# Concrete Lined Irrigation Channels
# New Concrete Linings

## 1 Overview

If a concrete-lined channel becomes badly deteriorated, but is still vital to the system as a whole, then it is likely that a new concrete lining will become the best option when considering repairs or replacement.

Although there are other possible ways of lining a channel, this section focuses on concrete, for all the reasons that made a concrete lining the option of choice in the first place. Concrete linings are tough, durable, relatively impermeable and hydraulically efficient.

Concrete linings constitute one type in which the benefits can sometimes demonstrably justify the cost. Properly designed, constructed and maintained concrete linings should have an average service life of over 40 years. If chemical attack and the development of cracks can be checked or do not occur, the lining may last indefinitely.

There are several methods for forming new concrete channel linings; each will be discussed, including the quite attractive option of constructing a concrete lining over a plastic membrane to obtain the benefits of each while minimising the drawbacks. This way, the toughness and durability of the concrete are obtained, while the membrane ensures zero permeability, even when the concrete cracks, and the membrane is protected from accidental damage and UV degradation.

A test section of the Coachella Canal in California was even lined this way without dewatering it. A PVC membrane was placed in the canal and covered by a slipformed concrete layer, all work being carried out under water.

## 2 Issues to be Considered

An important factor in the success or otherwise of concrete linings is ensuring that the lining has a good foundation. Lack of attention to foundation details are one of the fundamental reasons why concrete lining systems fail. All sinkholes and voids under the proposed concrete lining need to be filled in with appropriate material. It may be necessary to regrade the channel batters where the sub-base material has been washed out by the action of water through holes in the original lining. Whenever re-preparing the foundation for the new concrete lining it is essential that all highly plastic material (ie. clay ) is removed and replaced with a granular free-draining material.

A successful concrete lining must be durable and remain substantially watertight, to give many years of low-maintenance service life. In order to achieve this, cracks must develop only where they are catered for – in the deliberate joints, which must be sealed.

If the lining can be kept free of random cracking, leakage will be minimised and so will consequent damage such as loss of support from the foundation soils.

If the old concrete lining is badly broken up, undermined, etc, it would be foolish to install an identical lining once more. First, the sequence of events in the deterioration of the old lining must be deduced. The causes of failure of concrete linings are discussed in detail elsewhere in this document. Please refer to the paper on "Causes of Failure" for more information. The new lining can then be designed and detailed to overcome the original problems.

If gross soil movement is the main problem, then a concrete lining may not be the best solution, unless it is equipped with an external membrane to control leakage.

Concrete linings need to be fairly robust, yet as economical as possible. A lining thickness of 75 – 100 mm seems to be the optimum for economic construction with good service life, depending on channel size. Usually steel reinforcement is added to the lining, but this increases the cost, so the function of such reinforcement should be understood first.

Steel reinforcement alone will not guarantee the structural integrity of the concrete lining. This is especially the case if foundation settlement issues as referred to previously in this section, have not been adequately addressed prior to placement of the concrete lining. The addition of steel reinforcement to concrete linings will however control crack widths to serviceable limits. The question then remains as to how much steel reinforcement to include in the concrete lining. Excessive amounts of steel reinforcement will significantly increase the cost of concrete linings for little additional gain in the integrity of the lining. Experience in irrigation areas in Australia, including the Murrumbidgee Irrigation Area, has shown that the best results in replacing concrete lined channels are achieved when minimum steel reinforcement is added to new concrete linings. This minimum steel reinforcement should cater for shrinkage and temperature effects.

# 3 Option for forming New Linings

This section discusses various practical ways of obtaining a new concrete liner to a channel. It is assumed in each case that the old lining has been demolished and the foundation soils properly prepared.

Preparation should include filling all voids with suitable compacted material, ensuring adequate compaction of the rest of the foundation, trimming the foundation to correct shape and wetting the soils before pouring concrete. Pre-wetting of the soils ensures that they do not absorb excessive water from the concrete immediately on contact.

Since all concrete shrinks after hardening, joints will be required in all concrete liners to restrict cracking to known lines which can easily be sealed. Guidelines for joint spacing are quoted in the 'general' section and sealing is discussed elsewhere.

## 3.1 Manually Placed Concrete

For typical trapezoidal channels, work proceeds between longitudinal guide boards fixed along the top of the embankment at each side of the channel. These boards must be carefully aligned, levelled and fastened in place.

Concreting is carried out on alternate sections, each section being the length between joints. The concrete is spread and compacted, working from the base upwards, and screeded off between profiles, one at each end of the section, resting on the guide boards.

Some form of vibrating screed is normally employed for larger areas. Such screeds need to be of sufficient weight to avoid floating on the concrete being screeded. Lengths of heavy gauge sheet piling fitted with air driven vibrators have proved a suitable device. Mechanical lifting and winching is necessary with such a device.

Thus the edges of the concrete are formed by the guide boards along the top and by the profiles at the ends, the surfaces in between being formed by screeding off and then smoothing with wooden floats. It is unlikely that any benefits from steel trowelling would offset the extra cost involved.

When the sections of channel formed in this manner have hardened, the sections in between them are concreted in the same way, except that the previously-placed concrete is now used to guide the screeds, rather than the profiles used initially.

Sealant grooves can be formed where the sections butt against each other by placing rectangular timber fillets in the surface of the concrete. In the case of large channels, similar joints will be required between the base and the sides, which will be poured as separate panels. Consideration can also be given to the use of externally placed waterstops, which are laid on the foundation soils along the joint lines before the concrete is placed. Tee shaped water stops can also be incorporated into the guide boards, but experience has shown that vibration of the concrete around the water stop becomes very critical.

If forming large rectangular channels in suitable (non-expansive) soils, the sides can be made vertical and poured against conventional formwork. In this case, the concrete should be at least 100 mm thick, partly for robustness and partly so that there is sufficient room to compact the concrete with an immersion (poker) vibrator.

## 3.2 Precast Concrete Channel Sections

(NB. Precast concrete channel sections are covered in detail in a separate topic. Please refer to the Case Study on “Box Flumes” for more information).

Some irrigation authorities have had success with the use of precast channel sections for smaller U-shaped channel profiles. These are made in a precasting yard and incorporate externally placed waterstops at each end.

In use, the precast sections are placed as alternate sections on the channel foundation, and then the missing sections between them are formed in situ, using the precast sections as screed guides.

## 3.3 Slipformed Concrete

In this process, a channel-shaped steel form is winched along the line of the channel, either sliding along on the foundation soils or running on rails fixed along the embankments at either side. Slipforms can also be self-propelled, running on a pathway on top of each embankment.

A constant supply of low-slump concrete is fed into a hopper on the slipform, which is kept moving slowly but continuously. The concrete is compacted by vibrators as it moves through the form and is screeded to profile by the shaped back edge of the machine.

It is common for one or more personnel to ride on the back edge of the slipform, using trowels or floats to correct any blemishes in the extruded concrete surface.

If it is to proceed smoothly and effectively, this technique depends on an abundant supply of concrete with consistent properties. Such a supply is best furnished by a local pre-mixed concrete batch plant and delivered in agitator trucks.

Slipforms are expensive to construct, so long runs of channel are required to justify their cost. The expense could, however, be minimised by utilising any existing machinery or by standardising channel profiles and sharing slipforms between irrigation regions.

## 3.4 Sprayed Concrete

(NB. Sprayed Concrete is covered in detail in a separate topic. Please refer to the Guidelines for "Shotcrete" for more information).

Sprayed concrete (gunite if using aggregates smaller than 10 mm, shotcrete if using larger ones) has a long history of use throughout the world. Once in place, sprayed concrete is just concrete, with all the same beneficial attributes and all the same shrinkage characteristics.

Sprayed concrete must, therefore, be detailed with joints at regular intervals to control cracking,

Although conventional pumpable concretes can be sprayed (wet-mix process), better results are generally obtained from the dry-mix process. In the latter case, the dry ingredients are mixed and then propelled by compressed air, the water being added at the spray nozzle under direct control of the nozzleman. This requires skilled and experienced personnel, but produces dense concrete with less shrinkage and better durability than the wet-mix process.

The application of sprayed concrete involves spraying the material directly against the foundation soils without disrupting them, and then building up the required thickness of lining by repeated passes of the nozzle in a regular pattern.

The final shape and thickness are determined by screed boards and/or tensioned wires acting as guides for the operators. The concrete surface can then either be left as sprayed or smoothed off by wooden floats. Joints can be formed by the inclusion of suitable timber fillets or by tooling grooves into the surface.

## 3.5 Grout Injected Mattress

Used extensively worldwide for erosion control and similar works, grout injected mattresses consist of two layers of a woven or punched geotextile fabric, connected together at regular intervals. When a cementitious grout is pumped into the space between the layers of fabric, the result is a concrete-filled 'quilt' of some 75 mm thickness.

The preferred choice for water-retaining applications is a mattress with a uniform cross section rather than one with pressure relief holes through it. Both types have a long history of application in civil engineering.

Joints are still advised in this system, although at approximately twice the spacing recommended for plain concrete. Drying shrinkage is minimised, as a lot of water escapes through the weave of the fabric during filling, leaving quite a dry mortar mix in the mattress.

## 3.6 Plastic Membrane with Concrete Liner

(NB. Flexible membranes are covered in detail in a separate topic. Please refer to the "Geomembranes" topic page within this document for more information).

The US Department of the Interior, Bureau of Reclamation, have had considerable success with some test sections of channel which were lined with plastic membranes, the membranes then being covered with concrete.

The membranes used in different trial sections were polyethylene and PVC, the covering concrete formed by spraying and by using grout injected mattresses.

This approach has the benefit of total seepage control by virtue of the membranes, despite cracks forming in the concrete. The membranes, in turn, are protected from UV and accidental damage by the concrete layer. On well-prepared soft soils, it is possible to use a thinner membrane than would be required for exposed applications.

The five-year performance reports on these tests indicate that all the sections where the membrane was totally covered with concrete are in excellent condition and not subject to seepage losses.

No difficulties were reported with applying the concrete over the membranes by either method, although the membranes were apparently rather slippery to walk on. The shallow side slopes on most channels make the application of even sprayed concrete feasible without slumping, provided it is applied from the bottom up.

# 4 Installation Considerations

The installation considerations for each of the lining methods, listed below, are important if success is to be achieved with the lining project. It would be foolish to ignore or skimp any aspect of good concreting practice, as even a partial failure can incur great cost penalties and shorten the life of the lining considerably.

One procedure which is common to all the concrete solutions is good curing. This entails keeping the concrete moist for at least a week after it has set, in order for it to achieve its maximum potential strength and impermeability.

Good curing can be effected by covering the work with hessian and then keeping the hessian wet (with soaker hoses or similar), by covering the concrete with plastic sheeting, or by spraying a film-forming curing membrane over the concrete surface.

Filling the channel with water would also work, but is unlikely to be a practical option, since it would have to be emptied again for joint sealing. Early filling could also cause cracking in the green concrete if there was any ‘give’ in the supporting soils.

## 4.1 Manually Placed Concrete

Success with manually placed concrete depends on good formwork or guides, the right concrete for the job, and sufficient labour to handle the work.

Guide rails or boards must be set up carefully and fixed securely in place, for the line and level of the whole channel depends on them. The channel shape profiles which will be suspended from the guides and used as screed rails must also be accurate and robust enough to be used repeatedly without distortion or collapse.

The concrete used for this work can be a normal grade, but must be stiff enough to stay on the side slopes without sagging. This should be possible with a typical concrete of about 80 slump, but water must not be added to it for better workability on delivery. Air entrainment can aid workability without diluting the concrete and is recommended. Concretes with flyash as part of the cement content are also good in this regard (and will have enhanced resistance to chemical attack) but are even more dependent on a good curing regime for their final strength.

The other prime requirement for success is a sufficient labour supply to place, compact and screed off the concrete before it starts to set (this can mean the use of extra labour in warmer weather). The concrete can then be compacted well in place, working from the channel base towards the tops of the sides. For the relatively thin concrete sections employed in channel linings, adequate compaction can be obtained by working the concrete well as it is spaded and trampled into place, expelling as much air as possible. For larger areas, screeding and mechanical vibration becomes necessary.

## 4.2 Precast Concrete Channel Sections

(NB. Precast concrete channel sections are covered in detail in a separate topic. Please refer to the Case Study on “Box Flumes” for more information).

The precast elements of this option will be formed in factory-type conditions, preferably using steel moulds and a high-strength concrete, as is normal precasting practice. They should then be cured and stored for some months so that shrinkage occurs before use, minimising shrinkage in the channel.

The in-situ sections between precast units will be formed in the field, using techniques similar to the manually placed option, except that some form of mould will have to be employed to match the U-shape of the precast units. This will necessitate the use of vibrators to compact the concrete.

Care must also be taken, both at the precasting stage and in the field, to ensure that the waterstops are placed correctly and that the concrete is worked well into and around their ribs.

## 4.3 Slipformed Concrete

Success in slipforming concrete depends very much on thorough and accurate preparation of the formation soils to line, level and profile. Depending on the type of slipform used, some form of guidance system, either rails or wires, must also be accurately prepared.

Given thorough preparation, the next requisite is an adequate supply of suitable concrete to the slipform. The concrete must have sufficient workability to enable spreading and compaction by the machine in use, but be stiff enough to remain in place without distortion as the machine moves on. If it is too stiff, the concrete surface can also tear as the machine extrudes it.

The best concrete mix and most appropriate slump for a given slipform machine are best found by trial and error, so a test section at the outset is a good idea. Experienced operators are invaluable with this concrete placing method.

The concrete supply must also be capable of keeping the slipform fed at a rate consistent with smooth operation and steady progress. Such a supply will normally entail the use of pre-mixed concrete supplies, either from commercial batch plants or from a dedicated mobile batch plant on a large project.

## 4.4 Sprayed Concrete

(NB. Sprayed Concrete is covered in detail in a separate topic. Please refer to the Guidelines for “Shotcrete” for more information).

In order for the application of sprayed concrete to be successful, the foundation soil must be sufficiently cohesive to prevent erosion when the spray is applied. If necessary, the soils should be well compacted and dampened in order to achieve this condition.

Correct build-up of the required lining thickness is then a result of operator skill, familiarity with the equipment in use and intelligent use of guiding devices such as tensioned wires and profile boards.

The concrete mix is sprayed onto the work face in an overlapping pattern to achieve an even thickness, keeping the nozzle nearly perpendicular to the surface being sprayed, at a distance of 600 to 1200 mm.

A slight angle at the nozzle is required, so that rebound is always directed onto finished work, from where it can be removed. To this end, the channel base should be sprayed first, then the sides, working from the bottom up.

## 4.5 Grout Injected Mattress

Although the placement of a grout injected mattress can tolerate less rigorous foundation preparation than placed concrete, the smoother and more even the foundation, the easier and neater the job.

The mattresses can then be laid out over the channel profile and joined together with zips, welds or sewn seams, depending on type and manufacture. They must then be anchored temporarily in place, allowing for the fact that the mattresses tend to tighten and shrink as they are filled.

For durability, the mattresses must be anchored into the ground at upstream and downstream ends. This is accomplished by turning them down into trenches dug across the channel and up the sides, then concreting them in place.

The edges of the mattresses along the tops of the channel walls can be similarly anchored, or they can merely be left flat to form an apron along each side of the channel, held in place by their own weight when filled.

Successful mattress filling depends on a continuous supply of grout being available at the pump(s), so the operation must be organised with sufficient labour, materials or mixing facilities. Pre-mixed concrete suppliers can also be employed to mix and deliver the grout in quantity.

### 4.6 Plastic Membrane with Concrete Liner

(NB. Flexible membranes are covered in detail in a separate topic. Please refer to the “Geomembranes” topic page within this document for more information).

There are no specific requirements for this system which have not already been covered elsewhere, although skill and care are sometimes needed to avoid slumping of the concrete on the side slopes of the channel before it has hardened.

## 5 Summary and Recommendations

All of the concrete lining options described have merit and all will give good service if executed correctly. All have been implemented, in Australia and overseas, with excellent results.

The choice of one option over another will depend on a blend of economics and practicality, tempered by consideration of the foundation soils and their past behaviour under concrete channel linings.

The labour-intensive nature of some of the work, such as manual placing, will often mitigate against it economically, making more material-intensive options such as grout injected mattresses more competitive. The long-term durability of the latter system is, however, not yet known, although it seems promising at present.

## 6 References

‘Deschutes – Canal-Lining Demonstration Project: Construction Report’
Report R-94-06, US Department of the Interior, Bureau of Reclamation, May 1994.

‘Deschutes – Canal-Lining Demonstration Project: Year 5 Durability Report’
Report R-97-01, US Department of the Interior, Bureau of Reclamation, January 1997.

‘Recommended Practice: Sprayed Concrete’, Concrete Institute of Australia Publication Z5, February 1987.

Kepler, W.F., ‘Underwater Placement of a Concrete Canal Lining’, Concrete International, June 1990, PPS 54 – 59.

Rohe, F.P., 'Underwater PVC Geomembrane Placement', paper presented at Geosynthetics '91 in Atlanta, GA., February 1991.

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