PRACTICAL STEPS TO MAXIMISE THE VALUE OF YOUR CONCRETE PIPE ASSETS

Andrew DuFresne (AWT New Zealand)

Introduction

My talk to you today is primarily about large diameter spun concrete pipes, generally 900mm diameter and larger. However much of what we cover also applies to smaller diameter pipes. My presentation is predominantly based on a major stormwater pipeline assessment project carried out for Papakura District Council, along with my experience over the last 25 years in assessing wastewater pipeline condition. In the Papakura project AWTNZ assessed a total of 5.5 km of stormwater pipeline CCTV video records and categorised them according to condition and priority for repair, as follows:

- "Immediate" indicated that it was considered the pipe could fail catastrophically at any time, and the recommended rehabilitation works should be accorded urgent priority.
- "High" indicated that work should be carried out within the next 2 or 3 years.
- "Medium" indicated the work should be carried out within the next 4 to 6 years.
- "Low" indicated there is no urgency for the work but it should be carried out in the next 7 to 10 years.

It should be noted that the pipes were a mixture of earthenware, precast concrete and spun concrete, with the majority in large diameter spun concrete. The pipelines had been previously graded in accordance with the Pipe Inspection Manual, 2nd edition, and only pipelines graded as Structural Grade 4 and Grade 5 were assessed.

The results of the assessments are summarised as follows:

Priority for rehabilitation[1]	Length (m)	% of total
Immediate	487.8	8.9%
High	629.3	11.4%
Medium	1067.4	19.4%
Low	3313.9	60.3%
Total	5498.4	100.0%

Note:
1. It should be noted that only a very small percentage of spun concrete pipes were in need of rehabilitation, mostly for reasons that will be discussed later in this paper.

In the course of this project, walk-through inspections were carried out on a number of pipelines where there was visible cracking but there was no other visible evidence to indicate that the pipelines were in urgent need of attention.

However it is not the intention of this paper to discuss the Papakura project per se. Rather, the Papakura project highlighted ways in which spun concrete pipes could be damaged by poor quality design and/or installation, and ways in which visible defects in large diameter concrete pipelines differed in significance from similar defects in, say, earthenware or precast concrete pipelines.

Although spun concrete pipes are inherently very strong and durable they can be subjected to in situ forces capable of inflicting major damage on them.

- Excessive compaction during installation.
- Earthworks, particularly those involving compaction, after installation.

- Increased loading beyond original design loading, particularly as a result of filling operations or embankment construction.

The issues we will cover today include:

- A brief résumé of installation practices.
- The actions that can be taken to ensure your concrete pipelines are not damaged by external forces.
- Assessment of existing concrete pipeline condition.

The objectives of our presentation are twofold.

1. To discuss some general principles involved in managing stormwater assets to perform to the required standard and not fail at critical times, and
2. to highlight procedures to ensure future generations of ratepayers are not made liable for major expenditure as a result of substandard installation or post-installation damage.

Many of the topics I will bring up in my presentation can be found in the CPAA publications, most of which can be downloaded from the web in pdf format at no cost. In particular their publication *Recommended Practice – Installation of Concrete Pipelines* is highly recommended. Their website can be found at http://www.concpipe.asn.au.

I should make it clear that the general issues discussed in this presentation could be expected to apply to any new asset that is to be taken over and maintained by a TLA, and all pipeline materials. However I have concentrated on those aspects that are relevant to concrete pipe installations.

Setting the stage

Most concrete pipes installed in New Zealand will eventually become the property of a TLA and any defective workmanship that is inadvertently accepted will be paid for by ratepayers, who are you and me. From the TLA's aspect the acceptance procedures are paramount, and these will apply to all pipelines which are to be vested in the Council. In other words, not only do they apply to taking over infrastructure installed during a land development project, but also to new or replacement pipes installed by the TLA. Within the acceptance procedures there are numerous processes, starting from initial design, and these will be covered in this presentation.

The expectations of any client contemplating accepting total responsibility for any major asset are normally clearly documented prior to entering into an agreement to take on that responsibility. Without such documentation the client can end up with a "pig in a poke" and may require major resources to rectify a substandard asset. For stormwater pipeline assets it is not sufficient to require specific physical attributes. When it comes to the quality of the pipeline installation, smart, well-designed acceptance procedures are required and should be applied throughout the design, construction and acceptance phases. These requirements apply to any pipeline installation using any material, and some guiding principles include:

- Clearly documented acceptance and rejection criteria which are understood by all parties.
- Clearly documented procedures for all phases of the works, from initial design to final acceptance. From the TLA's perspective these could include approval procedures, documentation to be supplied, filing procedures, testing required and the like.
- A designated person authorised to sign off acceptance documents.
- Procedures to identify proposed works that could overload existing pipelines. These could be expected to include road reconstruction and projects which come within the scope of the Resource Management Act (RMA) (in other words, will be subject to Council approval and hence come to the attention of the TLA), and building projects that could involve earthworks or soil compaction. However it may not be possible to include projects involving earthworks or soil compaction where there are no TLA consents or approvals required.

Quality assurance

No matter how comprehensively a project is specified, if there are no checking procedures to ensure that specifications have been met then they count for very little.

The first and central issue is that it cannot be assumed that the Contractor knows what he is doing. The company may have installed kilometres of pipes, but a good starting point is to assume that this is their first pipe installation. For example:

- The foreman may be new to this kind of work.
- If the foreman has been in the business for a long time he may be continuing substandard practices that nobody has picked him up on before.
- There may be particular design requirements in the tender documents that have not been communicated to the people responsible for the actual installation.

There are all sorts of reasons why things can go wrong, and any single omission could substantially reduce the value of your concrete pipe asset or worse, leave the Territorial Local Authority (TLA) with a huge cost to bring the asset back into serviceable condition.

I would therefore like to briefly discuss aspects of quality assurance procedures that can be applied to ensure the full benefit of installing a concrete pipeline, is achieved. Quality assurance procedures should be designed to ensure the contractor takes responsibility for his own workmanship, and that as far as practicable there is a high level of confidence that the works have been carried out as specified.

1. Current best practice has moved away from the “Clerk of Works” format, where the Client’s representative spent extended hours on the site watching the contractor and intervening if the contractor made a mistake. Project managers for this type of work now go onto site armed with comprehensive checklists and check specific areas of concern. The checklists record what is required of the contractor and are checked off as complying (or not) and in some cases results are recorded.
2. Procedures where there is scope for mistake or omission, should be documented. There is a comprehensive generic checklist in *Recommended Practice - Installation of Steel-Reinforced Concrete Drainage Pipelines*, but site-specific checklists are still advisable.
    - Checklists should be consistent with the specifications applying to the project. A brief description of what is acceptable can be indicated where appropriate. For example in concrete pipelines, the maximum crack width permitted in the completed installation. The required accuracy of installation (horizontal and vertical alignment) will also normally be included in the checklists. A check on pipe rotation (which is discussed later) during site visits is also a useful check on installation practices.
    - Where minimum requirements vary (such as backfilling), checklists can make provision for recording the minimum requirements for the work being checked, and the results achieved by the Contractor.
    - Tick-boxes for checking compliance are useful for ease of use on site.
    - The works that are being checked must be clearly identified on the checklists.
    - All checklists should be signed and dated by the person actually doing the checking.
3. The checklist system should start with a design check and finish with the final CCTV inspection (acceptance video record) and pressure test if required. The design must incorporate temporary loads that may be imposed on the pipeline.
4. The checklists can be created by a specialist or senior engineer but their application can be carried out by graduate engineers and the like. In this way young engineers have an opportunity of applying the experience of senior engineers.
5. Deliverables. These may include the Contractor’s quality assurance documentation. Documentation that is considered crucial to the installation should be specified. This will normally include as-built information but could also include such things as Clegg Hammer readings where compaction is critical, pressure test results, the installation trench width and the like. (Contractors will sometimes seek to reduce costs by installing several assets in a single trench. Trench width is a major design factor and forces on a pipe will be significantly increased if trench width is greater than the design width.)

6. CCTV video records and logsheets of the final pipeline inspection. The timing of the final inspection is important and can be specified. For a land development project the final inspection should be on completion of earthworks and all road sealing, which may be some considerable time after the pipeline has been installed and backfilled. For a major road upgrading project the final inspection should again be on completion of sealing.
7. For concrete pipelines it can useful to have pipe information that is stencilled onto the inner walls of larger diameter pipes, recorded under the CF (Construction Feature) code. This applies particularly to pipe rotation information and also to the Class of the pipe. CCTV operators will normally need to be specifically instructed to do this as it is currently not standard practice.

Where construction or earthmoving works (such as road reconstruction) are proposed over an existing pipeline it is prudent to require CCTV inspections prior to commencement of the works and on completion of the works. In this manner the responsibility for any damage to the pipe as a result of the works can be clearly assigned. However this does not replace the need to check any temporary forces likely to be imposed on the pipe, as a preventative measure.

Design pipe capacity is a separate issue and is not covered in this presentation.

Assessing video records of concrete pipelines

This section covers acceptance video records and video records of existing pipelines for condition rating purposes.

CCTV contractors will generally provide video records of the inspections, and logsheets that record the conditions of the pipelines in accordance with the New Zealand Pipe Inspection Manual (PIM). Using the information in the logsheets as a basis, a preliminary condition assessment of the pipelines can be made to identify defects requiring closer examination.

A major benefit in viewing all video records is that it enables a full quality assurance check of the video records to be carried out. In particular common errors such as not presenting a video record of the full length of the pipeline, mis-recording of ID information and mis-recording of pipeline material (possibly the most common error) can be checked during this process. The video record QA checklist should incorporate confirmation of all the critical records in the logsheet header.

The Class of the concrete pipe and its rotation (ie its position in relation to the design top of the pipe) can sometimes be seen stencilled on the inner pipe wall in larger diameter pipes. This is useful information, particularly when assessing older pipes. There is no specific provision in the PIM for recording such information and it is suggested that CCTV contractors be required to record such information as “Construction Features” (CF) when carrying out CCTV inspections in larger diameter pipelines.

Pipeline condition

Concrete pipe will be either precast (CP) or spun concrete (CS). There may also be poured in situ (CIS) concrete culverts, particularly in older areas. There is a world of difference between the two circular concrete pipe materials. Precast pipes were often made in small factories and it would seem, often under less than ideal conditions. It is understood that many of them were not reinforced and there has been evidence of poor concrete quality in some pipelines. Precast pipes can be identified by their joint spacings, which are normally 0.9m to 1.2m apart. Spun concrete pipes are normally 1.8m or 2.4m joint spacing, although in some areas they have been manufactured in 1.2m lengths.

I should make it clear that the term “precast” as used in this presentation does not refer to a new manufacturing process currently used, I understand, in Hamilton. It involves a precasting process but the quality of the product is fully in compliance with the new Standards. The pipes manufactured by this process are 225mm diameter (2m long) and 300mm to 600mm diameter (2.5m long). All references to spun concrete pipes will therefore also apply to the new precast manufacturing process.

Some TLA's have reported a tendency for older precast pipes to catastrophically fail with little or no warning. In this photograph you can see a typical older precast concrete pipe in severely deteriorated condition. Longitudinal cracking indicates overloading and possibly imminent catastrophic failure. Note how the invert is seriously eroded, which indicates poor quality concrete. There could also have been an upstream discharge of acid, but in this case it was regarded as unlikely.

The reason I have brought up the subject of precast pipes is that they are sometimes mistaken for spun concrete. In general it is good practice to line or replace precast pipes.

On the other hand spun concrete pipes are made to a very high standard and should last in the ground a very long time. There is a common misconception that the life span of a pipeline is about 80 years. However we all know this is a gross simplification. The pipeline in the previous photo was probably good for about 40 years. The following photograph shows a section of concrete conduit built by the Romans. Some of these are still in use.

Frankly I don't think the condition of your concrete pipelines in 2000 years will overly concern me. Modern spun concrete pipes should last 100 years but in my opinion if they are not still in service at least 200 years hence then it is probably because they have not been looked after properly.

I will now concentrate on specific defects that may be evident in video records.

Longitudinal cracks

Longitudinal cracks are recorded as CL on the logsheets. Longitudinal cracks in concrete pipes at the quadrant points (3, 6, 9 and 12 o'clock) are indicative of over-stressing and can be a precursor of severe pipe deformation (DF) or even total collapse. The following photograph shows a severely overstressed spun concrete pipe.

This photograph was taken during laser profiling of a concrete stormwater about 1500mm diameter. The laser light provides an indication of the extent of the deformation of the pipeline.

A brief explanation of laser profiling. This is a new pipeline assessment tool which was developed by a New Zealand company in Albany in North Shore City. A laser light attached to a CCTV camera generates a ring of light which reflects off the pipeline interior wall. A computer programme analyses the difference between the laser light and a pre-set pipe base shape which can take practically any form, including box culverts, egg-shape culverts and circular pipes. The difference between the base shape and the actual interior wall can be measured to within 2-3mm. For a circular pipe its ovality is automatically calculated in accordance with the standard ASTM F1216.

There is a large longitudinal crack in the soffit at 12 o'clock which confirms the pipe has been severely overstressed. The ovality of this pipeline was measured at 9.6% at this point. At this stage it is thought that the overstressing was caused by major earthworks over the pipe. (I would like to point out that the actual laser profiling is carried out with the CCTV camera lights switched off, and the calculations for determining ovality are made with dedicated software off-site.)

The following damage was noted in a 525mm stormwater pipe. Laser profiling was not involved in this case.

This pipe was well within design depth and had no superimposed load. It is assumed that the crack at 12 o'clock and the apparent deformation was caused by temporary earthmoving loads.

Such damage will hopefully be very rare for TLA’s. The cracking that will be most often noted in the video records will be a lot less concerning and is not a sign of structural weakness. It is a sign that the reinforcing steel has taken up the stresses imposed on the concrete. Some typical photos follow:

In both the following photographs cracking in spun concrete pipes has autogenously healed. In other words the concrete has cracked due to tensile stresses imposed on it, and then the reinforcing has taken up the stresses. Changes to the chemical composition of the concrete in the cracking zone have created a matrix of calcium carbonate crystals, which effectively seal the cracks. In the first photograph the autogenous healing shows up as a white deposit in the cracking.

In the second photograph the cracking is a little wider but appears to have autogenously healed. A prudent engineer would confirm this scenario.

Circumferential cracks

Circumferential cracks are recorded as CS on the logsheets. They usually mean just one thing: the pipe has not been properly bedded down. In a stormwater system they are not usually a concern – unless the crack is very wide and a tomo forms or tree roots penetrate – but in a wastewater system severe circumferential cracking (M to L severity) will result in wastewater exfiltration and usually also groundwater infiltration. Due to the reinforcing, circumferential cracking will seldom be wider than S severity. In no case is there a significant structural implication.

Temporary overloading

In the Papakura stormwater assessment project, some pipes showing significant cracking, and even ovality, had very little cover and it was concluded that temporary overloading may have been responsible.

An Australian investigation into temporary construction loads on buried pipelines found that earthmoving and compaction equipment was capable of exerting a force on the ground of up to double a standard (Australian) wheel load of 7 tonnes in a W-7 configuration, and would typically be applied during backfilling, at depth of cover far less than design cover. This research underlies the necessity for not only allowing for temporary loads in design calculations, but more importantly for leaving the acceptance CCTV inspection of new (and existing) buried pipeline assets until all earthworks and road sealing, in the vicinity, is completed.

Acceptability of cracking

There are guidelines for acceptable cracking in spun concrete pipes, in the CPAA online technical publications. In brief they are as follows:

1. Design load crack width. Concrete pipes manufactured in accordance with AS/NZS 4058 should have a crack width not exceeding 0.15mm under design loads. In a normal loading situation such cracking will be longitudinal, generally at the soffit (where it will most commonly be visible), but cracking may also be present at the invert.
2. Crack widths of up to 0.5mm can be acceptable, even in a marine environment. In cracked reinforced concrete, the deterioration process involves oxidation and consequent weakening of the reinforcing steel. However the combination of dense concrete, substantial cover and small diameter steel in spun concrete pipes means that the reinforcing loses very little of its cross section to oxidation.

The New Zealand Pipe Inspection Manual makes provision for assessing crack widths in a CCTV inspection, to reflect their significance in concrete pipe condition assessment, with cracks of up to 0.5mm in width, or wider cracks that have autogenously healed classified as severity “S” cracks. Due to the increasing use of CCTV inspections as a basis for modelling pipeline system renewal requirements, the accurate recording of crack severity where minor cracking is observed is therefore critical.

I would now like to show a table prepared by David Millar. This can be found in the publication *Durability of Reinforced Concrete Pipe – The Hard Facts!* (Table 2), which is available on the CPAA web site.

Table 1: Pipeline Assessment

Defect	Description	Magnitude	Cause	Solution
Type 1	Circumferential crack	Width < 0.15mm	Point loading during handling or installation	Accept installation
	Longitudinal crack	Width < 0.15mm	Pipe uniformly loaded below allowable load	Accept installation
Type 2	Circumferential crack	0.15mm<width<0.5mm	Uneven bedding Excessive construction loading for overlay cover	Accept installation Accept installation
	Longitudinal crack	Width > 0.15mm	Inadequate bedding Excessive live loading Excessive soil dead load Inadequate pipe class for loads and bedding	Assess design Assess design Assess design Assess design
Type 3	Circumferential crack	Width > 0.5mm	Uneven bedding Excessive construction loading for overlay cover	Assess implication of ingress
	Longitudinal crack	Width > 0.15mm	As per Type 2	Assess implication of ingress
Type 4	Chip or spall	Depth < 0.25 x cover	Handling during installation	Accept installation
Type 5 & 6	Chip or spall	Depth > 0.25 x cover	Handling during installation	Assess implication of ingress Repair

However I would like to add a rider to this table. Suppose there is clear evidence of overloading – what then? I would like to suggest a fully pragmatic approach involving engineering investigations and assessment, rather than automatic replacement or structural rehabilitation. The overloading may have been due to temporary construction loading, in which case – so long as crack width is acceptable – a "leave it and see" approach may be most appropriate. The engineering investigations will usually involve a site inspection to determine if there are any long-term conditions that could lead to pipe failure. For example there may have been massive filling over the pipeline, causing soil dead loads far in excess of the design maximum for that class of pipe and bedding. Note that it must not be assumed that the pipe was laid in a trench. It may have been laid in embankment conditions, in which case the design maximum overlay can be significantly reduced.

Engineering investigations may also involve laser profiling to determine whether there is ovality, and if so, how much. If there is ovality in concrete pipe it indicates severe overloading and the pipe will be weaker because of it. Structural concerns then become significant.

If there are any doubts as to the severity of the cracking a walk-through inspection (pipelines 900mm or greater) or a more detailed CCTV inspection may be appropriate.

Unless there is major ovality and a concern about possible pipe collapse, a programme of repeat CCTV and/or profiling inspections every (say) 10-20 years to check for deterioration, will be a lot cheaper than replacement or structural rehabilitation.

When assessing newly laid pipe for acceptance by a TLA, consideration should be given to rejecting any pipelines with a Type 2 or greater longitudinal crack, or a Type 3 or greater circumferential crack. If such pipes are not rejected then they tend to become the new "standard". (See Table 1 above.) If there is a number of Type 2 circumferential cracks, consideration should be given to rejecting the pipeline as poorly constructed bedding may significantly reduce its load-bearing capacity.

Pipe rotation

The stencil “Top of Pipe” can sometimes be seen on the pipe wall in a CCTV video inspection. However if this is not at the exact soffit of the pipe there can be serious structural implications. Anecdotal advice is that for concrete pipes over 600mm diameter, a few degrees out of rotation can reduce strengths by up to 20%. At 90° rotation the reinforcing can have little effect. This is because reinforcing in larger pipes is designed for a fixed pipe rotation.

Cracking caused by incorrect pipe rotation will normally be restricted to individual pipe lengths as it is unlikely that all pipes will have been laid with a similar rotational error. Pipe rotation can be checked by the Project Manager during site visits, or on the acceptance CCTV video record for large diameter pipelines.

Open joints and void formation

It was at one time, quite common practice to lay stormwater pipes with open joints. It is not known if this practice continues. Open joints in stormwater pipelines will present three sets of problems.

1. Tree roots.
2. Voids. Voids typically form around leaks in gravity wastewater and stormwater pipelines. Groundwater moving slowly through drainage paths in the ground, accelerates when it encounters unrestrained movement conditions (such as an open joint) and as it does so, dislodges fine particles of soil and drags them into the pipe. Given suitable conditions voids can be large (in the United Kingdom they are sometimes quantified in units of DDB, or double decker bus), and in the wrong place can be very expensive.
3. Open joints can trap debris such as pieces of timber, which can then trap more debris until a partial blockage occurs.

Open joints are therefore to be avoided.

To summarise

1. Spun concrete pipes are immensely strong and forgiving in a construction situation. However like any other construction material they are not amour-plated and require to be treated properly to maximise their value and longevity.
2. Cracking in concrete pipes – spun and precast – is not necessarily indicative of imminent or future catastrophic failure. Nevertheless the possible causes of cracking should be assessed and it would also be prudent to measure typical crack widths in situ to gain a better understanding of the significance of the cracking.
3. If there is any doubt about the structural integrity of a concrete pipe due to observed cracking, regular monitoring (say 10-20 year intervals) is a lot cheaper than rehabilitation! However it may well be found that no deterioration is visible between consecutive inspections and monitoring intervals can be increased.
4. CCTV inspections are useful for identifying serviceability concerns. For example permanent obstructions due to cables, watermains and the like can significantly reduce the capacity of a stormwater pipeline. In particular if flood hazard modelling is proposed, the existence of such obstructions, if not identified and incorporated, could significantly affect the integrity of the model.
5. Where major earthworks over an existing stormwater (or wastewater pipeline) are proposed, pre- and post-construction CCTV inspections will provide a TLA with evidence of any damage caused by the construction works.
6. Newly installed stormwater pipelines should be inspected with CCTV prior to being vested in the TLA, to confirm that they are in acceptable condition. Although visible cracking should be treated with caution for the reasons stated above, cracking in excess of design widths should be cause for rejection of a pipeline. The inspections should be carried out on completion of all earthworks and road construction, where relevant.
7. Acceptable cracking types and crack widths can be incorporated in Codes of Practice. It is suggested that longitudinal cracking be permitted within limits, but circumferential cracking

should not be acceptable as this is indicative of substandard bedding which may limit the load-bearing capacity of the pipeline.

8. Stormwater pipelines (and wastewater pipelines) in new subdivisions should be designed for all temporary loads that may be exerted on them. Quality assurance systems could also include careful monitoring of backfill compaction.
9. There is provision in CCTV inspection codes for logsheets to include reference to the Class of spun concrete pipes, where it is visible. The information can be recorded under the "CF" (Construction Feature) code.
10. There is no specific provision in the Pipe Inspection Manual (3rd edition) for recording rotation of large diameter concrete pipelines, where an incorrectly rotated section of pipe is identified. The extent of this problem is not known and it would be useful if there was some feedback, particularly from CCTV operators. Incorrect rotation is a potentially significant problem, even if it is a rare occurrence. Rotation can be recorded as a Construction Feature (CF) but incorrect rotation will not attract a defect score.
11. The correct rotation of large diameter concrete pipelines could be incorporated in quality assurance checklists.
12. There will be many townships throughout New Zealand in which precast (as opposed to spun concrete) pipelines will have been installed. These should be clearly identified as many of them are of poor quality construction and could collapse with little warning.

Andrew DuFresne is a Technical Consultant to AWT New Zealand. He has been involved in reticulation management for over 25 years.