GUIDELINES FOR

THE REPAIR AND/OR REPLACEMENT OF

CONCRETE LINED IRRIGATION CHANNELS

SPRAYED CONCRETE

1 Overview

Sprayed concrete is a mixture of cement, aggregate, and water, conveyed through a hose and projected at high velocity from a nozzle onto the work surface to produce a dense homogenous mass. It may contain admixtures and reinforcing fibres and can be sprayed around reinforcing bars. It requires a gang of skilled men, some sophisticated machinery, compressed air in fairly large quantities, and about twice as much cement as ordinary concrete. Sprayed concrete in which the maximum aggregate size is less than 10mm is termed gunite, and when the maximum aggregate is 10mm or greater it is called shotcrete; although these terms are often interchanged.

Some advantages are its ease of application in situ, flexibility, control, strength, and savings in formwork. It can be applied over very irregular subgrade with little or no subgrade preparation, and by following the subgrade profile can reduce the quantity of material used. It has been noted suggested that channels lined with sprayed concrete are more visually appealing than exposed geomembranes [7].

Sprayed concrete can be placed either by dry mix or wet mix process. (Refer to Section A1.2 of the Specification for “Shotcrete” for definitions of the application processes). Both processes can produce satisfactory results however wet mix spraying may produce lower density and durability and greater shrinkage than dry mix. After spraying the surface of the sprayed concrete is rough. This may increase flow resistance, trap silt, and make cleaning difficult. The surface may however be screeded and trowelled to produce a smoother surface. Too smooth a surface would be undesirable as it could become slippery when wet making it difficult for people and animals to get out. A broomed or wood float finish would be desirable.

Reinforced concrete has a greater capacity to withstand loads from shrinkage, temperature effects, ground movements, and traffic. Any cracks which form can be held closed with properly designed reinforcement, and joint spacings can be increased. Reinforcement can be provided as steel reinforcing bars, steel fibres, or plastic fibres and the amount of reinforcement should be calculated in accordance with applicable codes. In the USA concrete reinforced with bars is only used in special conditions [9].

Sprayed concrete can also be applied over geomembrane linings to prevent flotation and protect them from damage due to solar radiation, animals, vandals, and the equipment used during channel cleaning. An option using a geomembrane with sprayed concrete on the side batters only has been tried but found to be unsatisfactory [7].

2 Issues to be Considered

2.1 Structural Performance

The concrete lining must resist all applied loads without developing excessive cracking, break up of the lining, or excessive joints movement. Loads that are likely to occur as a result of shrinkage stresses, temperature induced stresses, ground movements, and maintenance traffic. If concrete is to be sprayed over the existing lining cracks might reflect through the new work unless measures are taken to prevent it, eg. by using an unbonded overlay.

In plain (unreinforced) concrete, shrinkage and thermal stresses can be controlled by providing control joints at reasonably close intervals, although in stable soils consideration can be given to omitting all joints and allowing the concrete to form fine cracks. Plain concrete channels have proven to be poor at resisting ground movements and should not be used in problem soils.

Fibre reinforced concrete for structural applications is usually reinforced with steel or plastic fibres. Glass and other fibres are rarely used in these applications. Fibre reinforcement is added to the sprayed concrete mix and is uniformly distributed through the finished concrete. Fibre reinforced concrete for channel lining will generally not provide a watertight lining, although the fibres improve various properties of the sprayed concrete giving improved results.

Steel fibres provide greatly improved ductility and toughness and abrasion resistance. This allows the lining to tolerate some ground movement and resist impact and traffic damage. The fibres making it difficult to dislodge individual blocks by bridging small cracks. The linings in [6] used 30kg/m^3 and 15kg/m^3 of steel fibres and results were satisfactory up to the year 5 durability report [7]. This was for stable soil conditions and higher rates may be required where it is necessary to resist ground movements. Toughness as measured by the ASTM C1018 test appears to increase significantly up to 60kg/m^3.

Steel fibre reinforced sprayed concrete requires the use of microsilica and admixtures in order to cancel the effects of fibres on pumping and spraying. Furthermore it is important that the bonding between steel and concrete matrix is optimal, and this is achieved by the addition of microsilica and with a maximum aggregate size of 10mm.

Fibre reinforced concrete can also be reinforced with plastic fibres, generally collated fibrillated polypropylene (CFP). This reduces plastic shrinkage and settlement cracking but has limited effect on cracking due to drying shrinkage or temperature variations. Abrasion and impact resistance is improved. In addition the mixes are easier to pump, and there is less sag and rebound. The linings in [6] used 0.9kg/m^3 and 1.8kg/m^3 of CFP fibres and results were satisfactory up to the year 5 durability report [7]. These trials were conducted on stable soil conditions. Higher rates or CFP fibres may be required where it is necessary to resist ground movements.

Plain and fibre reinforced sprayed concrete linings 50 mm thick can be used over smooth foundations or over rough surfaces the thickness should be increased to 75mm or more. Irregular shotcrete thickness is not in itself detrimental but it increases the chance of thin spots needing repair in the future. [6]

In conventionally reinforced concrete, using bars or welded wire mesh, any cracks that form will usually be held tightly together by the reinforcing. Regular joints should be provided to relieve shrinkage strains. The reinforcement also provides higher deformation capacity to accommodate ground movements.

Steel reinforcing bars should be detailed to provide minimal interference when placing concrete. Heavy concentrations of reinforcement or large bar sizes can increase rebound and lead to voids or rebound inclusions. The normal maximum bar size is 16mm, and minimum recommended fabrics wire spacing is 100 x 100 mm. Steel reinforcement is susceptible to corrosion unless protected by concrete of sufficient cover and quality. In order to provide adequate cover, concrete at least 100mm thick is required, even using good quality concrete.

2.2 Durability

The concrete lining should not require major maintenance for the life of the structure, which may be taken to be 40 to 60 years. In this time it should not suffer abrasion in excess of design allowances or detrimental corrosion of any reinforcement. The requirements for sprayed concrete are similar to other concrete.

If conventional reinforced concrete is used sufficient cover and quality of concrete must be provided to protect the reinforcement from corrosion. The appropriate requirements are contained in AS 3735 *Concrete structures for retaining liquids*. The appropriate exposure classifications are listed in Table 4.1, quality requirements in clause 4.3, and required cover in Table 4.2. The required concrete thickness and quality requirements may make reinforced concrete too expensive. Concrete may also be attacked by reaction in silt deposits containing organic matter. This would also require good quality concrete and regular de-silting of the channel.

Steel fibre reinforced concrete made with high quality concrete has shown high resistance to corrosion although some surface marking may occur. Even though fibres extend to the surface there is no evidence to suggest that spalling will occur or that there will be progressive internal penetration of corrosion along the fibres. In 1997 Alan Carse examined a steel fibre reinforced repair to an irrigation channel at Leeton and noted that it was in excellent order after 10 years [11]. The possible effect of silt deposits containing organic matter is unknown but the best protection is probably good quality concrete and regular de-silting of the channel.

It is suggested that the minimum concrete quality should be as for reinforced concrete in the same environment, eg. 32MPa for B1 exposure category.

Plain concrete and concrete reinforced with plastic fibres is not subject to corrosion except for dowels at joints. They may be subject to abrasion, mechanical damage, and attack from water borne chemicals or silt deposits. It is difficult to quantify the effects of these things but it is suggested that the concrete quality should be the same as for reinforced concrete in the same environment, ie. Minimum 32 MPa.

Durability of concrete can be improved by the addition of microsilica which acts as an efficient void filler and reacts with calcium hydroxide formed during hydration to form calcium silica hydrate, adding to the strength and radically altering the pore structures to reduce permeability. This leads to

- improved resistance to chloride ion penetration
- improved sulphate resistance
- alkali silica reaction is suppressed
- improved abrasion resistance
- improved freeze thaw durability
- general resistance to chemical attack by inorganic and organic acids

Superfine fly ash (Kaolite) can be used instead of microsilica. Claimed benefits are that in most areas it provides similar performance to microsilica at a lower cost, and with less demand for water reducing agents. It is also claimed to be is more effective in reducing alkali silica reaction.

Adequate curing is important for durable concrete. The sloping surfaces and large areas can make curing difficult, particularly in remote areas. To ensure full curing and the elimination of micro-cracking resulting from evaporation induced shrinkage it is essential that the surface of the concrete remains moist during the curing period. Recommendations are given in [5].

Liquid membrane curing compounds can be used instead of wet curing and may be an advantage where there is limited water supply or manpower. A white wax emulsion spray is recommended because it reduces heat build up from solar radiation and has high curing efficiency when properly applied. Because uniform coverage is difficult to achieve on the job site, particularly if a nozzle finish is used, application rates may need to be considerably higher than recommended by the manufacturer. White wax, or compounds with a fugitive dye, permit a visual check and more even coverage.

Internal curing agents are also available. These can be added to the mix and are effective from the beginning of cement hydration, eliminating other curing methods, and avoiding such problems as late or inconsistent application of curing.

2.3 Maintain an Adequate Channel Capacity

If a sprayed concrete lining is to be applied over the existing lining, or is thicker than the original lining it may be necessary to check the capacity of the channel. If the flow rate would be reduced to an unacceptable level then it would be necessary to remove the existing lining and possibly excavate further to accommodate the additional thickness. Where the bulk of seepage occurs downwards significant water savings could be achieved at a lower cost by lining the channel bottom only, especially for wide and shallow channels.

2.4 Seepage Control

Where the intention is to reduce, rather than eliminate loss of water, minor cracks in the lining may not be critical. In this case sprayed concrete can be applied over large areas without joints. Typical seepage rates for newly constructed, sprayed concrete liner, 75 to 100 mm thick are reported to be in the order of 0.02 m^3/m^2/day [6]. This is likely to increase over time. Crack widths up to 3mm have been noted in channels lined with sprayed concrete without joints [7], and this may increase with time.

In problem soils such as dispersive soils, highly reactive soils, or soils prone to settlement when saturated, a completely watertight lining will be required. The cost of designing and constructing a watertight concrete lining in accordance with AS 3735 "*Concrete structures for retaining liquids*" may be prohibitive. A better solution would probably be a geomembrane lining with or without a sprayed concrete overlay.

3 Product Applications and Method Details

Sprayed concrete is a versatile repair material. Its use can range from reinstatement of a local wash out, to overlaying existing lining, to full replacement. Things that should be considered in choosing the correct option and to ensure a successful result are outlined below.

3.1 Sprayed Concrete as Replacement Lining or New Work

In considering concrete lining it must be remembered that the lining will crack and leak to some extent. Seepage losses are likely to be an order of magnitude less than for an unlined channel. In most cases, this is adequate to meet design requirements where reduction of seepage loss is the dominant design criteria. The leaks could however cause piping, settlement, or swelling in some soil types, in which case consideration should be given to using a geomembrane lining, with or without concrete protection.

In the Deschutes canal project little difference was noted in the performance of sprayed concrete linings with different types and amounts of reinforcement. In general however it could be expected that crack spacing and crack width will increase with increasing tensile strength in the concrete. This would suggest that concrete strength and reinforcement be kept to a minimum consistent with durability and structural requirements in order to reduce seepage losses overall.

Plain concrete is brittle with little tensile strength or ductility. It is prone to cracking due to plastic and drying shrinkage and soil movements or impact. Because of its limited capacity to tolerate soil movement or loss of support plain concrete should only be used over stable foundations.

Structurally, plastic fibres are resistant and durable in the concrete environment, yet their mechanical properties are similar to those of concrete and cannot improve them. However where only reinforcement against shrinkage, and especially plastic shrinkage is required, plastic fibres are well suited. They do provide other benefits in sprayed concrete. Benefits of polypropylene fibres :

- reduced rebound and material waste
- reduced sag and scatter on slopes
- improved resistance to spalling, impact, and thermal shock
- some post crack strength
- reduced plastic shrinkage cracking
- reduced permeability
- increased fatigue resistance
- chemically inert and corrosion proof
- easier to pump, with reduced segregation and improved homogeneity

The minimum dosage rate to achieve significant benefits is approximately 0.9kg/m^3. Because plastic fibre reinforcement has very little effect on the structural properties it should be used in similar situations to plain concrete. That is, over stable soils where soil movement or loss of support is unlikely.

Modern steel fibres can greatly increase the fracture energy and ductility of unreinforced concrete. This means a steel fibre reinforced layer may crack and deform and still have capacity left. In some cases its performance is better than wire mesh reinforcement.

Benefits of steel fibres include

- reduced rebound and material waste
- reduced sag and scatter on slopes
- improved resistance to spalling, impact, and thermal shock
- improved toughness ($I_{20} \simeq 10$), often superior to conventionally reinforced concrete
- reduced plastic shrinkage cracking
- increased fatigue resistance
- good corrosion resistance of embedded fibres
- reduced segregation and improved homogeneity

The Deschutes canal project used sections with 30kg/m^3 and 15kg/m^3 with both section performing satisfactorily; as did the unreinforced sections. However where ductility is required, a higher application rate of 40-60kg/m^3 may be appropriate.

For cost reasons the lining thickness should be minimised. The practical minimum as noted above is about 50mm over reasonably smooth surfaces. Thickness may need to be increased over rough surfaces, or to accommodate traffic, or soil conditions.

3.2 Sprayed Concrete as Geomembrane Protection

Where sprayed concrete is used as a protective lining over a geomembrane it must be remembered that the geomembrane provides no structural support, although it may reduce loads by reducing soil movements due to seepage losses. Soil movement can still occur as a result of other environmental changes. The choice of reinforcing, if required, will still depend largely on the size of the channel and soil conditions.

An advantage of this construction method is that geomembranes that would otherwise be unsuitable, due to risk of physical damage or sensitivity to solar radiation, can be used.

The Deschutes canal project trialed geomembranes with concrete protection on the side slopes only but this was found unsatisfactory due to formation of 'whales' in the bed and these trial sections were abandoned. Consequently any concrete lining should extend for the full width of the channel, with a minimum thickness of 50mm.

There is potential for increased plastic cracking because the underside of the concrete cannot lose water to the soil and will remain wet while the surface dries. This can be countered by careful attention to finishing and curing, and by the addition of fibre reinforcement.

3.3 Sprayed Concrete as an Overlay

If it is intended to use sprayed concrete as an overlay to existing concrete lining the cause of the original failure should be determined first to avoid failure from the same cause. Generally an overlay would be considered where there is extensive cracking in the existing lining. In which case an unbonded overlay would be preferred to reduce reflective cracking.

Debonding can be achieved by a thin layer of fine crushed rock or by a sheet material. If a sheet material is used this can be used as a geomembrane lining with the sprayed concrete providing a protective surface.

The bond breaking course can also serve as a levelling course, in which case a sprayed concrete thickness of 50mm could be used. Where the surface is irregular a greater thickness will be required but a maximum of 75mm should be sufficient in most cases. A thickness of 75mm was used in the Deschutes canal project over a very rough surface.

A thickness of less than 50mm is prone to excessive cracking based on experience in the Deschutes canal project where lining was tapered to 25mm thick over geomembrane anchorage trenches. The maximum aggregate size should not be more than 1/3 of the sprayed concrete thickness.

The use of steel fibre reinforcement should reduce the severity of reflective cracking by bridging the cracks and providing improved ductility. Long fibres and high dosage rates improve ductility. Dosage rates in the range of 40-60kg/m^3 may be appropriate in this situation.

3.4 Sprayed Concrete as a Patch Repair

In this application dry mix sprayed concrete may be superior to wet mix, although wet mix can produce satisfactory work and the choice of method is more likely to depend on the plant available. Because of establishment costs it may not be economic to use sprayed concrete for patch repair unless it is part of a larger project. Hand applied repair mortar may be a better option.

Unsound material in the repair area should be removed and there should be no offsets in the cavity that would cause an abrupt change in the thickness of the repair, and any square shoulders should be tapered. Significant cracks should be repaired and sealed. If the original concrete is reinforced, care should be taken to not disturb the bond between existing sound concrete and reinforcing steel, and all exposed reinforcement should be clean.

3.5 When to Use What

Plain concrete is suitable for small channels in stable soils. The maximum channel width should be no more than 4 - 5 metres to reduce the risk of longitudinal cracking. Even for small channels consideration should be given to using CFP reinforcement. In addition to reduced plastic shrinkage cracking the reduction in rebound may justify the additional cost of the fibres.

Plastic fibre reinforced concrete is suitable for larger channels in stable soils or to reduce plastic shrinkage cracking and provide additional abrasion or impact resistance. Longitudinal shrinkage cracking may develop in channels wider than 5 metres. A typical reinforcement rates for CFP is 0.9kg/m^3 will cost an additional \$20/m^3.

Steel fibre reinforced concrete should be used for channels in unstable soils to accommodate soil movement or loss of support. Steel fibre reinforced concrete is more resistant to shrinkage cracking than plain concrete. Based on pavement practice the risk of longitudinal shrinkage cracking should be small for a channel width up to 10 metres. Typical reinforcement rates are 40 - 60 kg/ m^3. Additional cost would be about \$65-70 / m^3 at 40kg/ m^3 (1998 costs).

There is no clear demarcation between stable and unstable soils. In intermediate soils, specialist advice should be sought. It is suggested that as a minimum CFP reinforcement be used and consideration be given to using steel fibres for larger widths and more unstable soils.

Unless frequent joints are used and careful attention is paid to detailing, concrete linings will leak. Transverse cracks can be expected to form at frequent intervals and the cost of preventing this is likely to be prohibitive. Geomembrane lining with sprayed concrete protection should be used where even minor seepage from the channel may cause problems.

Where construction or maintenance traffic will use the channel invert the concrete thickness in the invert should be sufficient to support the traffic, otherwise a minimum concrete thickness of 50mm should be used. Since un-dowelled cracks can be expected to form at random locations the concrete thickness should be uniform and based on loading at a free edge. Both the amount of traffic and wheel loads would normally be much less than for road pavements and hence thickness can be less, however a minimum thickness of 75mm is recommended.

3.6 Cost Comparisons

The best comparison of channel lining costs is contained in [6]. The different linings were all done at approximately the same time on continuous sections of the same channel and are an indication of relative costs. The cost of fibre reinforcing appears to be more expensive in Australia.

Deschutes Canal
Lining Demonstration Project

District	Section	Description	Installed Cost/m^2	Cost Relative to 3" shotcrete	4-5 year condition	Comments
Arnold	A-1	Petromat MBII with 3 inch shotcrete cover				
		Unreinforced shotcrete	$2.06	1.55	Excellent	No problems
		1.5 lbs/cubic yard (0.9 kg/cubic metre) polyfibre	$2.12	1.59	Excellent	No problems
	A-2	30-mil VLDPE textured geomembrane with 3 inch unreinforced shotcrete cover and 16 oz geotextile membrane	$2.14	1.61	Excellent	No problems
	A-3	80 mil HDPE textured geomembrane	$1.38	1.04	Very good	Several small tears and cuts
	A-4	Geolam with 6 oz geotextile cushion	$1.05	0.79	Very good	Several small tears and cuts
	A-5	45 mil Hypalon with 16 oz geotextile cushion	$1.11	0.83	Very good	Several small tears and cuts
	A-6	TerraTuff (36 mil Hypalon/8 oz geotextile)	$1.03	0.77	Very good	Several small tears and cuts
	A-7	40 mil PVC with 3 inch grout filled matress	$2.36	1.77	Excellent	No problems
	A-8	3 inch unreinforced grout filled matress	$1.86	1.40	Excellent	No problems
	A-9&A-10	60 mil VLDPE or HDPE with 12 oz geotextile cushion and 3inch grout filled matress on side slopes only	$1.79	1.35	Removed from study after 28 months	Linear "whales" were impeding flow
North Unit	N-1	Spray applied Polyurethane foam base with Urethane 500/550 protective coating	$4.33	3.26	Partially failed 50%	Partial foam wash out
	N-2	Spray applied Polyurethane foam base with Geothane 5020 protective coating	$3.92	2.95	Partially failed 30%	Partial foam wash out
	N-3	Tietex geotextile with spray applied Geothane 5020 protective coating	$2.64	1.98	Failed	Complete failure
	N-4	Phillips geotextile with spray applied Geothane 5020 protective coating	$2.64	1.98	Failed	Complete failure
	N-6	3 inch steel fibre reinforced shotcrete				
		50 lbs/cubic yard (30 kg/cubic metre)	$1.59	1.20	Excellent	No problems
		25 lbs/cubic yard (15 kg/cubic metre)	$1.44	1.08	Excellent	No problems
	N-7	3 inch Phillips Polyfibre reinforced shotcrete				
		3 lbs/cubic yard (1.8 kg/cubic metre)	$1.47	1.11	Excellent	No problems
		1.5 lbs/cubic yard (0.9 kg/cubic metre)	$1.39	1.05	Excellent	No problems
	N-8	3 inch Fibremesh Harbourite reinforced shotcrete				
		3 lbs/cubic yard (1.8 kg/cubic metre)	$1.47	1.11	Excellent	No problems
		1.5 lbs/cubic yard (0.9 kg/cubic metre)	$1.39	1.05	Excellent	No problems
	N-9	3 inch unreinforced shotcrete	$1.33	1.00	Excellent	No problems

4 Installation Considerations

4.1 Preparation

Surfaces to be sprayed should be trimmed and graded. Soil surfaces must be sufficiently cohesive to prevent erosion when the sprayed concrete is applied and prior treatment may be necessary to achieve this. All surfaces should be damp at the time of spraying, except smooth surfaced geomembranes.

4.2 Joints

In stable soils where movement joints are not used the only joints would be construction joints. Unformed joints are not recommended, as they are prone to poor compaction, spalling, and shrinkage. Preferred joint types are a screed joint, stop-end joint, or cut back joint. [1,p28]

Unless the intention is to produce watertight concrete the only joints would be construction joints. Joint sealants, water stops, and dowels could be omitted, reducing construction and maintenance costs, and removing a potential failure area.

If joints are dowelled or sealed they should be designed and detailed as for conventional concrete. Internal water stops are not recommended for sprayed concrete because they provide traps for rebound. Backstop type of water stops would be suitable for sprayed concrete but must be fixed firmly in position to prevent displacement during spraying.

4.3 Finishing

A nozzle finish can be acceptable in many cases and will provide the cheapest alternative in finishes. Virtually any finish that can be applied to conventional concrete can be applied to sprayed concrete. It is prudent to specify as simple a finish as possible, keeping in mind the serviceability and aesthetic requirements of the project. A broomed, wood float, or brush finish will smooth the coarse texture of the natural gun finish without making the surface too slippery when wet.

The finished sprayed concrete layer is generally built up slightly beyond the alignment devices and then cut back once it has started to stiffen. This requires some skill and the tolerance for sprayed concrete is commonly greater than for conventional concrete. It is bad practice to trowel too heavily as this disturbs the essential compaction of the concrete and may reduce durability.

In rapid drying conditions such as high temperatures, low humidity, and high winds, the application of an evaporation retardant such as a aliphatic alcohol may be necessary to enable finishing to acceptable levels. These are not curing agents.

4.4 Adverse Weather Conditions

The time of year available for repairs to irrigation channels may be limited to periods when demand for water is low and when weather conditions are less than ideal.

Spraying should not take place when temperatures are close to freezing or on to frozen surfaces, or at high temperatures (above 32°C) or on to hot surfaces. Working hours should be chosen in favourable times of the day.

Wind can disrupt spraying and if there is likelihood of even moderate wind, provision should be made to screen the nozzle, the jet, and the surface to prevent cement and fines from being blown out. Wind can also promote cracking by rapidly drying the surface of the fresh concrete.

Rain falling on freshly sprayed concrete may cause it to slip and will at least reduce the final surface strength and durability.

5 Summary and Recommendations

Sprayed concrete can provide an economical and durable lining for irrigation channels. Assessment should be made of exposure condition and foundation type to choose appropriate concrete quality and reinforcement. Prevention of all cracks is probably uneconomic and in problem soils a geomembrane under the sprayed concrete should be considered.

6 References

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