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Shotcrete as a good looking final finish—it *is* possible!

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ABSTRACT: Shotcrete has long been used in civil works for free-form structures such as swimming pools and vertical construction of embankment walls and slope stabilisation. The majority of this type of work is still applied by hand. One of the chief limitations to shotcrete being used as a final finish is the aesthetic quality of the finished product. To overcome this, a variety of surface finishes have been developed by leaders in the industry including trowelled, coloured and sculptured finishes. However, due to some well documented examples of poor shotcrete construction many urban planners, government departments, builders, consultants and perhaps also the general public, consider shotcrete to be an unattractive final finish. This paper examines the recent history of the use of shotcrete in public infrastructure in Australia and examines how the correct application of skill and technique can avoid these problems.

1 INTRODUCTION

Shotcrete was first introduced in 1907 in America as hand applied dry spray, commonly know as *gunite*. Wet-mix shotcrete was later introduced in 1955 which increased pumping volume capacity and thus production rates. As such, wet-mix was and remains perhaps more difficult to control and finish than gunite. In the late 1960s robotic equipment was introduced and is prevalent today for overhead spraying in mines and tunnels. Around 800,000 m^3 of shotcrete is sprayed in Australia per year.

Given its ease of application, suitability for free form construction and elimination of any formwork other than a surface upon which to spray, shotcrete became and remains perfect for construction of swimming pools, tanks, water features, shoring, underpinning, dam spillways, and ground stabilization including overhead application as well as many other structures.

2 LESSONS IN HOW NOT TO SPRAY SHOTCRETE

2.1 *M2 Motorway, Sydney NSW*

A construction contract was awarded to a large civil contractor. Work commenced on this 21 km long NSW project in 1994/95 and was completed in 1997.

Many, often deep, vertical and steep-battered excavations were required to allow the road and tunnel associated with this project to pass through this challenging site. The retaining systems employed were generally soil nailed or anchored walls constructed in a top-down excavation sequence. Once the soil nails and anchors were installed, the areas were meshed and shotcrete was sprayed with a natural shotcrete (grey) gun finish while in some areas coloured oxide was added. The excavation staging was poor resulting in highly irregular horizontal joints between shotcrete sprays. In addition, the finish was "off-the-gun" which is very basic and cheap and the general quality of the finished product was poor.

As a result it is possible to see the ribs of the mesh in places (Figure 1) and permanent anchor heads were not recessed into the shale/rock. Large knobs of shotcrete where sprayed over the top of each resulting in hundreds of unsightly lumps

Figure 1. M2 anchored walls—poor staging, poor spraying, extensive cracking.

sticking out of 12 m high walls about 300 m along both sides of the motorway (Figures 2 and 3). Over the last 12 years significant cracking has appeared and in some areas the shotcrete has come away from the base as no keying in was provided for (Figure 3). It is fair to say that the shotcrete construction on the M2 Motorway is an eye-sore. Worse still, thousands of motorists pass the work every day, leaving the poor standard of work etched into the public psyche.

It is not clear whether the specification, the superintendant or contractor employed was at fault on the M2 project, but it seems likely that all these elements were in some way responsible. It is believed that as a result of this project the Roads and Traffic Authority of NSW instructed that shotcrete not be used as a final finish or, wherever possible, be limited in use. RTA Shotcrete Design Guidelines (RTA, 2005) certainly suggest that this is true although it does not specifically state that the M2 is to blame. Whilst the document does not suggest shotcrete must be banned from all future roadways it says that it should be avoided wherever possible. The document states:

"The best strategy in dealing with shotcrete in terms of cost, safety, appearance and environment is to adopt the following hierarchy:

1. Avoidance
2. Minimization
3. Improve Appearance"

In retrospect, if point No 3 was more fully considered back in 1994 then perhaps this document would not exist! There are, of course, other poor examples of shotcrete (see F6 freeway, Sydney, Figure 4).

Generally the most damaging instances of poor finish for the shotcrete industry are those examples on the sides of roadways as they are open to public scrutiny. These works are characterized by:

- Generally large spans of gun finish (the most basic version of shotcrete)
- Poor excavation staging
- Poor application techniques
- Poor shotcrete quality resulting in excessive cracking.

Despite the public relations disaster of the M2 motorway project, the use of shotcrete has continued. One increasingly popular method is the use of vertical soil nail walls for embankment stabilisation. However, the shotcrete employed in the construction is often hidden from public view.

The construction method now commonly employed is as follows: a top capping beam is

Figure 2. M2 motorway anchored wall—mesh ribbing is evident suggesting inadequate cover to reinforcement.

Figure 3. M2 motorway—another poorly staged and sprayed wall with excessive cracking.

Figure 4. F6 freeway, Sydney—poor staging, poor spraying, overspray and excessive cracking.

installed, the soil nail walls are constructed in stages and sprayed to a gun finish, a bottom beam is built, and then concrete pre-cast panels are installed over the shotcrete. This requires large cranes, massive trucks, and boom lifts to complete. This is a very expensive process to eliminate unsightly shotcrete. Yet it is totally unnecessary if the shotcrete is well constructed and finished. The result of the current approach using pre-cast elements is: a tripling of the cost, a doubling the time to construct, and a site congested with trucks, cranes, boom lifts, additional labour and all the attendant safety issues.

3 WHAT SHOULD HAVE BEEN DONE AND WHAT CAN BE DONE

The shotcrete should have been specified with a quality final finish. With the correct application of skill and technique, almost any quality of finish is achievable. Pre-construction trials should have been carried out to prove the final finish was acceptable. Construction time would have been halved. The improved efficiency would have been reflected in much lower project costs. The reputation of shotcrete would also have been restored.

It is worth noting that, at the time of writing, a A$550 m upgrade of the M2 is due to commence in 2010 (Earthmoving & Civil Contractor, 2009).

Figure 5. These walls should be re-sprayed.

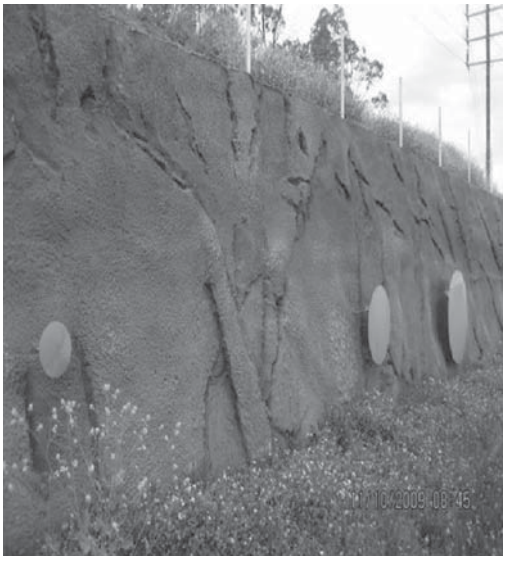

Figure 6. An example of a sculptured shotcrete wall, Geelong Ring Rd, Victoria.

Figure 7. A simple well-sprayed gun finish, Mount Conjola NSW.

The plan is to widen the roads and tunnels adding an extra lane in either direction (where possible) and construction of various on and off ramps. The design and method of construction is not yet clear but it seems likely that some of the existing shotcrete batters and walls may be re-cut to allow extra space.

Shotcrete soil nail walls remain an excellent solution for these cuts and thus would provide a great opportunity for the above advice to be considered and hopefully adopted. Of course this upgrade also offers the owner the opportunity to fix the remaining offending areas of poorly finished shotcrete cost-effectively as construction works proceed

(Figures 5, 6 & 7). Many simple shotcrete options could be adopted and a large variety of aesthetically pleasing finishes could be specified.

4 THE WAY FORWARD

4.1 *Some recent shotcrete projects*

Shotcrete has been adopted as a final finish on a number of new rail corridors in Australia. Road and tunnel builders are once again allowing skilled contractors the opportunity to construct various final finished shotcrete walls (Figures 8 to 10).

At Shannon Creek Dam in Queensland, the builder and the shotcrete contractor worked with the Department of Commerce to replace the designed formed and poured walls with shotcrete construction. Pre-construction testing included tests on compaction, strength, and finish. The method gained approval and 3200 m^2 of shotcrete walls were constructed. These were up to 300 mm thick with two layers of reinforcement and up to 11 m high (see Figure 11).

Figure 8. Finished walls with joints, LBBJV—Clem 7 for cycle ways (formerly North South Bypass Tunnel, Brisbane).

Figure 9. Finished walls with joints, LBBJV Clem 7 under bridges.

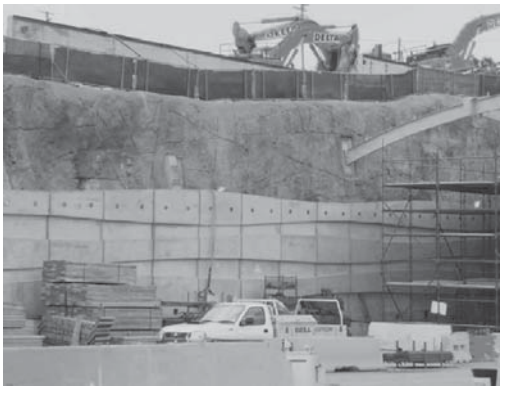

Figure 10. Simulated rock finish above pre-cast Clem 7 tunnel project, Brisbane.

Figure 11. Shannon Creek Dam spillway and stilling basin.

5 TYPES OF FINISHES

The following types of surface finish are available for shotcrete, listed in terms of quality of finish and therefore expense.

5.1.1 *Gun finish*

Also referred to as 'off-the-gun' or 'undisturbed natural finish'. Put simply the aggregate is not trowelled in, the surface is rough (but when applied

by an experienced and professional nozzleman it will be uniform) similar to a pebbledash or stipple finish (see Figure 12). This is the cheapest finish as it requires minimal labour.

5.1.2 *Screed finish*

Guide lines are set up to the required height and face and a screed is used to cut the wall back to the required line. Aggregate drag marks occur but when an experienced screeder with the correct tool attacks the wall it can be closed up and finished fairly well.

5.1.3 *Wood float and sponge finish*

After screeding, wood floats are used to close the face and once the shotcrete has set (but is still green) a sponge is finally used to produce an off-render finish (Figures 13 to 15).

Figure 12. Off-the-gun or natural finish—Shannon Creek Dam, Grafton NSW—Embankment stabilisation.

Figure 13. Wood float and sponge finish with dummy joints at 3 m intervals—cycle way, Clem 7 Brisbane.

Figure 14. Wood float and sponge finish over Gun Finish along side pre-cast panels Cycle Way Clem 7 Tunnel Project Brisbane.

Figure 15. Wall completed with block work, WFS shotcrete and pre-cast panels, cycle way, Clem 7 tunnel project, Brisbane.

5.1.4 *Steel trowel*

Once screeded the face is steel trowelled leading to a glassy smooth finish (see Figure 16). It is often more difficult to achieve a superior finish with this method unless the shotcrete and finishers are of the highest quality. It is generally a less forgiving final finish than wood, float and sponge as all elements—shotcrete, crew, prep work and weather—must be perfect to allow an excellent finish.

5.2 *Joints*

In most designs crack inducement is generally not specified where a gun finish is used. Dummy joints should be encouraged simply because like any concrete structure it will crack somewhere. It is recommended to install a dummy joint at no more than 3 m centres in order to induce cracking (Figure 17). Where panels of shotcrete are higher than 3 m then horizontal joints should also be considered.

Figure 16. Steel trowel finish for an in-ground trough.

Figure 17. Dummy joint in shotcreted wall.

5.3 *Oxides and pigments*

Coloured oxides and pigments can be added in an attempt to match the finished colour with surrounding areas. This can result in a very aesthetically pleasing finish, especially when surrounded by rock, sandstone or soil. The drawbacks are that they must be uniform throughout and, as sands and aggregates in shotcrete can vary from day to day or even from load to load, colours cannot be guaranteed. Many concrete suppliers require client's written acceptance that this may occur before they will agree to supply.

5.4 *Simulated rock or block finish*

Shotcrete, generally without coarse aggregate, can also be cut and molded then coloured to offer rock, sandstone, shale or block-work finishes. These finishes, when completed by competent artisans and matched to surrounding finishes, cannot generally be identified as shotcrete. In my opinion, especially when used with landscaping, they really do offer an aesthetically pleasing retaining solution (Figures 18 and 19).

When specifying walls for appearance a very important point to note about large spans of concrete and finished shotcrete is that they offer a very large blank canvas for graffiti artists. If you look at any rock face, be it simulated or natural, you will find that they are ignored by our 'alternative artists'! Gun finishes are also generally left alone. This definitely presents an advantage over the flat or smooth finishes typical of poured concrete.

The Figure 20 shows the recently completed Lane Cover Tunnel project in Sydney. This was a very challenging site in terms of the civil works.

Figure 18. Simulated rock finish at Kirribilli, Sydney. No graffiti problem after 7 years!

Figure 19. Simulated rock using shotcrete on side of M7 Freeway Sydney NSW.

Figure 20. Shotcrete covered with pre-cast panels partly covered with creepers, Lane Cover Tunnel project, Sydney.

New east- and west-bound lanes were built within an extremely tight corridor. Many very high and vertical excavations were required. The solution adopted throughout was top down excavation and staged shoring using soil nail and shotcrete walls. Basic gun finish was specified with all of it covered by pre-cast concrete panels.

After the pre-cast panels were installed garden beds and Jersey barriers were also added. Plants have now grown up the walls which soften the pre-cast concrete panels. It was, of course, possible to simply grow the vegetation over the shotcrete saving time and cost in the secondary construction and installation of the panels.

6 OTHER EXAMPLES OF SOFTENING OF LARGE SPANS OF SHOTCRETE

The famous Victoria Peak in Hong Kong allows the visitor the opportunity to walk around the top of this scenic area and enjoy the breathtaking view. In order to achieve this a large amount of stabilization was necessary in the form of dry sprayed shotcrete walls with many outlets for weep drains allowing hydrostatic pressure relief from the apparent ground water issues. The gun finished shotcrete is therefore pitted with holes but vegetation has been encouraged throughout. This can be achieved by spraying an organic material (such as yoghurt) over the gun finish to encourage moss and vegetation to flourish. The gun finish is thus camouflaged in part by the growth and the shotcrete is unnoticed by the passerby.

Figure 21. Victoria Peak, Hong Kong.

Figure 22. Creepers covering shotcrete wall in Singapore.

Another example (Figure 22) is in downtown Singapore where bored piles with gun finished shotcrete in-fills are simply covered over time with creepers and vines again offering the same softening to the large span of shotcrete. This is not dissimilar to the strategy seen on the Lane Cover Tunnel walls above.

7 SPECIFICATION FOR A QUALITY SHOTCRETE PROJECT

The following points must be considered when developing a specification for a high value project demanding quality shotcrete. Firstly, consider the available budget and research the finish options. Specify walls for appearance but remember they are large spans/canvases and consider what they may look like in the future. Specify that the contractor must have the required experience and request evidence that all personnel, especially the nozzlemen and finishers, are experienced before

they undertake these works. Request proof that the contractor has sufficient labour and high quality equipment to ensure project programme requirements are met. Specify that the shotcrete mix supplier must not only provide the required mix to meet specified design but also that it be of high quality at all times to allow ease of pumping, spraying and finishing.

Specify that the contractor must pass a rigorous pre-construction trial including: setting up a test panel reflecting what is to be built including specified reinforcement, hand spraying and finishing the specified mix with the intended qualified nozzleman and finishers. The shotcrete supplier's technician should attend the trial observing and noting any mix issues in respect to pumping (blockages, loss of water in the mix, increased pump pressures) and spraying (excessive rebound, sagging on the reinforcement, fall outs). The technician must also note finishing characteristics with regard to retardation or acceleration (long or short setting times which both hinder finishing and therefore the final appearance).

Specify realistic testing of the mix. As a minimum, cylinders must be taken from trucks for compressive strength. Cores can also be taken from sprayed panels to confirm compaction, density and in-situ compressive strength. Further testing required under the specification might include durability or toughness for fibre reinforced shotcrete.

Specify that all overspray is to be removed and limited wherever possible. Specify cover to reinforcement and that all surfaces should be wetted down at all times. Specify the method of curing. Curing compounds are generally recommended for ease of application. If the surface is to be painted a water based compound should be used. Specify that written approval of the finish by client is required before commencement of the works. In the absence of an Australian standard for shotcreting, reference should be made to the following for assistance when specifying shotcrete design, finish, application, testing etc: "Shotcreting in Australia" (2008) and RTA B82 Specification—*Shotcrete Work* (2006).

8 CONSTRUCTION PLAN FOR A SHOTCRETE PROJECT

Ensure that you price the works with sufficient allowance for the specified pre-construction works. Allow enough time and money to assure a high quality finish can be achieved. Undertake trials for shotcrete quality and finish to be approved by the client. Plan and set the works up well. The following target profile (Figure 23) suggests ideal heights, staging and benching. This allows productive and quality shotcrete placement and finishing.

Excavate ground to a given level horizontal line (this will ensure you have a straight joint in the shotcrete) and a maximum 2.5 m drop per level. This way a standard sheet of mesh can be used and eliminates the need for scaffolding or access equipment which is cumbersome and reduces productivity. Install reinforcement, drains, soil nails and all screed lines correctly. Reinforcement must be pinned and tied back rigidly and to the correct position for cover. Poorly fixed reinforcement with excessive cover to screed lines increases the risk of fallouts and results in lost time, poor finish and possibly failure of the structure during spraying.

Timbers or steel sections should be installed at required position of construction joints (generally 300 mm above the bottom of the mesh to offer lapping of mesh to the proceeding level) and in line with screed lines above. Spray good quality shotcrete with highly trained craftsmen who work as a team, take their time and give attention to detail. Reject poor quality shotcrete. Immediately contact the supplier and communicate any issue to minimize disruption. It is poor practice to continue with a poor quality shotcrete mix. This will cost time and money and will affect the final quality of finish.

Install joints as specified. Finished walls should have dummy joints as a minimum requirement. This helps to break up long stretches of shotcrete

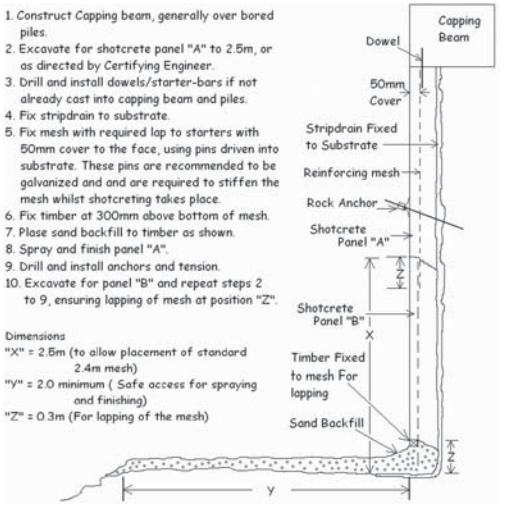

Figure 23. Suggested target shotcrete profile sequence for top-down construction. [Disclaimer: The intention of this profile is to demonstrate the best case scenario in terms of safety, productivity, cost and final finish when constructing walls in a top down nature. Final design and staging should always be checked and directed by a qualified engineer prior to commencement.]

and also helps to induce cracking. Finish the walls to a high standard with the crew working as a team at all times. Ensure that all overspray is cleaned off surrounding surfaces. Where possible, screen surrounding areas prior to commencement to prevent over-spray that requires subsequent cleaning. Avoid spraying in very hot temperatures and, if unavoidable, start and finish early. Extremely cold temperatures can also cause problems. Ensure the substrate is wetted down thoroughly and continually throughout the day as the moisture will be drawn out rapidly from dry substrates. When you sponge a wall, ensure your sponge is new, constantly washed out in clean water and is never too wet. Run a damp sponge over any wet sponge marks and repeat until the required final finish is complete.

Have the supervisor check all the work and fix any areas that are not up to standard. Apply a curing compound that does not stain the shotcrete and can be painted over if required. Ensure the works area is fully prepared and cleaned of all the previous days' rebound and screed waste. Screen any necessary areas from overspray. No matter how well your walls are finished, over-spray will ruin the appearance and spoil all the hard work. Clean sites are safe and most productive!

9 CONCLUSIONS

Where poor examples of finished shotcrete work are evident, it is generally the case that the constructor has:

- Not researched the available options for finishing,
- Specified it poorly,
- Calculated the budgets and programmes poorly,
- Produced the shotcrete poorly,
- Applied it poorly.

Shotcrete is more than capable of taking its place with most of the other structural retaining options in terms of finish as long as it is correctly specified and supervised. Given the same respect and attention to detail as competing options, shotcrete is at least as good as a final finish.

A greater understanding, awareness and recognition will be achieved with the completion of more examples of projects incorporating quality shotcrete finishes. Those that have continued to consider shotcrete in these instances should be applauded whilst the culprits will hopefully be purged from the industry. In the absence of any Australian standards for shotcreting the Australian Shotcrete Society's "Shotcreting in Australia" (2008) is a vital tool both locally and internationally and essential to any interested party.

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