GERALDTON CONCRETE SILOS REMEDIATION: A CASE STUDY IN THE STRUCTURAL STRENGTHENING AND CONCRETE REPAIR PRACTICES UTILISED FOR THE ONGOING OPERATIONAL EFFICIENCY AND DURABILITY OF 24 NUMBER CONCRETE SILOS AND 14 NUMBER STAR CELLS

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SUMMARY

Freyssinet Australia was engaged by Co-Operative Bulk Handling (CBH Group) of Western Australia in conjunction with their in-house Engineering division to develop a repair scheme for the 24 interconnected concrete grain silos at their Geraldton Port facility in 2008.

Originally constructed in the mid 1960’s, the design allowed for only static loading to the structures, failing to account for the ‘funnel’ effect during the emptying of the silos. The original design had insufficient hoop reinforcement to deal with such live loads and as such by 2000’s their condition had declined to an extreme state, rendering them in need of extensive structural strengthening and concrete repair.

Works on site commenced in 2008 to the first three silos as part of the initial 18 month ‘prototype’ phase. This phase was then followed by the ‘full scale works’ whereby the overall works package was split into four distinct separable portions (SP1 – SP4) with each addressed as sequential independent schemes as illustrated below in Figure 1.

![Figure 1 – Breakup of each phase of works](image-url)
UNDERSTANDING THE PROBLEM

Initial site inspections gave a clear indication of the level of cracking on the silos, extensive areas where corrosion was evident due to delamination of the concrete and pimples/ lateral deformations visible to the eye on some silo walls as a result of the ‘funnel effect’ (Figure 2) during the operational use of the silos.

Some remediation works had been carried out previously on the cracking with Kevlar tape placed over each crack to try and stem the cracking and also seal the cracks from the elements. The extent of the cracking exposed can be clearly seen in Figure 3 following removal of the tape as part of the initial repair process.
After detailed hammer surveys, coupled with exploratory breakout ‘windows’, areas of concern were identified, catalogued and each silo mapped accordingly which allowed for a repair scheme to be formulated in what became known as the ‘proto-type’ phase of the works. The ‘proto-type’ phase of the works utilised separate twin profiled mast climber systems for access to carry out the surveys and the repair works as shown below in Figure 4.
Internal 3D scanning of the worst affected silo (3.1) was carried out noting the ‘full thickness’ cracking that was affecting this particular silo wall. These cracks coincided with areas of the wall that appeared to be ‘bulging’ outwards (as shown from the 3D mapping in Figure 5). The 3D scanning mapped the extent of the internal cracking and also the profile of the lateral deformation in the wall. For this case a methodology for a full depth repair was required and developed.

Figure 5 – 3D mapping showing lateral bulge in silo 3.1 wall structure

These initial trials led to development of a structural repair and strengthening solution comprising of the Freyssinet 1X15 external post tensioning system being utilised as the structural strengthening component to combat the insufficient hoop reinforcement, together with varying different concrete repairs techniques to combat the extensive cracking, delaminated concrete and lateral deformation effecting one of the silo structures. Due to the facilities proximity to the coast the cracking also contributed to widespread chloride induced corrosion of the existing reinforcement embedded within the structure.
REPAIR SOLUTIONS

After the ‘proto-type’ phase Freyssinet Australia was engaged on a full design and construct contract to remediate the remaining 21 number interconnected silos and the 14 number star cells. Execution of the rehabilitation solution involving various different concrete repair techniques and structural strengthening, discussed in detail hereafter, ensured the ongoing operational efficiency and durability of the concrete storage facility.

The original contract estimate for repair area was set at 3000m². However over the course of the project with better access to carry out detailed surveys the final repair area grew to over 4400m². The Table 1 below illustrates the comparative spread of repair area across each of the Separable portions.

<table>
<thead>
<tr>
<th>Separable Portion</th>
<th>Repair Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP1</td>
<td>762.77m²</td>
</tr>
<tr>
<td>SP2</td>
<td>1064.73m²</td>
</tr>
<tr>
<td>SP3</td>
<td>930.21m²</td>
</tr>
<tr>
<td>SP4</td>
<td>1680.00m²</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4437.71m²</td>
</tr>
</tbody>
</table>

Table 1 – comparative repair areas across each Separable Portion

Out of the ‘proto-type’ phase of the works a defined project scope of works and access requirements were developed for each silo’s remediation.

Access Systems

During the ‘proto-type’ phase of the works profiled mast climbers (Figure 3) were utilised to access the repair areas. However it quickly became apparent that this access system was not the best solution for a project of this magnitude. With such large areas of repair to be completed, the mast climber system didn’t allow for the autonomy required to work on multiple work fronts at any given time. Coupled with the lower safe working load (S.W.L) of the mast climbers a traditional scaffold access system (Figure 6) was utilised for SP1 – SP4.

Figure 6 – typical scaffold access on site (prior to encapsulation)
Another unique challenge was the access system requirements for the internal star cells. Access into this area was a difficult challenge due to the confined space nature of the works. Access doors at the base of each cell allowed for scaffold material to be passed into each cell and a scaffold ‘donut’ platform (Figure 7) constructed to suit the cells configuration. Side guides/rollers and a winch system was used to traverse the ‘donut’ up and down the star cell walls. Emergency access was by means of rope access system in/out of the escape hatch at the top of each cell created by removal of each silos grain feed chutes.

Figure 7 – star cell scaffold platform

Outlined Scope of Works

The original design allowed for only static loading to the structures, failing to account for the ‘funnel’ effect during the emptying of the silos. This design allowed for insufficient hoop reinforcement to deal with such live loads and as such by 2000’s their condition had declined to an extreme state, with extensive cracking, spalled areas of concrete and widespread chloride induced corrosion due to the facilities proximity to the coast; rendering them in need of extensive structural strengthening and concrete repair. The following repair sequence was utilised across all silos:

1. Conduct Hammer Survey to identify areas of defective/ delaminated concrete.
2. Remove defective/ delaminated concrete using a combination of both Hydro-demolition and hand breakout techniques, and trim original concrete to behind (by a ‘gloved hand’/ ≥25mm) the existing reinforcement.
3. Remove existing horizontal reinforcement and replace with new galvanised steel. Blast and treat the existing vertical steel.
4. Apply concrete repairs to areas requiring reinstatement using Dry-Spray Gunite repair application.
5. Carry out crack repairs to any remaining structural cracks.
6. Apply 3-coat paint/ waterproofing system to silo external surfaces.
7. Install 1X15 external post tensioning system using diaphragm core holes to pass each cables external ducting which house the greased and sheathed 15.7mm strand through
and around each silo as a pre-determined location. Figure 8 shows a typical tendon layout for the silo structural strengthening.

8. Reinstate all infrastructure for each silo – fumigation pipes, chutes, access towers etc.

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**Figure 8 – 1X15 tendon layout**

In addition to the silos, the internal 'Star Cells' which made up the voids between the interconnecting silos and were also used for grain storage, required some works as part of the overall remediation project. The following repair sequence was utilised across all star cells:

1. Install stressing anchor to receive the external post tensioning cable.
2. Following completion of the post tensioning works, anchor steel mesh to face of each Star Cell wall.
3. Apply 80mm thick strengthening skin of Wet-Spray/ Shotcrete onto steel mesh and finish smooth.
4. Reinstate all infrastructure for each cell – fumigation pipes, chutes etc.

Silo 3.1 required special attention in the overall repair scheme due to the lateral deformation in its mid-section as identified by the 3D mapping and also from the visible penetration through the silo wall. Once access was establish a full depth repair to an area approximately 30m² was required. Briefed with the 3D mapping information and as-built drawings, a structural finite element analysis (FEA) was carried out to ascertain the structural integrity of the silo 3.1 and necessary repairs.

The results of the FEA confirmed that the silo could still function even with the lateral deformation/ 'bulge' left in place. This FEA analysis outcome allowed for the minimum possible area of full depth concrete repair to be addressed.
The results of the accompanying site investigations also highlighted the need for the extensive cracking around the full depth repair area to be treated so that the substrate would act in a homogenous manner during the stressing works, along with the need for stainless steel dowel pins to be installed to the segmented ‘blocks’ of concrete which had been created by the cracking.

Figure 9 – Project at completion

CONCLUSIONS

The concrete remediation techniques and practices adopted on the Geraldton Grain Silos project were both varied and challenging; making it a highly unique project within the Concrete Engineering field. The large-scale application of Dry Spray Gunite, Wet Spray Shotcrete, Reinforcement, Waterproof Substrate Coating and External Post-Tensioning to the silo structures, required dedicated expertise across and range of engineering disciplines.

However successful execution of these works was also greatly reliant upon the collaborative approach adopted by both the asset owner and contractor. Without this forward thinking approach, solutions to additional problems such as Silo 3.1’s full depth repair may not have been so readily derived and successfully implemented.

Moreover, the use of a prototype phase in order to establish the correct application techniques and quality management, helped contribute towards a ‘right first time’ culture that lasted the duration of the repair works, whilst enabling the facility to remain operational.
REFERENCES

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