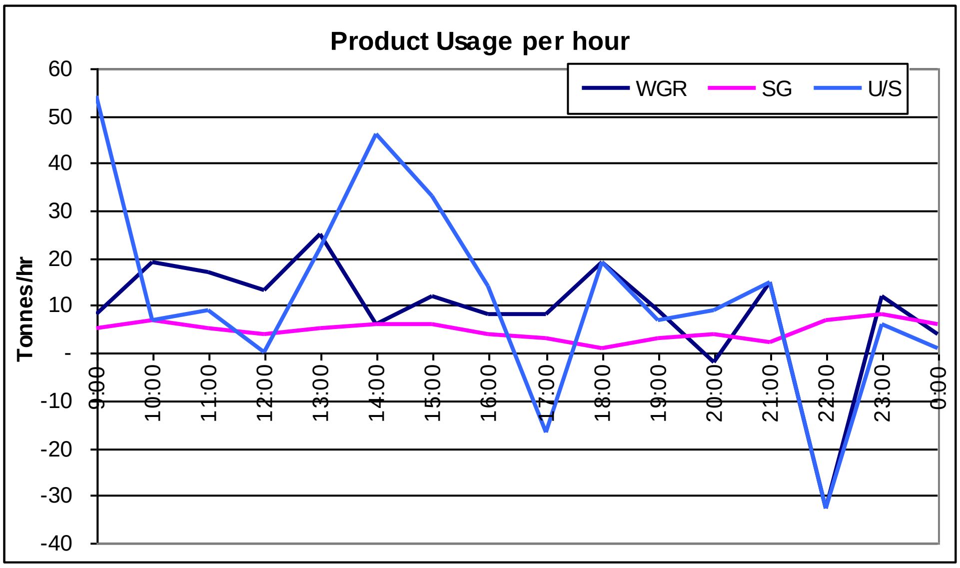
This is a similar trace as the initial filling, as the level increases the three traces converge onto a “common” trace with little variation.

This trace is a combined filling and usage trace. It can be seen that during the filling sections (increase in level) the traces converge and as the cement is used so the traces move apart. There is also evidence of major increases in the level displayed by the wire guided radar and the ultra sonic systems.
In this trace the wire guided radar and the strain gauge systems generally tend to follow each other, with some differences. However, the bigger difference is with the Ultrasonic level system.

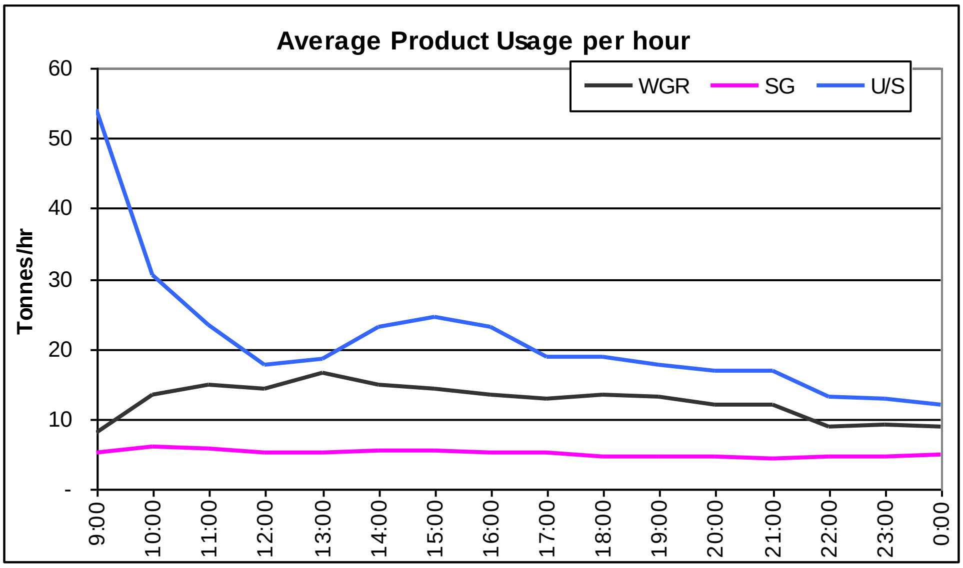
Following these findings, a further emptying cycle was conducted and this gave the following graph



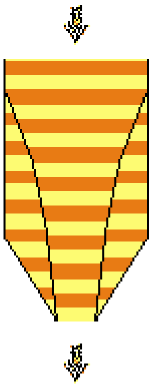
Again the three traces start off from a “common” high point, and again there is a very marked difference in the readings as the level reduces.



Again the trace of hourly cement usage can be seen and is very erratic on the wire guided radar and ultrasonic but more stable on the strain gauges. Eternit production rates run at a maximum of 8.4t/hr for one line and 3.6t/hr for the other giving a total of 12t/hr with both lines at maximum. Actual usage figures for the period are awaited from Eternit.



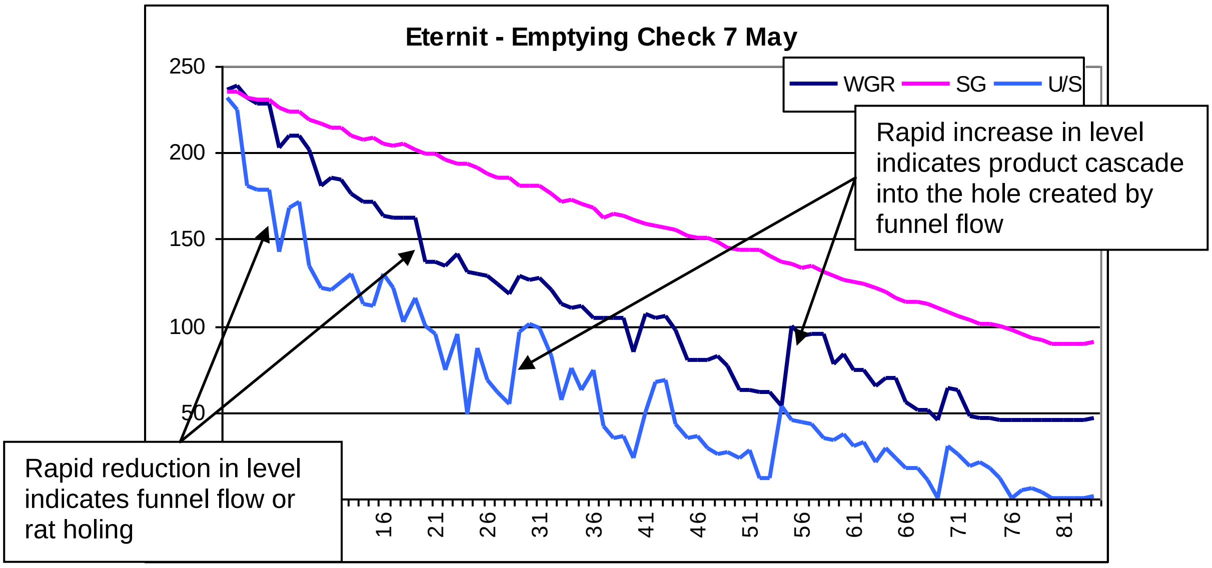
Looking at the averaged use over the same period shows the relative inaccuracies



The location of the wire guided radar and ultrasonic units in the top of the silo give an indication as to what is happening. The wire guide radar is some 2m from the edge of the silo and the unit looks straight down, the ultrasonic unit is some 2m from the edge and looks into the throat at an angle. The levels show that there is an increase in the reduction in level between the two. The lower point is closer to the centre.

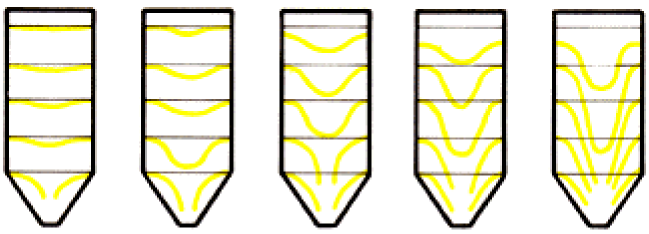
It is clear from this that the silo under investigation is subject to funnel flow. That is, the centre column of material flows out of the silo and slowly draws the outer edges into the funnel. At certain points the material at the edge will become unstable and there will be a slide of this material. This explains the sudden increases in the levels shown by the wire guided radar and the ultrasonic. This is further supported by the return to similar traces while filling.

Evidence of problem flow in the silo



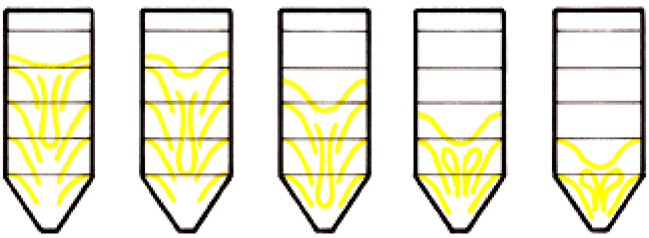
Solo Construction & Product Flow

A silo structure at London Concrete Wembley was reviewed with a view to installing remote silo monitoring. On the site visit it was found that the silo was a large square box with dividing plates creating four compartments. This would be unsuitable for strain gauges due to the common structure, and unsuitable for wire guided radar as the silos will be subject to funnel flow and hang up in the corners.



silo1 silo2 silo3 silo4 silo5

Typical silo flow,
Silo1 product tends to empty from the immediate area
Silo2 product will flow down into the outlet
Silo3 evidence of funnel flow starts
Silo4 & 5 product continues to flow out of the middle and not from the sides



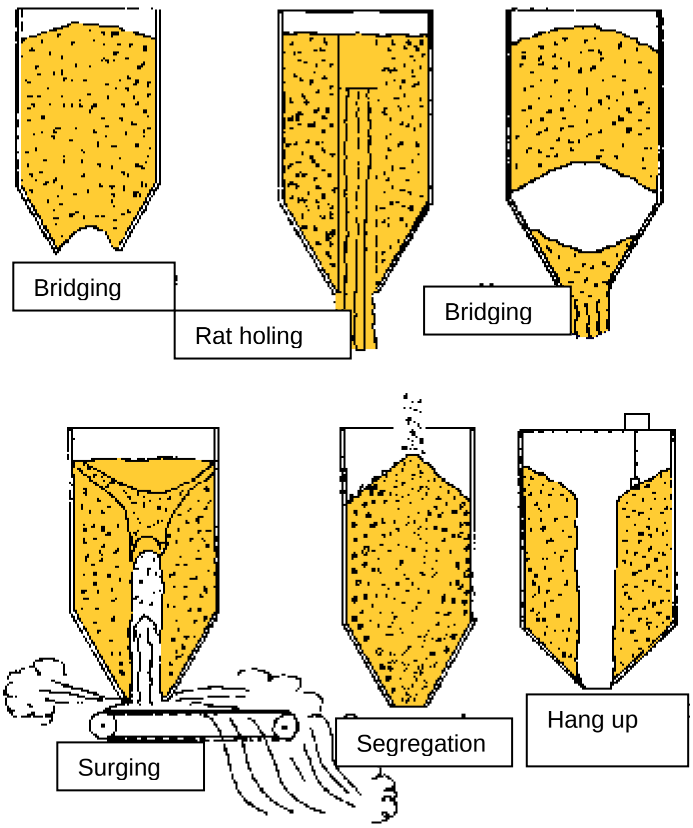
Silo6 silo7 silo8 silo9 silo10

Silo 6-10 funnel flow continues, product falls in from the sides

A more suitable installation would be achieved on a free standing cylindrical silo or the cylindrical silos on a common frame.

Signage on silos can cause problems as this would restrict the movement of the individual silos, as would pipe work and access platforms. An example of the problems caused by signage is illustrated on the London Conctere site

Typical Silo Flow Problems



Accuracy

During the filling of the silo the three systems proved fairly accurate and showed the following

Wire guided radar	= -2.65%
Strain gauges	= 0.00%
Ultra sonic	= 5.53%

It must be noted that the wire guided radar and the ultra sonic systems did show a higher level while filling but as the load neared completion the difference tended to reduce. By the end of the individual discharge the level remained higher and slowly dropped back to a similar reading to the strain gauges. This can be put down to the effects of the air used in the transport of the product into the silo being entrained in the product and slowly escaping, thus lowering the level. As the silo approached full, the wire guided radar and the ultra sonic systems did show an increased difference to the strain gauge system, this is likely to be due to the product banking up under the filling pipe and not having time to level out, as earlier in the filling process

However during the emptying stage the figures were greatly different

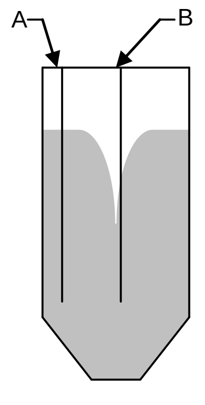
Wire guided radar	= -15.82% avg range from –2.58% to –32.73%
Strain gauges	= 0.00%
Ultra sonic	= -35.95% avg range from –3.44% to -60.69%

While filling these figures are acceptable if a little high, but the emptying figures for Ultrasonic and Wire guided radar are not acceptable

Under normal operation, the greater portion of the time will be taken up with emptying where the greater error on accuracy is found. Only when filling is the funnel filled and the level re-established. Use of the Ultrasonic system would present major problems with its poor accuracy based on recognising the funnel effect, as it would advise a load could go in when in fact it cannot.
A similar effect is found with the Wire guided radar, although not as drastic as with the Ultrasonic, but again the system gives inaccurate readings based on the funnel flow in the silo.

The strain gauges continued to give the best performance and the accuracy achieved was comparable to the actual filling and well within the ±3% stated by Minsterport.

The question of the required level of accuracy is interesting, in relation to what actual level of accuracy are we looking for with remote silo monitoring. The system is required to provide information for the shippers to keep the customers silos full, or between acceptable levels. Therefore, there needs to be a level of certainty that a load can be fitted in. If the load is taken as 30 tonnes and the system is ±10% accurate, then this could mean that there is space for 27 or 33 tonnes, not enough space if the error is negative but plenty if positive.



What is more important is that the representation of the level of the product is relevant, with the effects of funnel flow in action the level derived from the wire guided radar and ultrasonic systems causes a major problem as the available space in the silo is not as represented by this point as this is artificially lower. Once the product flows into the cone and a near level top surface is gained the level can jump a great amount. This is dependant on the location of the level equipment; if it is close to the edge (A) then the figure could be over stated in nearer the centre (B) then it will be under stated.

Acceptable accuracy is therefore dependant on the type of silo and the type of flow in the silo, a figure of ±5% would be acceptable on most installations.

The alarm levels are dependant on the type of flow in the silo, the size of the silo, the operational usage and the time to source a vehicle and get it to site with a load.

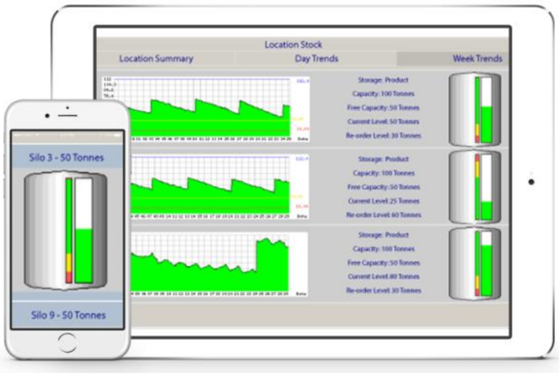
Transmittal devices

After an investigation into the different equipment required to transmit the level data to a site for display on a web page, the equipment from Dedicated VMI was chosen. This was down to the ability of the equipment to reside in often harmful environments for electrical equipment, the ability to capture the information and relay it to a site, and the ability to power the level sensing equipment through the monitoring equipment thus giving the ability to see if the level system is working correctly. Another important issue was the reputation, support and back up ability of the companies in question.

The Dedicated VMI SiloView RTU (Remote Terminal Unit) featured best in all areas and has proved to be suitable for installation. The units are fitted with a GSM dial in pack to remove the normal problems of obtaining a telephone line near the silo.

The Dedicated VMI SiloView Web Platform displays the real time level information and historical trends. The unit can update at set intervals from a minute to once a day - in this case, every hour.

In addition the SiloView has the ability to advise via email or SMS messaging a variety of alarms such as preset order point, high level, low level, critical low level, rate of usage alarm, equipment failure alarm, incorrect reading alarms and many more. If the level monitoring devices are powered through the RTU then there is also the ability to monitor the power to the device and report on power failure.



All of the readings captured on the web server are available for review to monitor the performance over a longer period. Currently these are obtained by calling or emailing Dedicated VMI and requesting the data.

Costs of Silo Level monitoring equipment

Minsterport Strain Gauges

Systems consist of a number of bolt on sensors, display and Installation. The number of sensors is dependant on the type of structure and accuracy required

1 to 25 systems; 4 sensors = £1,750.00 each, 8 bolt on sensors = £2,910.00 each
26 to 50 systems; 4 sensors = £1,690.00 each, 8 bolt on sensors = £2,680.00 each
51 + systems; 4 sensors = £1,620.00 each, 8 bolt on sensors = £2,365.00 each

The equipment can be leased at the following rates
3 years @ £30 per £1,000 for 3 years (3+33 months)
5 years @ £21 per £1,000 for 5 years (5+55 months)

Vega Wire Guided Radar

All systems are the same price irrespective of the number purchased. Vega will not consider leasing the equipment

VegaFlex	£1,155.00
VegaDis371	£ 371.00
Installation	£ 500.00 (est)
Total	£2,026.00 (subject to installation costs)

Vega Ultrasonic

All systems are the same price irrespective of the number purchased. Vega will not consider leasing the equipment

VegaFlex	£1,436.00
VegaDis371	£ 371.00
Installation	£ 500.00 (est)
Total	£2,307.00 (subject to installation costs)

As Vega will not lease, alternative suppliers of wire guided radar and ultrasonic level measurement are being investigated.

Dedicated VMI RTU

All systems consisting of 1 midi RTU, GSM modem, installation & setup = £1,870.00

Lease rates

ITEM	QTY	Term of Lease (Months)	Number of Payments	First Month Payment Per RTU	Rent per Month Per RTU months 2 to 34
SiloView RTU	0-10	36	34	£150	£50
SiloView RTU	11-25	36	34	£135	£45
SiloView RTU	26+	36	34	£129	£43
GSM modem additional cost. No SIM	N/A	36	34	£30	£10
Signal Isolator	N/A	36	34	£18	£6

4-20/4-20/12V					

Comparison of Current Costs

Russell Roof Tiles

Item	Cost
Dedicated VMI RTU, etc.	£1,870.00
Level monitoring system - Silo 1	Already installed
Level monitoring system - Silo 2	Already installed
Total =	£1,870.00

Leased cost = £198.00 plus £66.00 per month for months 2 to 36

Eternit

Item	Cost
Dedicated VMI RTU, etc.	£1,870.00
Level monitoring system - Minsterport	£1,750.00
Total =	£3,620.00

Leased cost;
Dedicated VMI = £198.00 plus £66.00 per month for months 2 to 36
Minsterport 3yr = £52.50 per month for 3+33months
Minsterport 5yr = £36.75 per month for 5+55months

Item	Cost
Dedicated VMI RTU, etc.	£1,870.00
Level monitoring system - Vega WGR	£2,026.00
Total =	£3,896.00

Leased cost
Dedicated VMI = £198.00 plus £66.00 per month for months 2 to 36
Vega will not lease

Item	Cost
Dedicated VMI RTU, etc.	£1,870.00
Level monitoring system - Vega Ultrasonic	£2,307.00
Total =	£4,177.00

Leased cost
Dedicated VMI = £198.00 plus £66.00 per month for months 2 to 36
Vega will not lease

Conclusions

From the results of the various tests conducted on the Eternit silo, a number of conclusions can be drawn.

The strain gauges perform the best with an acceptable degree of accuracy. The benefit of strain gauges is that once zeroed at empty and calibrated to full they provide the actual mass of the product in the silo. Any effects of funnel flow, bridging and cone filling are not seen. Strain gauges are considered to be the preferred solution for remote silo monitoring, however they cannot be fitted to all silos as multi funnel or cell silos are not suitable for strain gauges. This type has been found at London concrete and is in place at some other readymix plants. A detailed assessment of the silo structure and support is required to determine the suitability of strain gauges.

Wire guided radar provides a fairly accurate trace while filling but is subject to miss readings due to aeration of the product and cone filling. The level will also decrease as the air is released from the product. While emptying the level is subject to funnel flow, rat holing and bridging, and may well give an incorrect representation of the actual content of the silo. Location of the wire rope is important as if this is close to the centre of the silo the effect of funnel flow or rat holing will show a lower level than actual, if to close to the edge the level will be higher. If the correct positioning can be established, or the silo is of a mass flow design, or the silo is of a small diameter then the use of wire guided radar can be considered as a second choice to strain gauges.

Ultrasonic level measurement is subject to the same problems and errors as wire guided radar. The accuracy found was very poor even compared to the wire guided radar. In addition the power of the unit has to be such that it can see through the dust generated while filling and or with dust generated from the dust collector. The ultrasonic equipment tested is not considered to be suitable for the roll out of remote silo monitoring.

The preferred way forward with remote silo monitoring would be to use strain gauges wherever possible and relay the readings back through the Dedicated VMI remote terminal unit for display on the web site. In the event of a particular customer with a silo or silos not suited to strain gauges, the system would then have to be based around the wire guide radar or ultrasonic system. A more detailed assessment of the customer’s silos and the silo flow properties would have to be undertaken to determine the preferred positioning of the equipment used.

Use of the Dedicated VMI RTU should continue, and all level monitoring devices should be powered through the RTU, this will provide for a level of equipment monitoring reported through the Dedicated VMI alarm system

While there are still relatively few sites in operation, the use of the Dedicated VMI bureaux service should continue. As the number of sites increase there may be some benefit to providing our own PC as a server to Dedicated VMI to further reduce the monitoring costs. Dedicated VMI have stated an interest in providing this service on an ongoing basis and are looking at a proposal. Further study into the options will be undertaken if remote silo monitoring is to be further progressed.

The option to lease the Misterport strain gauge and Dedicated VMI systems allow for the roll out of the remote silo monitoring to be undertaken without the requirement for capital investment at each site.

Not all silo installations are suitable for remote monitoring as a customer who has a small capacity silo and a high level of usage is better to place a standing order for a number of loads per day based on the projected usage.

Remote silo monitoring is practical but there are a number of considerations which affect the decision as to which level-monitoring system is to be used. These have to be evaluated based on the type of silo to be monitored.

Steven Grublys, Rugby Cement UK

3rd May 2006