STATE OF THE ART GROUTING FOR POST-TENSIONED STRUCTURES
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ABSTRACT

In 1985, a failure of a post-tensioned bridge in the UK brought about a complete review of grouting associated with post-tensioned structures. There were some special circumstances that contributed to the failure but the European market embarked on a total review of grouting procedures including materials, equipment and techniques. Over the ensuing two decades, the European and US markets have introduced various guides to best practice and there are now provisional European Standards in use to accompany the new mandatory European Technical Approval protocols for post-tensioning systems. These guides and codes pay particular attention to durability and a large amount of research has resulted in new grout formulations, special additives, bleed water analysis and best practice execution.

While all of this has been going on, the NZ market has continued with its use of the grouting requirements as specified by NZS 3109 and there are some significant differences between the NZ standard and latest European and Australian practices. The local market has not experienced problems as have been encountered overseas and it would appear that there have been no drivers to make changes. However, in recent times, some NZ specifications have included reference to certain aspects of the European protocols – with respect to testing for flow time, bleed and volume change. This presents a dilemma as only parts of the European codes are being referenced and there are some conflicts when trying to adhere to the local hybrid specifications.

This paper will outline the state of the art practices now commonly in use in Europe and compare them to the practices in New Zealand. It will cover reasons for the new codes, mix design, testing, special equipment and techniques including execution by specialists. It does not intend to try to cover all the detail associated with grout design and execution procedures because these are extensively covered in many recognised publications. However, it will highlight key aspects of state of the art grouting and direct readers to other documents. The paper will conclude with some suggestions on appropriate measures that might be adopted for the New Zealand market place.

INTRODUCTION

The principal objectives of grouting in a post-tensioning application are:

- Protect the prestressing steel from corrosion by completely surrounding it in an alkaline environment and filling all cavities with grout.
- Provide the necessary bond between the prestressing steel and the concrete structure member in bonded applications.

When looking at corrosion protection for bonded tendons as a whole, grout is a key element. This is the last protection layer in the fight to prevent corrosion and to improve durability. For unbonded systems, soft filling materials such as grease and wax or plastic sheathing fulfill this function. Cementitious grout provides excellent protection for prestressing steel, thanks to the highly alkaline environment which passivates it against corrosion. All the analysis demonstrates that the vast majority of post-tensioned structures have behaved satisfactorily – demonstrating excellent durability of the post-tensioning tendons with, at the very least, good design principles and best practice installation techniques. However, enough deficiencies were found to prompt a review of the quality of the grout specified for use – but most of all, of the grouting practice itself.

In the early projects carried out using post-tensioning technology, durability was not a concern – in the sense that it was considered an intrinsic feature of the technology itself – just as with reinforced concrete. Practical experience in the last few decades has demonstrated this belief to have been ill founded and has forced a more holistic consideration of durability – as a problem relating not only to the post-tensioning system in isolation, but also to the concrete structure as a whole.

With the introduction of the multilayer protection strategy, protection against corrosion is provided by a combination of features in any design – waterproofing, dense impermeable concrete, sealed ducts and good quality grouts. The

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erstwhile design principles have been refocused to improve durability – and items such as waterproofing, drainage, concrete cover and concrete quality are taking a higher profile. In the case of post-tensioning, this has been provided with a first protective barrier against corrosion – namely, grout. The second protective barrier is provided by the duct. Commonly used metal corrugated or smooth ducts do not necessarily constitute permanent corrosion protection. So, to mitigate the risks, the sealing of the ducts – and the entire tendon – has been improved, and the use of plastic ducts has been introduced for some applications.

It is well documented that better quality of grouting materials and of on site grouting activities are a small additional cost to the owner compared to the consequences of poor or improper grouting.

Quality grouting is achieved through:

- Careful selection of the based materials comprising cement, water and admixtures
- Consistency in the grout properties by a high level of quality control
- Use of appropriate mix design and mixing procedures adapted to the specific materials, environment and equipment
- Trials to test grout systems for any particular set of factors
- Execution of grouting on site by qualified personnel following approved method statements

The Concrete Institute of Australia Recommended Practice Grouting of Prestressing Ducts (2007) sums up by saying “While a good grout mix is a necessity, it is not a guarantee for successful grouting. Successful grouting needs proper preparation, execution and supervision of works by qualified and well trained personnel.”

With all of this in mind, let us consider some of the detail associated with grouting practice in New Zealand.

CURRENT NEW ZEALAND PRACTICE

The base requirement for grout is commonly sourced from Section 8.8 of NZS 3109:1997. This is usually supplemented by project specifications which provide further detail on grouting equipment and methodologies specific to the application. It is probably worth putting this into context with the more common guidelines and standards now seen in other parts of the world. Section 8.8 of NZS 3109 is a little over 1 page in length covering the full range of grouting requirements. Other international guideline documents cover the topic in anything ranging from 16-50 pages. This is representative of the importance placed on this component of work and the extensive international development over the past 15 years with respect to material selection, testing, execution of work and qualification and training of staff. Key aspects of the New Zealand grouting standards are:

- Materials – Type GP cement with approved additives to improve workability or reduce water content.
- Flow time – in accordance with Section 3 of NZS3112:Part 4 and between 18-22 seconds unless an admixture is added and then flow time may be reduced to 15 seconds
- Bleeding – Determined in accordance with Section 4 of NZS 3112:Part 4 and shall not exceed 2% of the initial volume 3 hours after mixing. Bleed water shall be re-absorbed after 24 hours. A simple test usually performed in a calibrated vertical glass tube. This is a test relating solely to the grout with no other reference to how prestressing strand may influence the tracking or “wicking” of grout inside a tube or duct.

This is basically the requirement for what has typically been termed “common grout.” There are some other fairly general requirements relating to plant, procedures and safety but all of this is included in another 2 pages in NZS 3109. The additional designer-provided specifications add to these standard requirements and typically cover off more detail associated with specific material requirements, compressive strength, equipment capability, grouting pressures, temperature controls and venting of air/bleed water.

The detail relating to the testing noted above is quite basic and not further outlined in this paper. Common grouts mixed and pumped using basic equipment can quite readily attain the characteristics required in New Zealand standard specifications.

More recently, there has been recognition in New Zealand that enhanced grout designs should be utilised to ensure post-tensioned structures are more durable. The key driver to this was presumably to provide a grout which had less bleed water – with less tendency to bleed, there would be less free water in the
grout to create problems. A new requirement was seen to be entering specifications whereby the quantity of bleeding of water and air from the grout should be determined in accordance with fib Bulletin 20 Guide to good practice: Grouting of tendons in prestressed concrete (2002). The intentions were very sound, but the reality was that common grouts cannot satisfy the requirements and the reference to bleed limits alone means that all of the other important information relating to material selection, quality control, trials and execution by qualified people was essentially omitted. In many respects, the stipulation that a grout achieve a lower bleed limit would do little more in ensuring that the grout would perform its primary functions of providing corrosion protection to the strand and effective bond to the concrete. These things can all be looked at in isolation but this will not raise the bar for grouting (or for enhanced durability in our structures) unless all of the components are addressed collectively. This is not a profound observation – it is simply restating the original objective of the international working groups that formed to improve the durability and long-term performance of structures comprising grouted post-tensioned tendons.

It was also determined that many conflicts existed when omitting other aspects of the fib document i.e. the grouts that may be able to be designed to achieve the low bleed may not be able to be pumped by the same equipment. A wider understanding of the changes to grouting protocols was required and this means a closer look at the detailed changes introduced into current international practice.

INTERNATIONAL GROUTING PRACTICE

Grouting is no different to any other engineering activity – the nature of the codes and guidelines are quite specific to the geographic location and the peculiarities of the market. As such, there are documents that exist in UK, France, European Union (a normalising approach for all of Europe), USA and Australia. No doubt there are many others but these do not come to light in the NZ market very often.

The European and USA documents all stemmed from the problems discovered in the 1980’s and early 1990’s. The content of the documentation does deal with a total solution approach and the material covered typically includes:

- Design detailing – covers ducting and connectors, grout inlets, vents and caps
- Grout materials and mix design – cement, admixtures, water, performance criteria
- Testing – testing regime, suitability tests, acceptance tests, pre-approvals
- Grout production and grouting operations – equipment, batching and mixing, grouting methodologies and requirements for special grouting procedures
- Personnel and training – qualification and training of personnel including verification of experience and approval by regulatory bodies

These documents do not reference these sections as mutually exclusive – they all work together to provide a compliant grouting system to meet the primary objective of delivering a durable concrete structure.

Even though available international documents have different geographic markets, they are all very similar in their themes. Having said this, they also have slightly different testing criteria and this is the reason that selecting isolated sections for use in New Zealand is not necessarily a productive way forward.

Each of the main items is elaborated on below. It is not possible to cover the detail of each but the main points are highlighted. The first item is chosen to be the testing as this is the main driver behind finding a grout which will primarily comply.

Testing

The general testing regime is to ensure suitability of the grout and this may involve proving tests (either in a laboratory or on site), suitability tests (generally on site) and acceptance tests (on site). Additionally, some countries require system type testing with approvals given by regulatory authorities.

Proving tests are usually detailed for special projects and are designed to verify grout performance and the completeness of the filling of the ducts, particularly at anchorages and high points where air voids may form. In addition to all the regular testing, proving tests also involve physical dissection and examination of the trial ducts and anchorages to verify compliance. Some countries require prestressing systems to undergo rigorous testing with independent certification, which may include grouting. Figure 1 depicts proving tests being performed on some large tendons and tendon inspection to confirm that strands are completely grouted.
Suitability tests are carried out on site and include testing strength, bleeding, volume change, fluidity (flow time), density and sedimentation and demonstrating compliance with the specified limits. It is extremely important that the same equipment is used for suitability tests as is to be used for the project grouting.

Acceptance testing is routinely carried out on all projects during grouting operations to demonstrate compliance and consistency with the project requirements and to confirm that the required durability can be achieved. The testing includes strength, density, bleeding, volume change and fluidity.

For obvious reasons, the key area of interest from a materials performance perspective is the bleed test. Experience has shown that the starting point for demonstrating compliance with international grouting standards is the bleed test and the compliance threshold is now set at a level 0.3% in most documents (compared with the NZ Standard threshold of 2%). The new protocols have also introduced a "wick induced" bleed test to replicate the wick action created by prestressing strand which is present in the duct.

The simple vertical tube test is illustrated in Figure 2. The presence of this strand provides a passage for any bleed water to rise to the surface. A vertical or inclined tube test may be carried out and the inclined test is essentially a larger-scale test which further replicates the use of multiple strands and orientation of a tendon in practice.

The inclined tube test is illustrated in Figure 3. There is ongoing development with regard to the inclined tube test as it is recognised that it is more difficult to conduct and a simple vertical test may be representative and more applicable for site conditions.

The dilemma with this overall testing regime is that there are many different forms of wick-induced bleed tests and the actual grout testing is very sensitive to the particular requirements of each test.

A summary table is shown in Figure 4 to illustrate the different types of test which exist in various standards and guidelines.
<table>
<thead>
<tr>
<th>Test Method</th>
<th>Cylinder Dia. (mm)</th>
<th>Cylinder Height (mm)</th>
<th>Strand</th>
<th>Bleed</th>
<th>Volume Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>European Standard prEN 445:2007 Grout for Prestressing Tendons – Test Methods</td>
<td>60-80</td>
<td>1000</td>
<td>Single 900mm length Dia. not specified</td>
<td>&lt; 0.3% (at 3 hrs)</td>
<td>-1 to +5% (prEN447:2007)</td>
</tr>
<tr>
<td>fib Bulletin 20, 2002</td>
<td>60-100</td>
<td>1500</td>
<td>Multiple 16mm dia. to fill approx 30% of cross sectional area of duct</td>
<td>&lt; 0.3% (at 3 hrs)</td>
<td>-0.5 to +5%</td>
</tr>
<tr>
<td>Federal Highway Administration ASTM C940 Modified</td>
<td>800ml in a graduated measuring cylinder</td>
<td></td>
<td>Single 12.7mm strand x 500mm</td>
<td>0.0%  [\text{(at 3 hrs)}]</td>
<td>0.0% to 0.1% at 24 hours &lt; +0.2% at 28 days</td>
</tr>
<tr>
<td>Concrete Institute of Australia Recommended Practice: Grouting of Prestressing Ducts, 2007 ASTM C940 Modified</td>
<td>Similar to ASTM C940 Modified Approx 1000mm</td>
<td>15.2mm single strand x 1000mm</td>
<td></td>
<td>&lt; 0.5%</td>
<td>&lt; 2% at 3 hours</td>
</tr>
<tr>
<td>BBR Grouting training manual</td>
<td>60-80</td>
<td>1000</td>
<td>Single 900mm</td>
<td>&lt; 0.3%</td>
<td>-0.5 to +5%</td>
</tr>
</tbody>
</table>

*Figure 4: Grout “Wick Induced” Bleed Test - Comparison of Test Methods*

As previously noted, NZS 3109 does not require a wick induced test and hence the compliance criteria are drastically different. Grouting trials in New Zealand have shown that common grouts will not comply with the bleed thresholds for any of the wick tests shown in Figure 4. Trials have also shown that there is significant variation in the results when using *fib* Bulletin 20 wick requirements which require multiple strands to be inserted into the testing tube – as opposed to other tests which only require single strands. There are mixes which will pass the bleed test using the single strand but will not pass the test when multiple strands are used.

It is significant to note that the Concrete Institute of Australia Recommended Practice document places the bleeding threshold at 0.5% as opposed to 0.3% and additionally nominates a vertical tube test. The document provides specific commentary on this point and outlines that the requirement of a maximum of 0.5% bleed is achievable consistently on site. We can read into this that perhaps the 0.3% threshold was considered to be too much of a change, not necessarily required for the Australian environment and not able to be consistently achieved on site.

The tests for strength, volume change, fluidity, sedimentation and density are all relatively similar to what has been seen previously in New Zealand and no further detail is included in this paper. Information on these tests can be readily accessed from the reference documents as noted at the end of this paper.

**Design Detailing**

There is a greater tendency to specifically detail the requirements for ducts, grout inlets and outlets, vents and caps. Documents deal with both steel and plastic ducts and make reference to the diameter of duct, nature of corrugations and pressure ratings for couplings, inlets, outlets and vents. These details have obviously been developed based on experience so that the guidelines can be followed to maximise the performance of the grout when it is injected. They do not override any project specification but would certainly demonstrate what is considered to be best practice. Personnel involved with this type of work are expected to be suitably qualified and familiar with the detailing for these items.

**Grout Materials and Mix Design**

The base materials include cement, admixtures and water. Cement used for grouting should be ordinary Portland cement consistent with local standards. Chloride and sulphate constituent limits are usually stipulated and the cement must not contain any substances harmful to prestressing strand.

With the stringent thresholds stipulated for bleed, there are usually tighter controls on the type of admixtures used. Admixtures would usually include plasticisers, stabilisers and retarding agents which improve:

- flowability for given W/C ratio
- elimination of bleed water
• prevention of segregation in high pressure grouting
• retarding of the setting of grout
• ensuring stability of the grout

Only well proven admixtures should be used and these would obviously be subject to rigorous testing as part of the proving, suitability and project or system approval process.

The mix design is very much performance based and is required to produce a grout which has high bleed resistance, low shrinkage and high fluidity. Grouts must comply with the performance requirements relating to strength, bleeding, volume change and fluidity as specified so trials, pre-approvals, equipment and trained personnel all link integrally with the chosen mix design. There is a greater emphasis on new generation or “special” grouts and these are most likely to involve pre-bagged and proprietary products. The nature of the new international grouting guidelines would appear to place common grouts out of contention for most post-tensioning work. If a filtered down specification was considered, then common grouts may be able to comply although this is not the trend seen in the documents reviewed.

**Grout Production and Grouting Operations**

It would be fair to say that the international documentation relating the actual mixing and injection of grout has been compiled based on experience and the best practice to employ to mitigate problems in almost every situation that might be encountered. This same voice of experience clearly espouses that grouting is a critical post-tensioning activity that must be carried out under supervision of a qualified post-tensioning supervisor and include personnel who are appropriately trained and experienced.

The requirements for mixing and pumping, type of equipment, back-up equipment, grouting procedures, grouting pressures and trouble shooting is very prescriptive as there is a known expectation of how grouting operations should be carried out. There is little left to chance and the grouting procedure section of most guidelines and recommended practice documents reads more like an operations manual than a code.

There are also procedures recommended for special grouting applications such as would be used for vertical tendons or long horizontal tendons. In some cases vacuum grouting techniques are stipulated and there are again prescriptive procedures for how this should be best carried out and under what circumstances.

It is quite a shift in philosophy to have such detailed guidelines for this aspect of the grouting work but the organisations involved in preparing this information obviously determined that it was vitally important to prescribe the requirements. In this way, all grouting operations could be benchmarked to a certain standard and there would be little left open to interpretation. It actually makes it easier for personnel involved in grouting operations to be trained and certified and there is a fairly standard set of guidelines to abide by. Clients can also benefit because they can apply pre-approval processes based on universal and industry regulated best practice.

Having said all of this, the only way that the recommended practices can be effective is for supervising engineers and other regulatory bodies to check that the guidelines are being adhered to and demand verification of compliance. This takes the process to a new level where there has to be evidence of compliance and practitioners have to be experienced, trained with systems pre-approved and certified by regulatory bodies.

**Personnel and Training**

All of the international best practice documents have an underlying and openly stated theme that grouting of post-tensioning ducts needs proper execution by appropriately trained personnel with supervision of works by qualified and experienced people. Assurance of the quality of grout can only be achieved by experienced, well qualified and trained personnel. As such, the qualification and training of grouting personnel is of prime importance. Many of the main post-tensioning companies operate training/QA schemes and in some countries there are certification schemes in force.

Certification schemes are very much in force in Europe under the new post-tensioning system protocols and certification of post-tensioning system suppliers is a mandatory requirement and requires a European Technical Approval (ETA). In conjunction with post-tensioning system ETA’s is an inseparable requirement that these certified systems are installed by approved post-tensioning specialists which employ suitably qualified personnel.

These same initiatives are now filtering into Australia. With respect to grouting alone, the Concrete Institute of Australia Recommended...
Practice Grouting of Prestressing Ducts defines the roles of a post-tensioning supervisor and in some states formal approval of such personnel is required from the state road authority. This reflects the trends in Europe and reinforces the emphasis being placed on the training, experience and certification of skilled specialists.

RECOMMENDATIONS FOR NEW ZEALAND

The basic codes for grouting of post-tensioned structures in New Zealand are now quite old and international experience has shown that certain aspects of these older codes are now outdated and arguably inadequate for producing the most durable structures into the future. The New Zealand environment is arguably less aggressive than those found in Europe and the USA but the desire to design and construct more durable structures in no less prevalent. Designers in New Zealand are starting to introduce new requirements into specifications to take the latest thinking into account but this may need a more structured and detailed approach to ensure that all aspects of the revised grouting practice are considered.

The two relevant international documents of interest would appear to be fib Bulletin 20 (2002) and Concrete Institute of Australia Recommended Practice for Grouting of Prestressing Ducts (2007). From a code perspective, the draft European Standards prEN445, 446 and 447 should also be considered as key documents.

Summary suggestions for advancing New Zealand practice in this direction would include:

- Assemble a working group to examine the requirements of the Australian Recommended Practice document with a view to adopting this as a best practice guide for NZ projects. This group should also evaluate whether the European Standards prEN445, 446 and 447 should be adopted.
- Identify the aspects of these documents which may conflict with NZS 3109 and prepare an industry standard addendum to correct these. This would include a check of the codes which are cross referenced to Australian and American Standards to ensure consistency.
- Prepare standard revisions to the guidelines to amend any specific reference to approvals required from Australian Road Authorities.
- Examine the case for pre-approving grouting systems and the level of qualification and certification that would apply to relevant personnel involved in grouting.
- Determine the types of projects or structures that these guidelines might be applicable to.
- Consult with industry to discuss implementation of these recommendations and determine a timeframe for adopting them as industry recommendations.
- Liaise with NZ Concrete Society as a possible vehicle to seek industry comment and disseminate information. The same types of industry organisations in other parts of the world appear to have played key roles in coordinating developments and implementing changes.

The steps as noted above would necessarily involve consultation with bridge designers and Transit at an early stage so that requirements could be integrated with the Transit Bridge Manual and any future bridge projects as deemed appropriate.

CONCLUSIONS

Whilst no single protection layer will guarantee durability, a good quality grout and good grouting practice are of prime importance for the robustness of any post-tensioning installation. Grout can provide excellent protection for post-tensioned structures – even more than any other protection layer. But it needs to be recognised as a total approach which is well understood by all related parties with appropriate training. The current method of utilising the existing NZ Standard and adding to this with isolated extracts from more recent international documents for materials testing (bleed only) is not considered the most effective way of achieving more durable structures. Early workshop studies conducted in Europe focused on a total solution approach with input from a wide cross section of the post-tensioning industry. Nothing has changed in this regard and it is more imperative than ever that the adoption of new designs, materials, testing regimes and execution techniques be well understood by the people carrying out the work. We don’t need to reinvent the wheel in New Zealand – there is a high level of appropriate documentation and experience available for our use. In many respects, the changes initiated in the UK in the 1990’s and subsequently adopted in other parts of the world takes the form of licensed building practitioners – something that New Zealand has embarked upon in some areas of the industry. This type of work was recognised as something which demanded a
high level of training and expertise and as such the practitioners and methods of application needed to be approved and qualified. To what extent are we prepared to adopt this and to what extent are we prepared to risk the future durability of our structures by not adopting this? A partial uptake on the recommended practice in this field will surely only result in partial success at best. Most countries around the world are recognising the value and importance in abiding with best practice guidelines and the critical nature of having a full understanding of the whole process – there is a strong case to suggest that it’s time to pay more attention to them here.

REFERENCES

- Concrete Institute of Australia. 2007. Recommended Practice Grouting of Prestressing Ducts.
- UK Concrete Society. 1996. Technical Report TR47: Durable Post-tensioned Concrete Bridges