Instrumental Survey of a Vertical Silo. Assessment of Deformation and Condition of the External Shell

Object: vertical cylindrical silo for storing bulk materials (H≈26.82 m, R≈3.25 m).

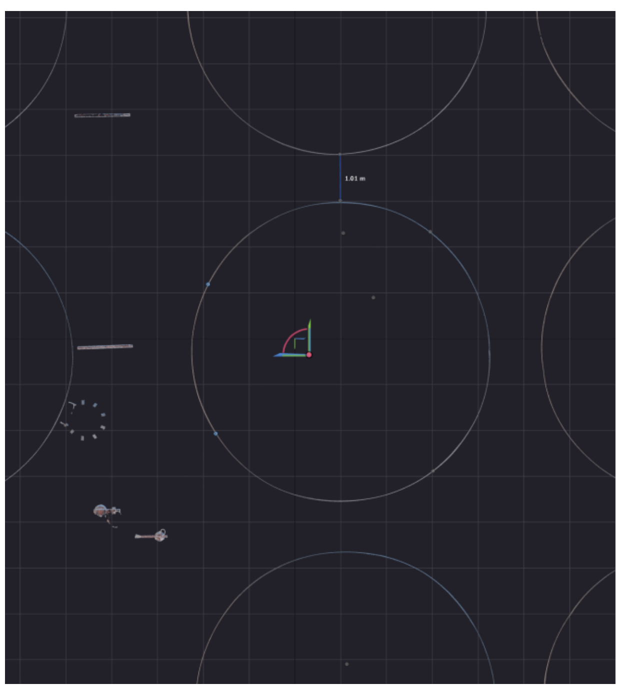
Site Characteristics and Access

The surveyed facility is one of a series of vertical silos arranged in a dense group; the minimum clear spacing between adjacent shells is about 1–1.5 m, with the shell height H≈26.82 m. This layout imposes significant constraints on direct line of sight, safe instrument set-up areas, and incidence angles to the surface, complicating both instrument measurements and visual condition assessment.

Constraints:

- Limited line of sight and “shadowed” sectors. Narrow corridors create zones inaccessible from a single instrument setup.
- Optical effects of metallic surfaces. Local gaps in terrestrial laser scanning (TLS) data due to grazing incidence and glare, as well as uneven illumination for photogrammetry.

Layout of the vertical silos on site, top view (slice from the point cloud):



Survey Methodology

Given the above features and constraints, the source data were acquired using a combined approach: terrestrial laser scanning (TLS), total station control network, and UAV-based photogrammetric capture.

The terrestrial laser scanner was positioned around accessible areas from multiple setups to cover shadows and obtain a stable geometry of the vertical silo. A total station network (~7 control points) provided a unified coordinate system and tie-in of targets/scans, preventing accumulation of errors during setup registration. UAV imaging was used for hard-to-reach areas (middle and upper belts).

For critical zones, increased view-angle overlap was ensured, and the resulting point clouds were cross-checked using control features (rings/belts) to rule out local geometric shifts caused by glare or incomplete coverage.

Based on the fusion of laser scanning and photogrammetry, a triangulated mesh and a point cloud of the surveyed object were created in a local coordinate system with accuracy on the order of a few millimetres, for subsequent calculations of deviations, ovality, verticality, and local deformations.

In the absence of design documentation, the geometric evaluation was performed by comparing the actual shell with a reference (ideal) cylinder. The reference geometry was obtained as follows: from the bottom ring of the silo, the best-fit circle (centre and radius) was computed, the cylinder axis was defined, and then an ideal cylinder of that radius was "extended" over the full actual shell height ($H \approx 26.82$ m). For each vertex/point of the actual surface, the signed radial deviations Δr relative to the reference cylinder were computed (sign convention fixed: "+" — outward bulge; "−" — inward dent). The Δr values were written to the vertex attributes of the model, which enabled a colour map of deviations with a unified legend (cool tones — negative Δr, warm tones — positive Δr) and interactive readout at arbitrary points.

For visual analysis, the cylindrical surface was unwrapped to a plane and two ortho-images (unwraps) were prepared:
— a deformation map based on the Δr field with a colour scale and labelled deviation magnitudes;
— a phototexture unwrap (visible spectrum) for detailed assessment of welds and shell surface.

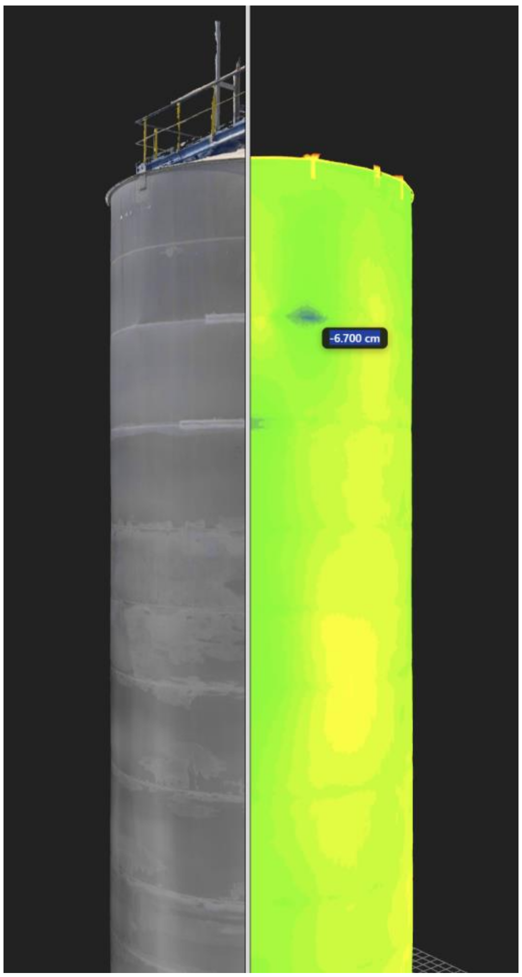
Based on the Δr field, key metrics were computed:
— ovality for a series of horizontal sections (difference $D_{max} - D_{min}$, in mm and as % of D_{nom});
— verticality (out-of-plumb) of the shell axis by section centres/reference-cylinder axis;
— parameters of local deformations (dents/bulges).

All calculations were performed in a single coordinate system with units stated (m/mm) and a fixed Δr sign convention; consistent section thickness and a common legend range were used for comparability by height.

Web Visualization of Results

The results are presented via a purpose-built web service for visualising the 3D model of the silo in visible-spectrum mode and in deviation-map mode with on-cursor readout of deviation values:

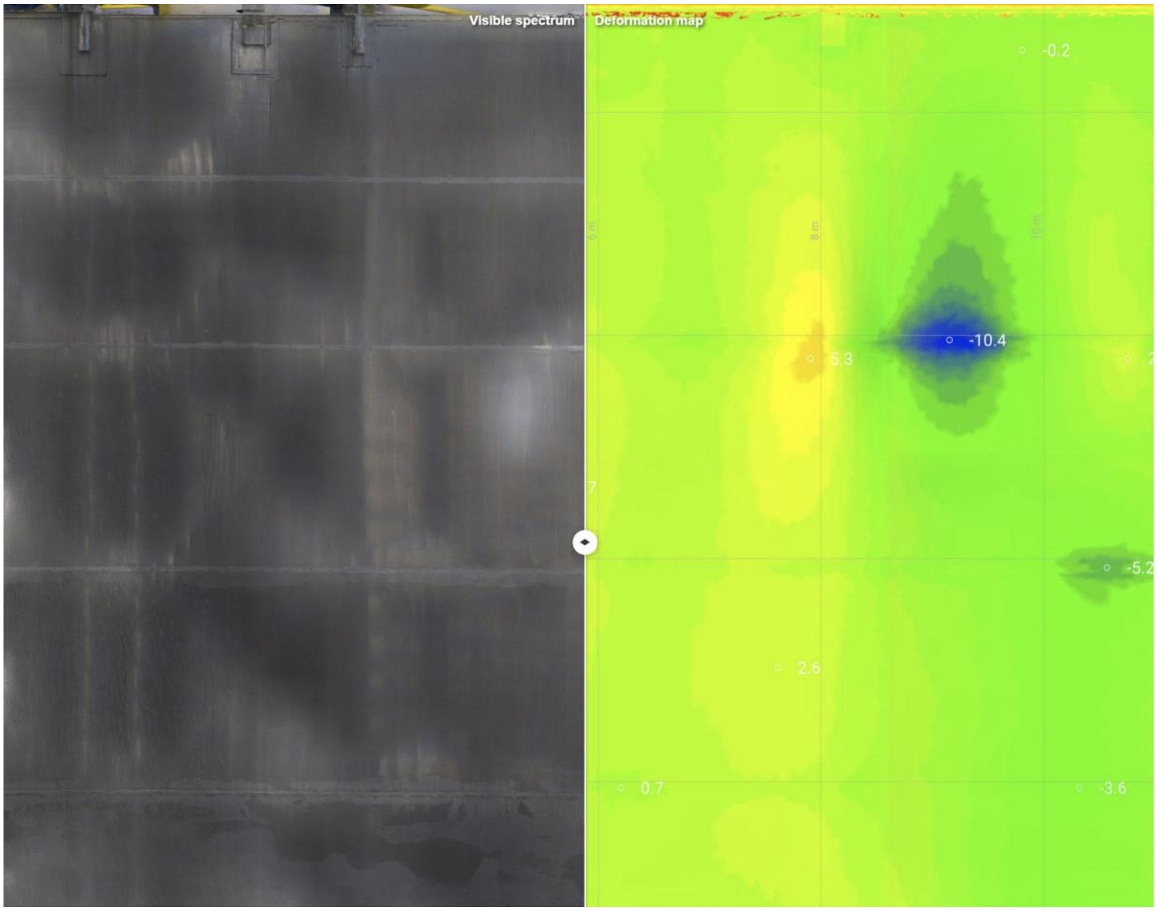
https://storage.3dreality.pro/barrel-deviations-explorer/index.html



A vertical slider is provided to switch from the model view to the deviation-map view.

A separate web page also displays the deformation-map unwrap with colour scale and labelled deviation magnitudes, and the phototexture unwrap (visible spectrum) for detailed assessment of welds and surface condition:

https://storage.3dreality.pro/barrel-unwrap-side-by-side/index.html

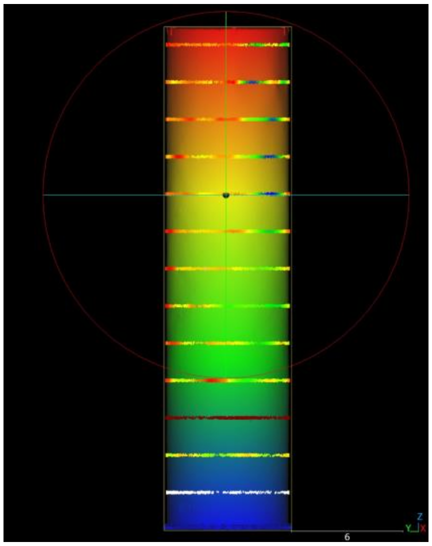


On the deviation map, additional deviation labels and a scale grid are shown. Use the vertical slider to switch between the visible-spectrum view and the deviation map.

It should also be noted that, during a repeat survey, the condition results and comparisons with the previous survey can be published on the developed web service.

Ovality by Height

To calculate ovality by height, 0.1 m-thick sections were created every 2 metres of height.



Method of Calculation

The nominal diameter was taken as D_nom = 6.50 m (R = 3.25 m). Ovality of a single section was defined as the difference between the maximum and minimum actual diameters: Ovality_mm = D_max − D_min, where D_max = D_nom + 2·Δr_max and D_min = D_nom + 2·Δr_min. Relative ovality: Ovality_% = (D_max − D_min)/D_nom · 100.

The deviation Δr is the signed radial distance from the actual shell surface to the reference cylinder measured along the normal, with the sign convention: "+" — outward bulge; "−" — inward dent.

Results for 13 sections every 2 metres:

Z (m)	Δr_min (mm)	Δr_max (mm)	D_min (mm)	D_max (mm)	Ovality (mm)	Ovality (%)
2	-11.6	34.3	6476.9	6568.5	91.7	1.410
4	-41.3	39.5	6417.5	6579.1	161.6	2.486
6	-44.2	33.3	6411.6	6566.5	154.9	2.383
8	-51.7	43.6	6396.7	6587.1	190.5	2.930
10	-43.6	42.4	6412.7	6584.8	172.0	2.646
12	-33.5	52.5	6432.9	6605.0	172.1	2.648
14	-64.9	54.3	6370.3	6608.7	238.4	3.668
16	-47.3	47.6	6405.4	6595.3	189.9	2.921
18	-32.5	41.5	6435.0	6583.1	148.1	2.279
20	-38.6	36.0	6422.9	6572.0	149.2	2.295
22	-59.0	34.0	6382.1	6567.9	185.9	2.859
24	-111.6	53.0	6276.8	6606.0	329.2	5.065
26	-43.7	25.1	6412.5	6550.2	137.7	2.118

Summary: the maximum ovality is at elevation 24 m — 329.2 mm (5.065 %); the second-largest at 14 m — 238.4 mm (3.668 %). The mean ovality over the series is ~179 mm (≈2.75 %), the median is ~172 mm (2.648 %). At 24 m a pronounced local indentation is observed (Δr_min ≈ −112 mm).

Out-of-Plumb (Deviation from Vertical)

To assess verticality, circle data were taken for sections at heights of 2 m and 26 m.

Method: based on the centres of two circular sections (lower and upper), the horizontal axis offset and the related indicators were computed.

Given (section circle centres):

z≈2 m: (0.631611, 7.242920, 4.350007)

z≈26 m: (0.621240, 7.243370, 28.3499995)

Calculations:

Height difference: H ≈ 24.000 m

Horizontal axis offset:

$$\delta = \sqrt{\Delta x^2 + \Delta y^2} \approx \sqrt{(-0.010371)^2 + 0.000450^2} \approx \mathbf{10.38\ мм}$$

Deviation from vertical:

$$p = \delta / H \approx \mathbf{0.433\ мм/м}$$

Axis tilt angle:

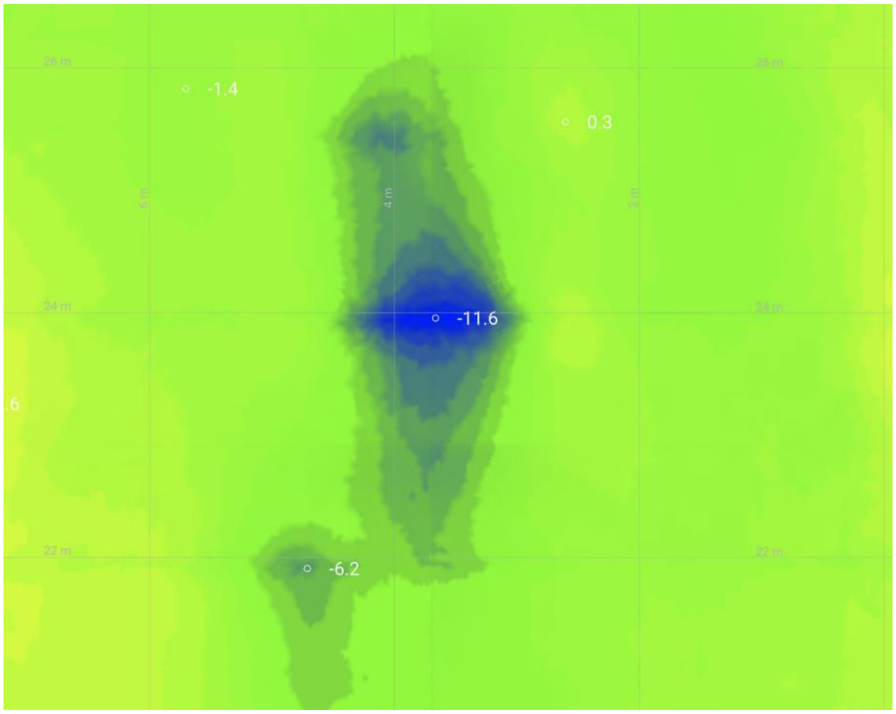
$$\theta = \arctan(\delta / H) \approx \mathbf{0.0248}^\circ$$

Conclusion on verticality:
The silo axis is practically vertical: ~0.43 mm/m and 0.025°. The magnitude of the deviation is small and does not materially affect the overall shell geometry.

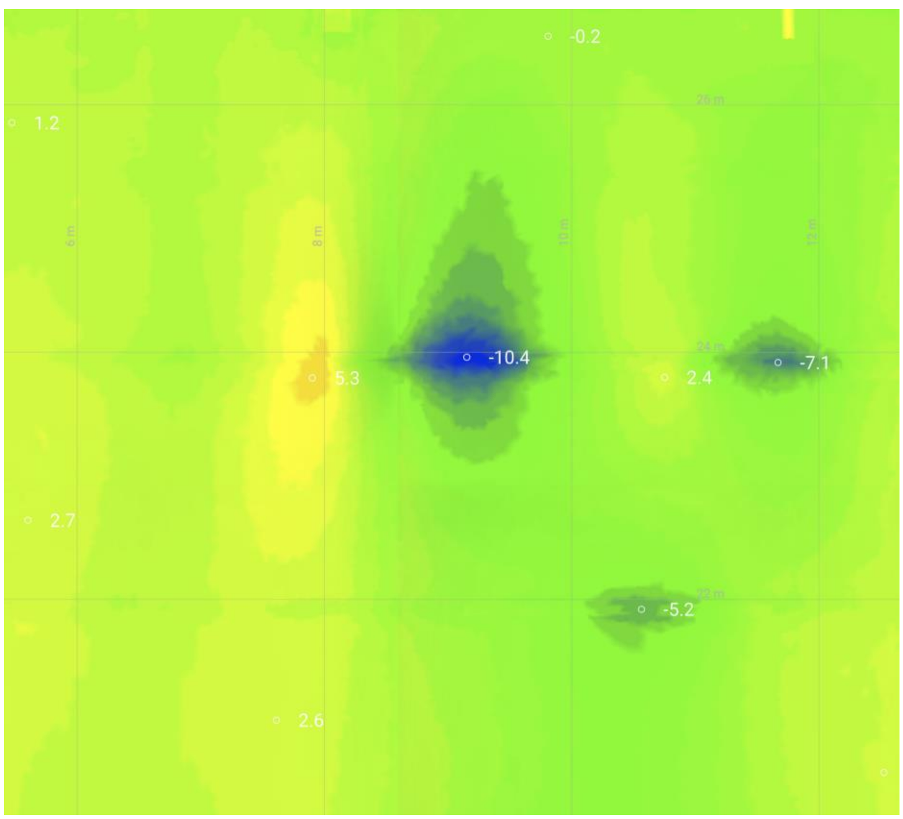
Local Deformations (Dents/Bulges)

Analysis performed on the Δr field https://storage.3dreality.pro/barrel-unwrap-side-by-side/index.html

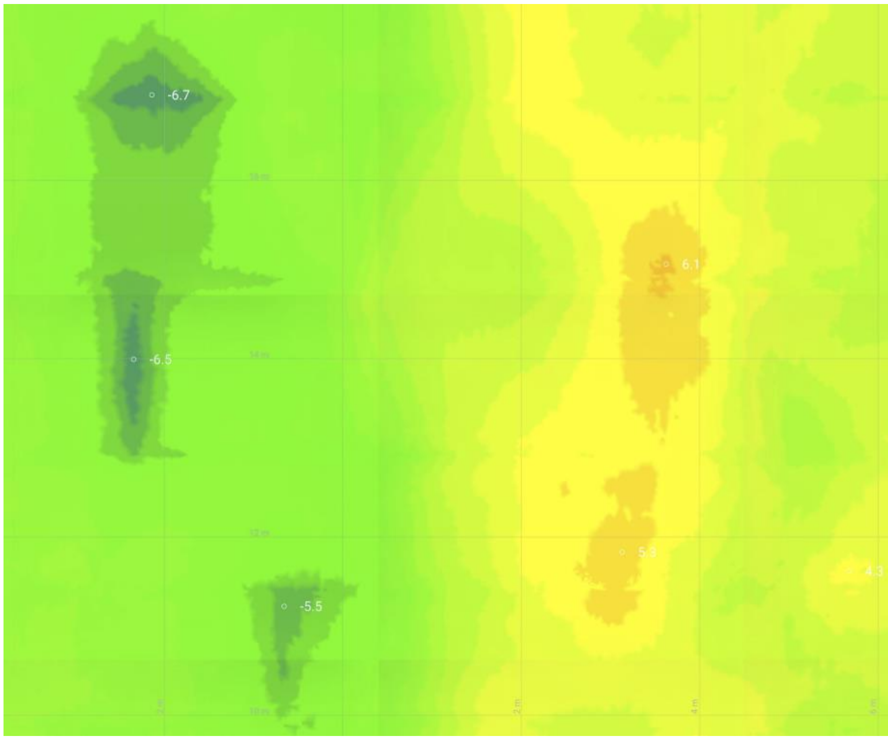
Analysis based on the Δr field (signed radial deviations) identified local zones exceeding threshold values in absolute terms. The largest dents were recorded in the upper part at about 24 m (up to −111.6 mm and −104 mm relative to the reference cylinder), and the largest bulge at ~14 m (up to +61 mm). In total, 12 areas with |Δr| > 50 mm were noted, with clustering around 24 m.



-1.4
0.3
-11.6
.6
-6.2



-0.2
1.2
-10.4
5.3
2.4
-7.1
2.7
-5.2
2.6



External Surface Defects

Based on the visible-spectrum orthophoto, local weld defects and traces of pitting corrosion were identified.

Recommendations

1) Perform repeat geometry control (ovality/Δr) in 6–12 months or after a representative operating cycle (full ↔ empty).

2) Carry out targeted inspection of welds and areas with maximum |Δr| (especially at ~24 m and ~14 m).