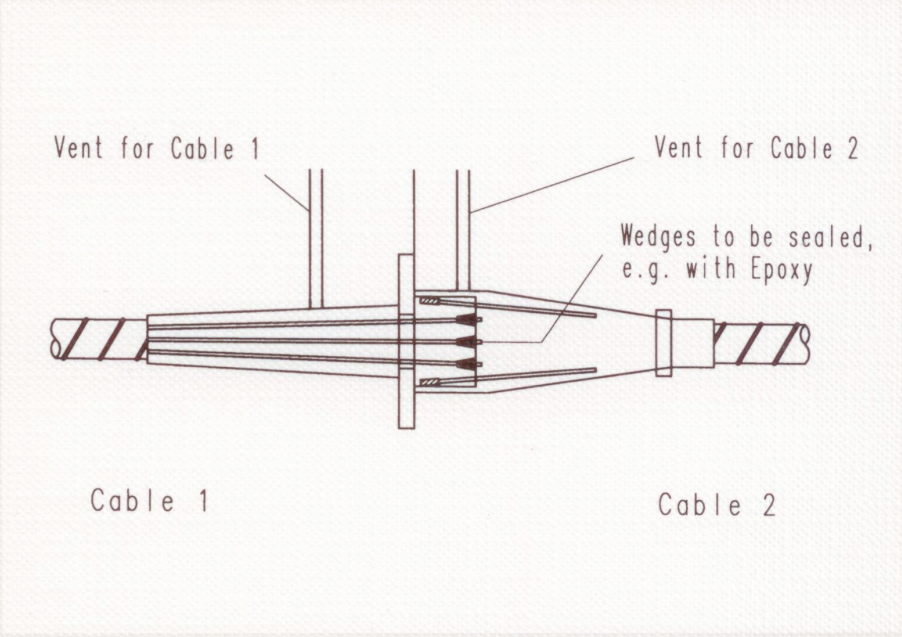
bulletin 20

guide to good practice

fib
CEB-FIP



Grouting of tendons in prestressed concrete

Grouting of tendons in prestressed concrete

Guide to good practice

prepared by *fib* Task Group 9.8 *Grouting*

July 2002

Subject to priorities defined by the Steering Committee and the Praesidium, the results of ***fib***'s work in Commissions and Task Groups are published in a continuously numbered series of technical publications called 'Bulletins'. The following categories are used:

category	minimum approval procedure required prior to publication
Technical Report	approved by a Task Group and the Chairpersons of the Commission
State-of-Art report	approved by a Commission
Manual or Guide (to good practice)	approved by the Steering Committee of ***fib*** or its Publication Board
Recommendation	approved by the Council of ***fib***
Model Code	approved by the General Assembly of ***fib***

Any publication not having met the above requirements will be clearly identified as preliminary draft.

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Cover figure: Tendons with couplers (Fig. 5.2)

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Foreword

Prestressed Concrete is a very efficient form of construction; it takes advantage of the strength of concrete in compression. Developed mainly over the second part of the 20th century, it has proven to be reliable and durable.

However, in the 1990's some cause for concern was discovered, first in the UK and followed by many other countries of the world. It appeared that the grout, an important means of protection of the steel against corrosion for internally ducted tendons, was in some cases inadequate.

Major investigations followed including physical intrusive examination of ducts, mainly in bridges, and re-writing of procedures, processes and specifications, and in 1998 FIP launched a Task Group to review their advice note "Guidelines for Grouting" which had first been published in 1990. *[1]* The merger of FIP and CEB brings this under the auspices of *fib*. Structural deficiencies have only been found in a small number of bridges and in most of these cases the cause is clearly identifiable as either design detailing, workmanship or materials.

In the UK, Concrete Society report TR47 "Durable Post-tensioned Concrete Bridges" had been published in 1996, *[2]* which was the culmination of four years of investigative research, and contained major new specifications and procedures aimed at improving the quality of grouting.

In the USA, the Post Tensioning Institute published in 2001 their guide "Specification for Grouting of Post-Tensioned Structures", *[3]* which also represented major steps forward in materials and testing requirements. The American Segmental Bridge Institute has set up a Committee to re-examine their guidelines, as have many other National Bodies worldwide.

In Europe, France has issued a "Fascicule No. 65A" *[4]* covering requirements for grouting and there are many developments in hand in other countries.

Also in Europe, a European Technical Approval Guideline (ETAG) has been published for approval of post-tensioning systems which covers several aspects of grout and grouting. *[11]*

In November 2001 an international workshop was held in Ghent, Belgium on "Durability of Post-Tensioning Tendons" *[14]* at which international experience was exchanged. The theme was clearly apparent; those bridge owners that have looked, have found some problems with a few of their post-tensioned bridges. In most cases steps are being taken to repair existing bridges, where considered necessary, and to improve future construction by reviewing national specifications.

Emphasis is being put on a multi-layer protection strategy whereby protection against corrosion is provided by waterproofing, dense impermeable concrete, sealed ducts and good quality grout. Design detailing and rain water management are seen as important aspects.

It is now timely for ***fib*** to publish state-of-the-art guidelines to assist in developing and improving the quality of a major line of defence against corrosion, the cement grout. This document represents a consensus view of current practitioners of what is a rapidly developing awareness of some of the shortcomings of previous practice and suggests improvments. This document is a major update of the previous FIP Guidelines and may be taken as a future basis for updating EN 445-447. *[18]*

New areas include understanding of the deleterious effects of an unstable grout, bleeding and how to avoid it, the importance of training and proper procedures, mix design and testing/trials and some new test procedures. It is now understood and generally accepted that the properties of common grout made from cement and water can be very variable and sometimes unpredictable and such grout is not recommended.

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Convenor of the Task Group

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1 Objectives

1.1 Introduction

This guide to good practice applies to grouting of post-tensioned prestressing tendons inside ducts using cement grout. It is intended to cover injection of grout into ducts for both internal and external tendons. Some of the principles may apply to other applications such as stay cables and ground anchors but the scope of this document is not intended to cover any application other than internal and external prestressing.

The function of the grout is normally to provide protection to the tendon against corrosion and, in the case of bonded tendons, to provide bond between the prestressing steel and the concrete member. In order to act effectively as a protective medium for the long term, the grouting must ensure complete filling of the ducts and the guidelines given are intended to assist in achieving that aim.

Experience in many countries of the world has shown that past practices have on some occasions not achieved this and inspection of ducts has shown that voids exist, although the extent of these varies. In response, suppliers and specifiers have introduced new systems, tests and procedures and this guide is intended to explain these, which have the objective of improving durability. Designers are also improving design details for buildability and rain water management.

1.2 New systems

In recognition of the fact that metal ducting does not necessarily constitute a permanent watertight corrosion protection, many suppliers, to provide extra protection, have introduced plastic ducts. The use of polyethylene or polypropylene ducts of sufficient thickness provides corrosion protection for the prestressing steel, if duct joints are suitably watertight.

The ducts may be designed so as to provide an additional protective layer to add to the protection provided by the grout with, for internal tendons, the concrete cover and surface waterproofing layer (if applicable). For external tendons the inspectability provides to some extent a reduction of risk, so could be considered overall as a degree of protection. A multi-layer protection strategy is recommended because no single layer can necessarily be relied upon, and in many countries improved design details are now recommended *[2] [14]*.

In some instances, electrically isolated tendons, completely encapsulated in plastics, are used to provide extra protection. Some unbonded systems for external tendons are using wax or grease injection into ducts. The scope of this document does not include these products.

1.3 New requirements

Traditionally the composition of grout has been simply ordinary cement, water and admixtures mixed on site (common grout). Whilst this is capable of providing a basic grout mixture suitable for use and providing a good active alkaline corrosion protection, it is now recognised that a better quality material can be achieved using rigorously designed, tested and certified grout which may be pre-bagged or may be a prescribed mixture of controlled cements and formulated additions. The design of the grout must take into account compatibility with the equipment. In the context of these guidelines the term "grout" will be used to refer to this improved quality product referred to in other documents as "special grout".

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Testing procedures and methods have been developed and improved recently and these guidelines set out current best practice with the aim of producing the best quality and suitability of grout. Some new tests are described and limits for acceptance have been made more strict in common with trends world-wide.

The training of personnel carrying out the grouting is vital to the success of the operations and the introduction of Certification Schemes, Training requirements, Site Control and QA procedures is becoming common in many countries. Suggestions are made in these guidelines for adoption as part of the overall objective of improving quality and durability.

2 Design detailing

2.1 Duct arrangements

Ducts for bonded post-tensioning accommodate the prestressing steel within the structure. Ducts and their couplers should be sealed to prevent the entrance of water or cement paste and strong enough to retain their shape and to resist damage during handling and concreting. Duct material should not have any adverse chemical reaction with concrete, tendons, or grout. The duct inner surface should be such as to minimise the friction between prestressing steel and ducts during stressing.

Ducts or sheathing for unbonded post-tensioning (mostly external, but sometimes internal, in slabs) constitute a primary layer of corrosion protection of the post-tensioning steel and should also be resistant against mechanical damage and chemical attacks which may be encountered within the special environment they are used.

2.2 Types of duct

2.2.1 Corrugated metal ducts

The most common types of metal ducts are semi rigid cold-rolled corrugated ducts made of steel strips. They have been the standard for many years and substantial experience has been collected. These types of ducts vary with regard to geometry of corrugation, thickness of strip steel, and fabrication method. The corrugations must provide sufficient bond and can assist in encompassing the strands with grout. The thickness of strip steel varies between 0.2mm for small tendons and 0.6mm for large tendons. Strip steel thicknesses as given in Fig. 2.1 may be adopted, or as stipulated in EN 523 *[5]* or PTI Guide Specification *[3]*. Greater steel thickness improves the robustness of the ducts and helps avoid damage during installation and concreting.

The properties of metal ducts, such as resistance to bending, lateral load resistance, tensile strength, and water tightness, and the respective test methods are covered by EN 523, EN 524 or PTI Acceptance Standards for Post-Tensioning Systems *[9]*.

2.2.2 Smooth metal ducts

Smooth steel pipes with a wall thickness of diameter/50 or in the order of 2.0-5.0mm are used for special applications such as nuclear power stations, vertical ducts for Liquid Nitrogen Gas and other tanks. A minimum thickness of 3.0mm is recommended if the duct is to be welded.

Possible reasons for using smooth steel pipes with increased wall thickness are:

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(a) to avoid deformation and deflection of an empty duct during installation and concreting
(b) to withstand high grouting pressure or for external tendons, especially in long vertical ducts or where higher than normal pressures are anticipated and particularly in structures with little concrete cover
(c) to prevent damage to the duct due to special circumstances, e.g. during welding activities in the vicinity of ducts
(d) in areas of high curvature.

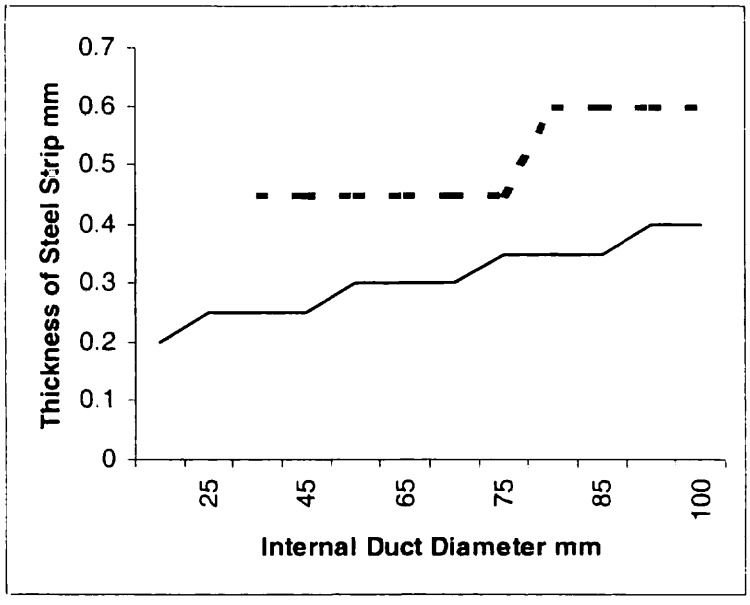


Fig. 2.1 Thickness of strip steel versus internal duct diameters
Cable installation after concreting - - - - - - - - - -
Cable installation before concreting ——————

2.2.3 Corrugated plastic ducts

Corrugated plastic ducts of polyethylene (PE) or polypropylene (PP), with a minimum residual thickness of 1.0mm for small ducts, increasing for larger tendons.

Corrugated plastic ducts for internal, bonded post-tensioning have recently become more popular and *fib* has issued a separate guideline for these products which are recommended *[8]*.

2.2.4 Smooth plastic ducts

Smooth plastic ducts of polyethylene (PE) or polypropylene (PP) with a wall thickness of diameter/16 to 18 or the order of 4-10mm are used for external prestressing.

For special applications such as ground anchors or monostrands utilising individually sheathed strands, smooth plastic coatings of 1.0-2.0mm are used.

Further guidance is given in the *fib* Bulletin No.7 *[8]*.

2.3 Diameter of the duct

Ducts for bonded post-tensioning need to have a large enough cross sectional size to ensure the tendon can be installed and that the duct can be completely filled with grout in order to provide the expected corrosion protection as well as bond to the concrete.

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The internal diameter of the duct depends therefore on the cross-sectional area of the prestressing steel. The cross-sectional area of the ducts should normally be 2.5 times that of the actual area of the prestressing steel. Depending on the length and geometry of the tendon as well as on the installation method (complete bundle) the ratio may be reduced to 2.0. Too small ducts can lead to grout blockages, excessive friction and too high stresses on the concrete and may create difficulties in inserting (threading) the prestressing steel. If for any reason the duct/steel ratio falls outside the given limits, it should be proven by tests that proper grouting is possible. The rate of grouting speed will be affected by the proportion that the duct is filled with prestressing steel.

The diameter of ducts for external unbonded post-tensioning should be generally of the same size as for internal bonded since the requirement for complete filling of the duct is the same.

For bar systems, duct diameters should be agreed with the suppliers. The steel/duct area ratio is often larger, because the bars are generally quite short and straight, but care is advised in this respect.

2.4 Duct connectors and couplers

2.4.1 Anchorage - duct connection

The duct should be firmly and tightly connected to the anchorage in such a way that it cannot be loosened during concrete placement, vibration and curing. The joints should be sealed by means of banding with adhesive tape or thermo shrink sleeves to preclude ingress of cement slurry or water. Furthermore the duct should be properly aligned with the axis of the anchorage. Kinks have to be avoided. The assembly must be leak-tight.

2.4.2 Duct coupler and sleeves

They should be of the same material and profile as the duct itself.

The duct coupler sleeves should have a minimum of 150mm length or 3 times the diameter of the duct to be connected and properly fit over the duct. The joints should be properly sealed by using a proprietary joint coupler or by wrapping two layers of adhesive tape or welded or by means of thermo-shrink sleeves. The proper alignment of the duct should be maintained through the duct joints and kinks should be avoided. Special attention should be made to ensure continuity of a smooth profile across the joints.

- For bonded internal prestressing with corrugated metal ducts, the connector should consist of a sleeve with similar corrugation and screwable to the duct.
- For bonded internal prestressing with plastic ducts, the connecting sleeve may be a clamp-type or fusion-welded system. A screwable corrugated connector sleeve with integrated O-rings for proper sealing is also possible as well as butt-welding.
- For unbonded external prestressing in a smooth plastic pipe, the duct connection may consist of an oversize sleeve, of butt welding or even a clamp type connector system.

2.5 Protection of the ducts

Ducts should be protected during transport and storage and handled with care during placing to avoid damage. Temporary corrosion protection should be provided for metal ducts. During transportation and storage, adequate protection against environmental influences should be provided. If required, steel ducts can be protected by galvanising, or by use of

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water-soluble oils. Closing the ends of the duct with plastic caps or similar may also be suitable to prevent entry of water and debris.

Attention should be given to the possible galvanic action between different metal elements, and to the type of oil used (it must be non-aggressive). There is no evidence that galvanised ducts present a corrosion risk when used with strand and cold drawn wire.

In normal circumstances it is not necessary to protect ducts against corrosion when they are placed within the concrete structure. In some cases, however, such as when empty ducts are placed a considerable time before the insertion or stressing of the tendons, protection of the ducts is recommended. This may be accomplished by an oil coating inside the ducts before installation.

Flushing of ducts with water is not recommended and should be avoided wherever possible for strand and wire tendons because experience has shown that residual water remains in the ducts, especially in corrugated ducts, and this adversely affects grout performance. However for bar systems, flushing with water is recommended by suppliers because of the need to clean the narrow annulus between the bars and the duct, but caution is advised in this respect.

2.6 Temporary protection of tendons before grouting

As a general rule, grouting should be carried out as soon as possible and feasible after the stressing of the tendons. If the prestressing steel remains in the duct (stressed or unstressed) for a longer period of time, temporary corrosion protection measures have to be considered. For individually greased and sheathed monostrands no further protection is required. It should be remembered that grouting may be delayed due to cold weather (see 5.3.2.6).

Guidance on the maximum length of time between installation, stressing and grouting of tendons with bare prestressing steel is typically specified in international codes or project specifications. In this context reference is made to the following documents:

- AASHTO Standard Specifications for Highway Bridges *[15]*
- UK Specification TR 47 *[2]*
- ENV 13670 "Execution of concrete structures" *[16]*

The ENV "Execution of concrete structures" recommends the following construction periods to be observed provided that penetration of water or excessive humidity to the prestressing steel can be prevented:

- maximum 12 weeks between fabrication of tendon and grouting
- maximum 4 weeks in the formwork before casting the concrete
- approximately 2 weeks in the tensioned condition before applying the protective measures (permanent or temporary corrosion protection).

If in extreme cases the grouting has to be delayed beyond the above maximum durations, the prestressing steel needs to be temporarily protected against corrosion by one of the following measures:

- Use strand protected with a coating of water-soluble oil of a type that does not require to be flushed out with water. This is the preferred solution. In this case the reduction of bond should be checked with the designer. It is understood that there are products which have minimal effect on the bond.
- Blowing of dry air through the duct. This requires a quite sizeable installation with dryer, ventilator and a considerable steady power consumption.
- In any case, all access points to the ducts at anchorages, vents and drains need to be properly sealed to prevent ingress of water and humidity into the duct.

For threaded bar systems unsoluble wax coatings are used. For smooth bar systems water soluble oil can be flushed with water to improve bond.

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If an unforeseen delay occurs, used but **not recommended** is the following temporary corrosion protection measure:

The use of VPI (vapour phase inhibitor) powder is problematic since the concentration along the duct can vary considerably with over and under dosage. Either one of these conditions can lead to increased local corrosion. In addition VPI powder is toxic.

For further details refer to FIP Recommendations "Corrosion Protection of Prestressing Steels" *[13].*

2.7 Inlets, outlets and vents

Inlets are used for injecting the grout into the duct; outlets are needed for escape of air, water, grout and bleed water. The inner diameter should normally be at least 19mm and the length sufficient to guide them into buckets to catch the escape grout although smaller diameter vents can be used for smaller tendons.

For bar tendons smaller diameter inlets can be satisfactory.

The position of the inlets and outlets is related to the direction in which the grout flows, the tendon length, the inclination of the ducts, anchorages, and couplers, and the allowable grout pressure. In some situations they may be interchanged to make grouting and regrouting possible.

Inlets and outlets are placed:

(a) at the anchorage of the tendon [Figs 2.2(a), 2.2(c)]

(b) at the high points of the duct when the vertical distance between the highest and lowest points is more than 0.5m [Figs 2.2(e), 2.2(f)]

(c) in special cases, at the lowest point of a tendon having a small bending radius, e.g. a loop [Fig 2.2(b)]

(d) at major changes in the cross-section of the duct, such as trumpets of couplers and anchorages [Figs 2.2(a), 2.2(c), 2.2(d)]

(e) At project specific interval distances (this may range between 30-75m depending on tendon geometry, grouting and equipment etc.)

An additional outlet on the downward side of the high point of the duct assists in avoiding voids in the grout.

The locations of inlets and outlets should be detailed by the installer on shop drawings, based on the intended grouting procedure.

When detailing grout inlets and outlets, particular attention should be paid to any location where a significant directional change to the tendon profile or a change in cross-section occurs.

In very high vertical ducts, when the grouting pressure becomes excessive, such that step-by-step grouting is necessary, extra inlets should be used.

For long tendons, provisions should be made for allowing grouting to proceed through successive inlets. In this case an outlet may also have to become an intermediate inlet.

No intermediate vents are normally required for short and shallow tendons where the drape of the tendon or difference in elevation of any part of the tendon is less than about 0.5m.

As a general rule for all above cases the spacing of in/outlets should be such that grouting pressure at the inlet does not exceed 10 bars.

The provision of vents at high points of external tendons is often difficult or even impossible because of the deviator pipe and the diaphragm. In such cases, the vent pipes should be arranged outside of the deviator pipe on both sides. The duct section downstream of the high point is critical and needs special attention during grouting and inspection, as the risk of air being entrapped is considerable. An additional vent (as previously described) about 1·2m downstream is desirable. In some procedures, air needs to be expelled by post-grouting

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through the vents provided on either side of the deviator pipes. Alternatively, the use of vacuum assisted grouting minimises the risk of air entrapment.

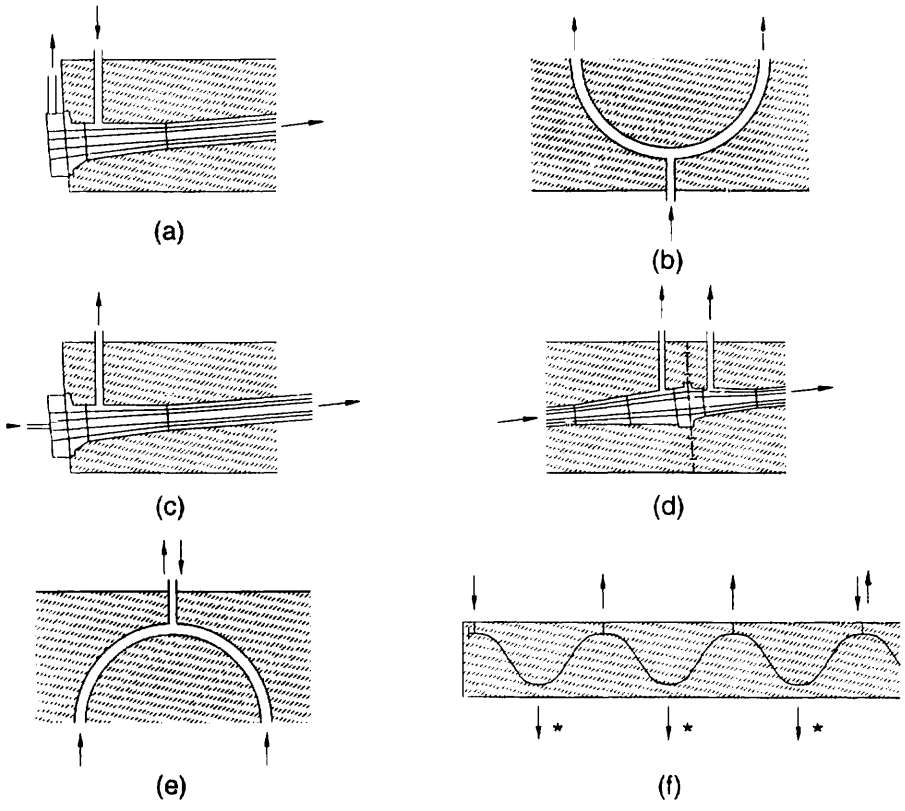


Fig 2.2 Location of inlets and outlets

* Low point drains may be required for special application during winter installation. Care is needed in this case to avoid blockage in freezing conditions.

All inlets and outlets should be such that they can be tightly closed either with valves or by other means.

Different options for closing the vents are available. Preferred solutions are:

(a) plugging
(b) different types of screw-on caps, and
(c) a valve. The commonly used practice of bending and fixing with tie-wire is less preferable as it is not as reliable in sealing the vent. At all vents the expelled grout has to be collected for environmental reasons and to avoid staining of the structure.

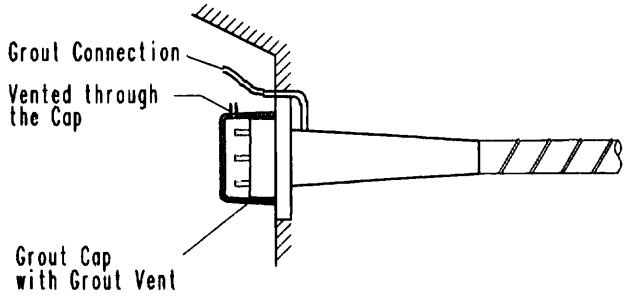
At anchorages, inlets and outlets are used in combination during various grouting operations. Depending on the type of anchorage, the inlet and outlet can be made through the anchor head, the anchor plate, through the trumpet, or through a recoverable grout cap with in/outlet valves.

The tendon ends need to be sealed and fitted with grout inlets and shut-off valves. For sealing the terminations the methods are reusable grout caps with inlets and vents and non-recoverable plastic caps for one time use. The latter is preferred. Concreting of block-out with grouting tube through the casting plate or quick setting mortar with grouting tube

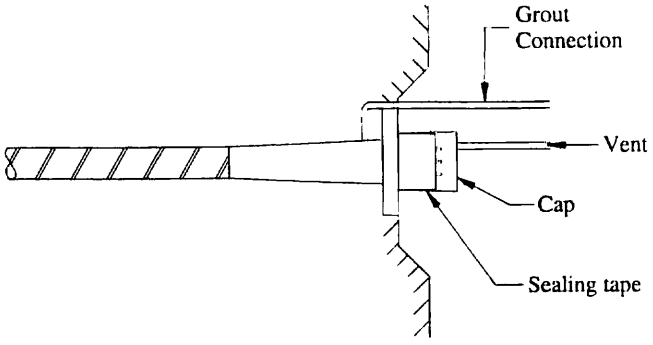
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through the trumpet have been used, depending on the particular conditions on site and the end anchorage details.

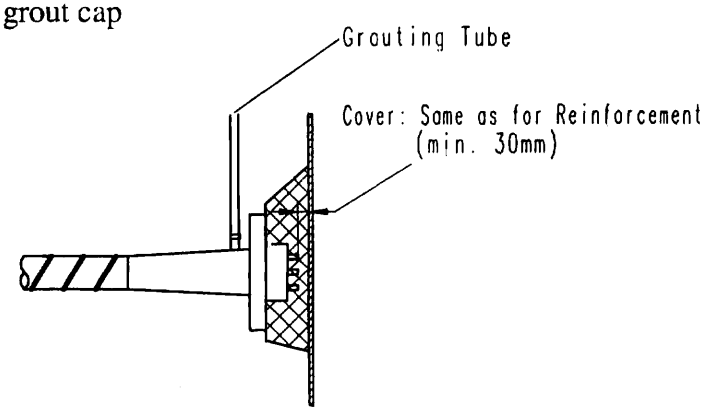
If quick setting mortar or concreting of the block out is chosen for sealing the termination, a small amount of air between the grouting tube and anchorage can not escape through the anchorage and may remain trapped. Furthermore these methods do not allow inspection to check for complete filling of the anchorage. Sketches of the above solutions are shown in figure 2.3. In some conditions it may be desirable to consider waterproofing membranes.



(a) Permanent grout cap (internal or external tendons) (non-metallic preferred)



(b) Temporary grout cap



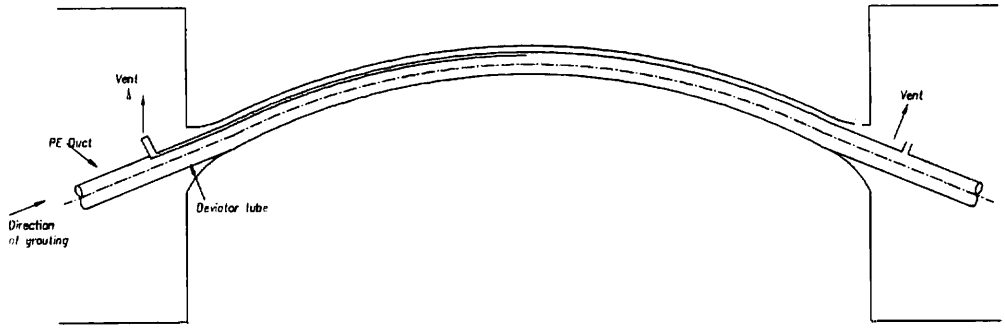
(c)Concrete pour back (no grout cap). (Not recommended except after grouting). More than 30mm cover may be required in special applications such as offshore structures.

Fig 2.3 : Different methods of sealing tendon terminations

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Anchorages of external tendons with corrosion protection by means of grout, typically have a permanent protection cap, which is fitted with a vent or inlet, through which the grout is injected.

For external post-tensioned ducts the inlet or outlet can often not be placed directly at the high point because of fixed deviation pipes and proximity of the ducts to the underside of a concrete slab. In such cases one vent, inlet or outlet should be installed adjacent to the deviator. A vent should be connected to the duct at the highest point of the duct, where possible, as in Fig. 2.4.



Top deviator for external tendon

Fig 2.4 Top deviator for external tendon

2.8 Duct installation

2.8.1 Supporting of ducts

In order to prevent buoyancy of the duct and subsequent misalignment the duct must be firmly tied to the reinforcement cage at regular intervals at least equal to the tendon support spacing. Special attention should be made to the design of the duct supports to ensure continuity of a smooth profile. For plastic ducts this can be successfully achieved using half shell duct pieces at critical locations such as high points on small radius curves.

Additionally for particular applications e.g. segmental in-situ construction stiffening of the ducts through the element joints by means of a retractable plastic pipe or some strands may be envisaged. These stiffening and buoyancy-reducing elements will be removed after the concrete has hardened.

For external tendons special attention must be given to the adequacy of support of the ducts to carry the weight of the wet grout during injection and setting.

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2.8.2 Checking of duct clearance after concreting

If the prestressing steel is installed after the concrete pour, the clearance inside the duct should be verified. For this purpose a calibration gauge of slightly smaller diameter than the internal diameter ID of the duct should be blown through the duct. The duct calibration gauge should be attached to a string, so that it can be drawn back in case of presence of an obstruction in the duct.

2.8.3 Precast segmental construction

Special precautions are required in the case of joints in precast segmental constructions. Leakages, as well as interconnections between ducts, should be avoided.

Duct spacing should be detailed by the designer such that there is sufficient concrete between parallel ducts to prevent interconnections between ducts during grouting operations, and to comply with relevant standards for precast members.

As a general rule, the joints of precast segmental construction are treated with epoxy resin, if internal grouted tendons are used. The epoxy resin seals the joint and prevents grout leaking through and out of the segment joint. However the epoxy may also unintentionally be squeezed into adjacent ducts, when the segments are pressed together, causing blockages. To prevent this a compressible foam seal can be provided in the segment joint around the ducts, and consideration given to scraping out the excess with plastic or rubber scrapers before the epoxy sets. However, duct continuity is the preferable option and it is understood that system suppliers are developing these.

2.9 Duct testing

Corrugated metal ducts may be tested according to EN523 ***[5]*** and EN 524 part 1 through 6 ***[7]***

Corrugated plastic ducts may be tested according to *fib* Bulletin 7 ***[8]***.

Alternative requirements are set out in PTI Guide Specification "Acceptance Standards for Post-Tensioning Systems" ***[9]***.

2.10 System testing

These tests should document the proof and suitability of the system and therefore be performed as full scale proving tests for the initial system approval and certifications.

- a full scale assembly test
- a groutability test
- a leak tightness test
- a stressing – friction test should be performed

The procedures for the above systems tests are described in the *fib* Bulletin No. 7 "Corrugated Plastic Ducts for Internal Bonded Post-Tensioning" ***[8]***.

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3 Grout materials

3.1 Cement

Cement used for grouting should be ordinary Portland cement in accordance with relevant National Standards.

Further, cement should comply with the following requirements:

- Cl^- $\leq 0.05\%$
- S^{2-} $<0.01\%$
- no lumps
- not contain any substances harmful to the prestressing steel
- additives $<0.1\%$. Only grinding agent should be allowed.
- cement should not exhibit false set.

It should be delivered in bags of defined weight, usually 50kg or 25kg and wrapped on pallets or in containers and stored in a dry place to protect them from humidity and moisture. Tolerance in weight should be less than 2% (1% less than defined weight and 1% more than defined weight).

To control consistent quality of grout, the particule size of cement can be defined by a nominal Blaine specific area. Variation of chemical and physical composition have a significant effect on the properties.

The manufacturing date of the cement should be printed on each bag to control the age before use in the grout. Cement properties change with age so caution is advised in storing for prolonged periods.

3.2 Admixtures

Admixtures should not contain any substances harmful to the prestressing steel, especially thiocyanates, nitrites, nitrates, formiates and sulphates and should comply with the following requirements:

- Cl^- $\leq 0.10\%$ in weight of powder admixtures
- Cl^- <1 gramme per litre of liquid admixtures
- pH has to be included within limits which are specified by the manufacturer
- dry extract : included in a scale of +/- 5% from the specified value.

Well proven admixtures should be used which comply with appropriate standards. The admixtures are usually a plastifier, a stabilising and a retarding agent which improve:

- flowability at a given water/cement ratio
- elimination of bleeding water
- prevention of segregation in high pressure grouting
- retarding of the setting of the grout
- ensure stability of the grout

The admixtures may also provide additional properties such as :

- accelerating the setting
- expansion of grout to compensate the shrinkage
- air entertainment to improve freeze resistance during the setting period
- thixotropy
- corrosion inhibition

However, some tests have shown the effectiveness of corrosion inhibitors is unreliable and it is recommended to confirm their effectiveness in representative test samples which include the prestressing steel.

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The product should be in bags or containers or within a pre-bagged mix with the identification and the instructions of the manufacturer (product sheet, safety data sheets....). Retarders delay the setting of the grout, and are particularly useful for grouting of long ducts. By using methanol or glycol, the grout can be made freeze-resistant during the setting period, but this may cause some reduction in strength and problems with setting, segregation and bleeding. Compatibility and suitability checks should be made for the various component products. Care should be taken to use admixtures prior to end of shelf life.

3.3 Water

The water should not contain ingredients harmful to the prestressing steel or the cement grout. It should not contain more than 300mg of chloride ions per litre or 200mg per litre of SO_4^{2-} ions, or any organic materials. Drinking water from the public water supply may be used.

When public drinking water is not available, a chemical analysis should be performed. Water should comply with relevant National Standards.

3.4 Grout performance

The cement grout has to be designed considering all materials included in it. The grout should not contain more than :

- Cl^- <0.10% by weight of cement
- SO_3 (expressed) <4.50% by weight of cement
- S^{2-} ions <0.01%

Furthermore, the following performances should be achieved:

- **Flowability**
  The flow time with a cone in accordance with Appendix B6 has to be less than 25 seconds in the range of temperatures defined by the manufacturer. For thixotropic grouts other limits and test methods will apply (see 4.5.4). Other test methods are available in some countries.
- **Maintenance of the flowability**
  The flow time has to be under 25 seconds until at least 30 minutes after the grout manufacturing or until the time defined by the manufacturer or specified by the designer. The flow time should not vary more than 20% over this period.
- **Bleeding Requirements**
  The quantity of bleeding of water and air from the grout after 3 hours kept at rest, has to be less than 0.3% in the bleeding tests given in Appendix B1 and B2. This requirement should be the same with grout kept at rest during 24 hours. The grout has to be designed to meet these requirements in the range of temperatures defined by the manufacturer (see 4.5.2).
- **Mechanical Strength**
  This is not considered an overriding parameter but typically the following are guidelines:
  The compressive strength after 7 days should exceed 27 MPa on 100mm cubes (see 4.5.1).
  Additionally some countries choose to test the flexural strength which should exceed 3 MPa after 7 days.
- **Setting time**
  Beginning of setting time of the grout : > 3 hours, in the range of temperature defined by the manufacturer.

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Ending of setting time of the grout : < 24 hours, in the range of temperature defined by the manufacturer.

- **Volume change**
  Volume change should be between –0.5% and +5% from the initial volume (see 4.5.3).
- **Test of stability with inclined tubes** for initial approval of grout mix – see Appendix B1
  In an inclined tube, prestressing strands are placed and grout is injected. The quantity of bleeding water is measured from 0 hours to 24 hours.
  Test is satisfied if:
  - grout has no obvious segregation in tubes
  - there is no liquid coming from bleeding or filtration in excess of the permitted limit of 0.3%.
- **Sedimentation and Density**
  The variation in density of samples taken from the top and bottom of the bleeding tube should not exceed 5% (see 4.5.5). Density is an important measure for consistency of the quality of grout production and should be monitored on a regular basis.
- **Other Tests**
  Some countries test for capillary absorption *[4]*, bleed under pressure *[3]* and corrosion *[3]*.

3.5 Quality Plan

Designing a grout means to determine a grout formulation based on rheological, chemical and mechanical properties which are focused, fixed and defined so as to develop a grout formulation and choice of right cement and admixtures. Nevertheless, regular controls of quality and regularity of the manufacture of each material are necessary during production.

In all cases test results should be submitted for use of grout constituents, systems and products proposed that relate to the anticipated environmental site conditions.

In some cases cement and admixtures are designed for a specific job under a defined range of temperature of grout. Alternatively, previously formulated grouting products are used, designed to meet the performance requirements and proven by previous records. In all cases the manufacturer of each material should develop a quality assurance plan to warrant the performance of the grout.

Cement

Chemical analysis and granulometric analysis is required to ensure the regularity of the cement should be provided and shown to be within fixed tolerances.

The weight of sacks and packaging (with manufacturing date printed) should be provided, to ensure correct dosages between cement and admixtures.

Admixtures

Chemical analysis should be supplied to ensure the conformity of products.

Control of quantity packaged is required to ensure correct mix proportions. For liquid admixtures the weight of the dry extract must be controlled.

Grout

Two conditions (design and manufacture controls) are necessary to assist contractors for repeatable quality of grout made on site.

That is the reason why manufacturers of cement and admixtures need to work together and put on the market products including not only cement but also admixtures. This is the best

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way to warrant a uniformity of performance of a grout designed to be effective, whatever site conditions there will be (temperature, type of site equipment etc). For many applications it is envisaged this could be factory formulated.

In all cases the properties of the grout have to be verified on site using the actual equipment for grouting.

4 Testing

4.1 Testing regime

The purpose of testing is to ensure suitability of the grout to achieve the aim of full protection and bond to the prestressing steel and to the concrete structure, in the case of internal tendons. The testing regime may include proving tests (either in a laboratory or site conditions), suitability tests (generally on the site) and acceptance tests (on site). Additionally in some countries system type approvals are given by the authorities which may include the testing of groutability and of the grout itself.

4.2 Proving tests

Experience has shown that full-scale trials of grout and grouting procedures are valuable to prove adequacy. For some projects it may be advisable to carry out project specific trials of grouting which should be planned and carried out well in advance of site operations. However, recent test results of identical grout mixes with the same cement properties for similar tendon configurations may be acceptable for many projects. Proving tests should include results of examining the completeness of filling of the duct, particularly at anchorages and at high points of the tendon profiles where air voids may form. This can be achieved by coring into the trial after the grout has set and by physical examination.

Some countries now have requirements for prestressing systems to undergo rigorous testing with independent certification, to be given a system type approval for use, which may include the grouting. Such testing includes the inclined tube test and vertical tube test (see Appendices B1 and B2) in order to establish correlation for future site testing and can obviate the need for full-scale trials.

4.3 Suitability tests

In all cases it is advisable to perform the testing of the suitability of the grout for the site conditions before using the grout in the project. This should be carried out on site with the same equipment to be used for the grouting. **It is crucially important to use the same equipment.** Suitability testing includes testing strength, bleeding, volume change, fluidity density and sedimentation and demonstrating compliance with the specified limits.

4.4 Acceptance tests

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

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4.5 Test methods

Suggested test procedures are given in Appendix B.

4.5.1 Strength

The compressive strength of the grout is measured on cubes of 50 x 50 x 50 millimetres up to 100 x 100 x 100 millimetres or on cylinders, diameter 50-100 millimetres with a length similar to their diameter. The samples should be cured in site conditions. Generally it is sufficient to test one set of three cubes for each day of site operations but testing frequency should be in relation to the volume of grout being used.

4.5.2 Bleeding

The test consists of measuring the quantity of water and air remaining on the surface of the grout, which has been allowed to stand protected from evaporation. Simple tests using small glass or plastic cylinders have been shown to inadequately represent the true conditions inside ducts **and are no longer recommended.**

An inclined or vertical tube test containing prestressing strand as used on site has been shown to better represent the conditions inside ducts. The presence of this steel provides a passage for any bleed water to rise to the surface. (See Appendices B1 and B2). The vertical tube test is simple to use and appropriate for site testing (one test per half day is appropriate for acceptance testing).

The inclined tube is suggested as appropriate for proving tests or for system type approval. It may also be used for suitability testing for large projects. Correlation testing should be carried out using the inclined and vertical tubes so that site verification can use the vertical test, which is less complex.

4.5.3 Volume change

This test measures the expansion or contraction of the grout and is conventionally carried out using small glass or plastic cylinders protected from evaporation. The method in Appendix B2 can also be used. The volume change is reported after 24 hours. For acceptance testing the test should be performed at least one each half day.

4.5.4 Fluidity

The fluidity of the grout, expressed in seconds, is a measure of the injectability and flowability of the grout. It can be measured by three methods. The generally adopted method consists of measuring the time for a stated quantity of grout to flow through a cone. Alternative test methods are measuring the time for an immersion body to plunge down a tube filled with grout or by use of a shear vane (see Appendix B). The cone test is more commonly used and is simpler to use and appropriate for most applications. Thixotropic grouts may need to be tested by alternative methods.

It is important in suitability testing to measure the fluidity at times after mixing which represent the likely length of time the grout will be required to remain fluid for injection through the ducts which could be significantly longer than the 30 minutes suggested.

For acceptance testing the test should be performed at least 3 times per day.

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4.5.5 Sedimentation

The sedimentation is measured as the difference in density of hardened grout samples taken from the top and bottom of a glass or plastic test cylinder after 24 hours. This test is required for proving and suitability tests only.

4.5.6 Density

Density is a good indicator of grout acceptability. For acceptance testing the tests can be used to demonstrate that the grout expelled at vents and anchorages remote from the injection point is of satisfactory quality. The density of the fluid grout should be recorded once per half day.

Summary of tests

Test	Proving	Suitability	Acceptance
Strength	✓	✓	✓
Bleeding/Stability (Inclined Tube)	✓		
Bleeding for correlation with the above or stand alone (Vertical Tube)	✓	✓	✓
Volume Change	✓	✓	✓
Fluidity	✓	✓	✓
Sedimentation	✓	✓	
Density	✓	✓	✓

Summary of acceptance test requirements

Test	Minimum frequency
Strength	One set of 3 tests per day
Bleeding	One test per half day but at least two per grouting stage
Volume Change	One test per half day but at least two per grouting stage
Fluidity	Three tests per day or every 2 hours from the pump
Density	One test per half day from the pump and the last vent but at least two per grouting stage

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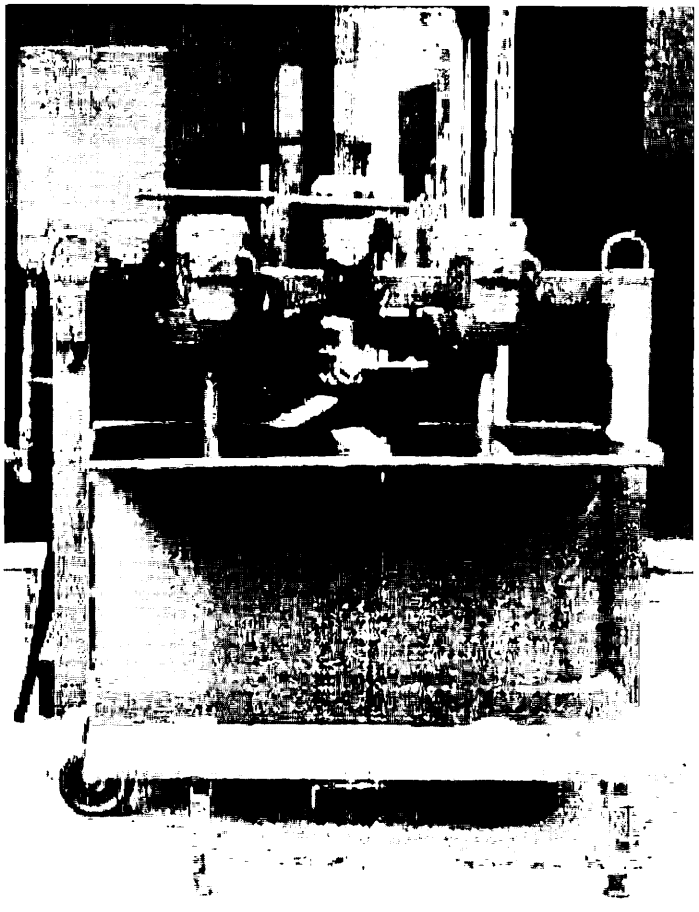
5 Grout production and grouting

A designed and proven grout mix, a well-functioning grouting equipment and correct grouting procedure are a prerequisite for a durable corrosion protection of the prestressing steel and the bond behaviour between the tendon and the concrete, hence for the long-term integrity of the structure. The grouting operation should only be carried out by qualified and trained personnel, directed by a grouting specialist. Grouting work should be under the responsibility of the prestressing system supplier or grouting personnel with certified experience and training. It is recommended that staff carrying out inspection on behalf of the client should have a similar level of training.

5.1 Equipment

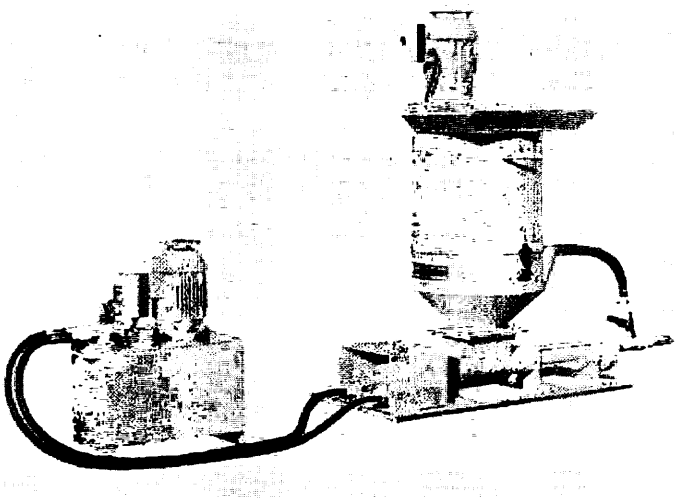
5.1.1. General

A grout of good and consistent quality can only be produced in grouting equipment designed for the intended purpose. It should be equipped with a mixing tank, preferably with a complementary agitator tank (as reservoir), a pumping unit, permitting a continuous grout flow, a device for water supply and measurement, and accessories as hoses, valves and manometer. To achieve best grouting results, regular maintenance and a frequent cleaning of the grouting equipment should be selected to meet the requirements of the particular application, considering among other things the site and temperature conditions, tendon capacity, length and profile (draped, vertical, horizontal).



(a) Twin mixing reservoir equipment

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(b) Single mixing reservoir equipment

Fig 5.1: Typical grouting equipment

5.1.2 Requirements for the grouting equipment

The grouting equipment should meet the following minimum requirements and at least be equipped with:

- a high speed mechanical mixer
- an agitator with storage tank for keeping the grout in motion before pumping
- a pump with a max. pressure of 20 bars and adequate delivery, permitting a continuous flow of the grout at the desirable speed
- shut-off valve between mixing resp. agitator tank and pump
- shut-off value between pump and grout hose
- a manometer at the pump with reading dial up to 20 bar
- weighing or volume meter system (for water) with a weighing accuracy of 2%
- flowmeter (optional but recommended)
- tight hose connections to avoid water leakage
- intact seals at the pump so that it cannot suck air and to prevent lubricants to be mixed with the grout
- a sieve upstream of the pump to prevent lumps from getting into the system
- stand-by grouting equipment, may be considered for critical grouting operations
- data sheets of the grouting equipment, operation manual and maintenance instructions should be available on site.

When water content is measured by volume, attention must be paid to use stable systems not unduly affected by levelling tolerance and vibrations of the mixer.

5.1.3 Mixers

The volume of the agitator tank should be similar to the mixing tank. The capacity of the mixing tank should be adequate to allow mixing one or a multiple of bags of cement. The mixing and the agitator tank should be connected with a shut-off valve.

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5.1.4 Pumps

The delivery should be such that up to the maximum pressure, a grout flow speed of up to 12.0 m/min can be maintained in the tendon. A manometer and a shut-off valve should be fitted to the exit of the pump. A flowmeter is a useful optional addition.

5.1.5 Hoses, connections and valves

Hoses should be sufficiently long, but not excessively long, and fitted with tight quick couplings at both ends. They have to withstand with adequate safety the maximum grouting pressure of the pump. The grout hoses and valves should have an inside diameter of minimum 19mm, but preferably at least 25mm. They must be flexible to accommodate a particular geometry imposed by the project. Some spare valves and couplings should be available for each major grouting operation. Thorough cleaning after every grouting operation and proper maintenance of these accessories should be rigorously observed.

5.1.6 Efficiency of grout mixers

Types of grout mixers may differ by many parameters, such as power, speed of mixing (rpm), shape and size of mixing tool (helix, paddle, dissolver plate), volume of bath, additional colloidal mixing unit or not, etc. Important to the user is the quality/homogeneity of the particular grout mix achieved with the particular mixer.

It is especially important to establish the optimum mixing regime of the mixer for the proposed grout mix design. This can be confirmed by the sedimentation test during suitability testing.

5.2 Batching and mixing

The sequence of adding of the components of the grout is generally: water, cement and admixtures, unless required or specified differently by the suppliers. The instructions given by the manufacturers of the admixture should be observed. The most suitable proportion of the grout mix and the optimum mixing time is determined by means of previous proving and suitability tests and the efficiency test of the grout mixer and the proven procedures should be followed on site.

The admixture should be added in proportion as determined in proving tests.

Climatic conditions and local temperatures should be considered when defining the grout mixes for the suitability test.

5.3 Grouting of tendons

The majority of grouting is done by normal injection methods but variations and alternatives are sometimes used such as post-grouting, vacuum assisted grouting and high-pressure grouting. These techniques are described later with the special applications they are used for. For normal methods the procedures would be as follows.

5.3.1 Preparatory work on site

Before the actual grouting work is commenced on site the following actions and preparatory work should be carried out.

- Check if all the personnel involved are properly trained.

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- Check the presence on site of any approved grouting method statement, the equipment data sheets and the maintenance manual, covering all proposed operations and eventualities including risk assessment.
- Position the grouting equipment close to the inlets to avoid long grouting hoses and corresponding loss of pressure.
- Check that all required equipment is available including additional pump for flushing water, if required, compressed air for blowing out ducts, as well as possible stand-by equipment.
- Check the proper functioning of all the equipment according to the instructions of the operation manual. The mixer should be free from encrusted cement, since it may come loose and cause blockages. It has to be flushed out with water to guarantee cleanliness. The tightness of the valves, the seals of the pump and quick couplers of the hoses should be checked.
- Check that the cement and admixtures have been made available in the required quality and sufficient quantities in the immediate vicinity of the grouting equipment. They should be protected from moisture (rain, splashing from the mixer, etc.). The supply of clean water should be assured, if necessary by a water tank.
- If not yet available, carry out proving or suitability grout tests according to the method statement for grout mixes, or according to the client's project specifications.
- Plan the tendon grouting sequence and prepare the grouting report sheet accordingly.
- Inform the checking or resident Engineer of readiness.

5.3.2 Grouting operation

Grouting of the tendons should always follow the method statement with procedures derived from the proving or suitability tests for the particular project. Generally speaking, the following steps have to be observed:

- It must be checked that all vents have been properly installed as shown on the shop drawings, are closed and free of obstructions. The vent positions should be marked with a tag indicating tendon and vent number for identification in the grouting records. Only shortly before the start of the grouting operation, all vents should be opened.
- Immediately before grouting operations start, ducts of strand tendons should normally be blown out with compressed air in order to expel water and debris present in the ducts and to detect possible obstructions and blockages but this is commonly omitted for bar tendons of small size.
- Start the mixer and pump according to the instruction manual and commence mixing according to the method statement, observing the sequence of adding the components (water, cement, admixture).
- Check the grout consistency at the pump or at the nozzle, connect the nozzle with the lowest grout connection, open the valves at the pump and at the inlet so that the prepared grout mix flows into the tendon duct. The flow of grout in the duct should have a speed up to 12m/min. Grouting should always progress in the same direction.
- Proceed with mixing and grouting until grout is flowing out of the first vent. When the consistency of the grout is similar to that previously measured at the pump, the vent can be closed.
- Progressively close all vents to the end of the tendon according to the method statement. When grout of the correct consistency is flowing out of the last vent, close the vent, and hold the pressure for about one minute. In the event that pressure drops during this period this would indicate a leak which should be investigated.

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- If the grouting pressure reaches a value of around 10 bar, the nozzle of the grout hose should be disconnected from the inlet and connected to the last vent where grout of the correct consistency has been vented out.
- Special cases are tendon couplers, vertical tendons, horizontal and external tendons where special precautions have to be observed. Depending on the detailing of the system, e.g. additional vents and/or inlets need to be arranged or another method of surcharging with grout should be devised.

5.3.2.1 Tendons with couplers

If the first tendon can be grouted before the next one is coupled on, the coupling head can be sealed with a reusable grout cap and the procedure of grouting follows the steps of a normal tendon. This is the preferred method, in which case the first tendon is sealed like a stressing anchorage [Fig 2.3(b)].

- If the first tendon cannot be grouted before the second one has been coupled on, the connection point must be sealed so that no grout can flow from one tendon into the other. The tendons can be treated individually and be grouted as uncoupled tendons (see Fig 5.2). If the risk exists that the connection between the tendons cannot properly be sealed, the two tendons have to be grouted immediately one after the other. This prevents clogging of grout which may have passed through the connection.

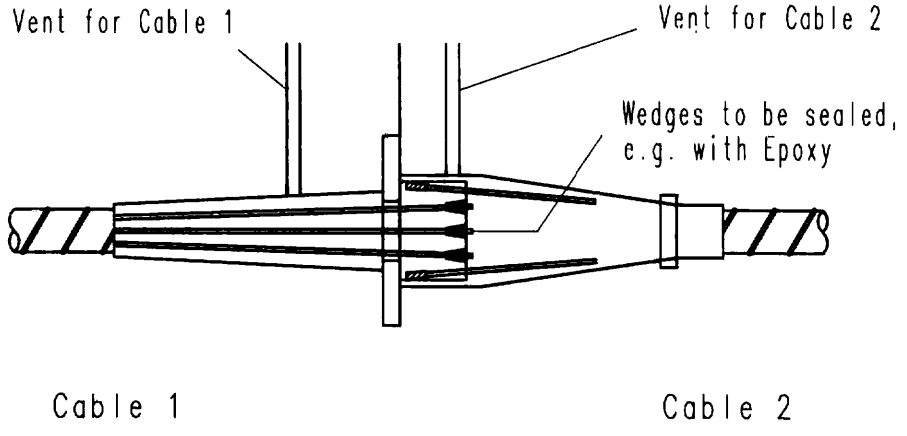


Fig 5.2 Tendons with couplers

5.3.2.2 Vertical tendons

Special attention must be paid to the grouting of vertical tendons:

- The grout pressure can be assumed as 2 bar per 10m height plus an allowance for pressure losses in the piping. Due to the high pressure and the filtering effect of the strands, there is an increased risk of segregation and excessive water bleeding at the top of the grout column. The addition of stabilizing admixtures can largely reduce segregation and bleeding. It is advisable to carry out grout optimisation tests including stabilising admixtures and simulation of the grouting pressure as expected in reality.
- Vertical tendons must be grouted from the bottom upwards.
- The maximum grouting head should be determined, so that the expected maximum grouting pressure does not cause problems to the duct or the structure, such as splitting of concrete. Therefore long vertical tendons sometimes need to be grouted in stages. At the transition of the grouting stages two connections at a spacing of about 1 m

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distance have to be arranged. The lower connection serves as vent for the lower grout section, and the upper one as an inlet for the upper grout section [see figure 5.3(d)]. The grout inlet must be capable of being closed by a valve which can sustain the pressure of the grout head.

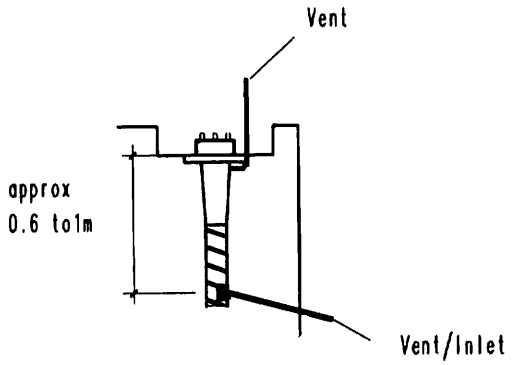
- Special attention should be paid to the nature of sealing the lower termination of the vertical tendon, as it has to sustain a considerable pressure. The grout cap and its fixings have to be designed for the actual pressure. As an additional measure the lowest zone of the tendon can be pregrouted, as can be seen in figure 5.3 (b).
- At the upper end of the tendon, even with the use of stabilising admixture, a certain segregation and bleeding of the grout may be expected. In order to assure complete filling and protection of this top zone of the tendon with its termination, one of the two following solutions shown in figure 5.3, can be adopted:
  - (a) About 1.0m below the anchorage an additional connection is provided [see Fig 5.3(a)]. The tendon is initially only grouted up to this connection and then the connection is blown out with compressed air. In a second step the last 1.0m section is filled with grout through the connection. Alternatively two independent connections at approximately 0.5m spacing can be installed and grouting is carried out as for intermediate grouting stages.
  - (b) A hose with a funnel is fitted to the upper anchorage after grout has exuded out at this point. The funnel is placed about 1m above the anchorage and filled with grout. It thus constitutes a reservoir, from which topping up grout can flow down and displace the air and bleed water that may have accumulated at the top of the tendon [see figure 5.3(c)]. To ensure that bleed water and air can flow up through the hose for a sufficient duration of time, it is recommended that the grout has high fluidity and that setting of the grout be delayed (if necessary by means of a retarder) and that the hose has a diameter preferably in excess of 25mm. The strands projecting through the anchor head seal also facilitate the escape of water and air. Use of the funnel can be unreliable because of blockage and this should be checked. Alternatively, complete filling followed by post-grouting can be successful, using a second inlet about 1m below the top anchorage.

5.3.2.3 Horizontal tendons

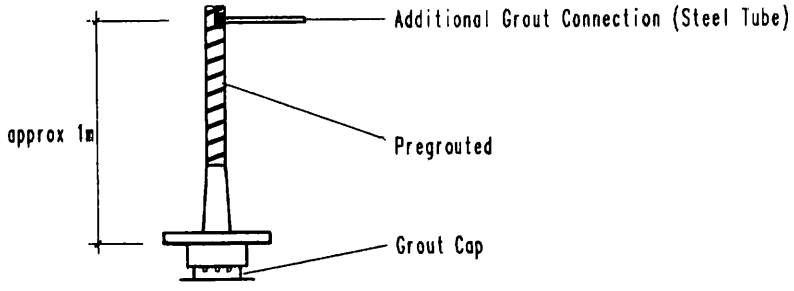
It can be difficult to completely expel air from long horizontal tendons. Small voids may be formed on top of the duct along the horizontal duct length. If the voids are within the tolerable limit the prestressing steel can be considered effectively protected and the grouting result is acceptable.

Vacuum grouting can assist for long flat horizontal tendons (see 5.3.2.4). Vents at closer intervals do not necessarily help to improve the grouting quality. Two adjacent vents arranged at tendon half points, combined with simultaneous post-grouting from both tendon ends could theoretically help expel the remaining air and is held by some to improve the grouting result, but there must be concern over trapping air. Care should be taken not to attempt grouting excessively long lengths from one end and trials may be necessary to prove this.

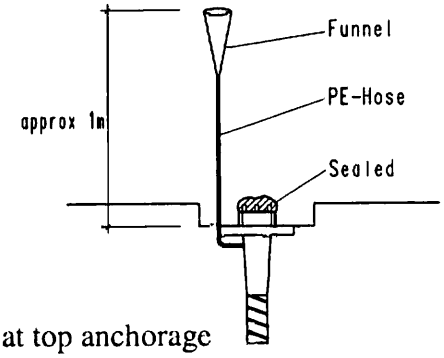
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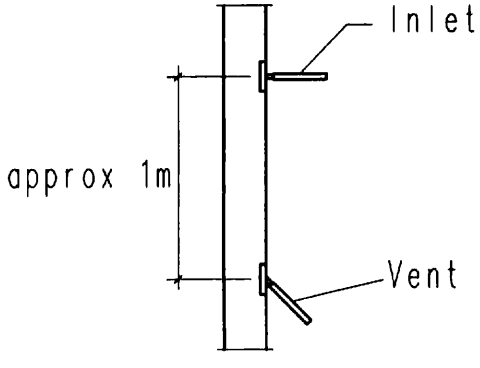
(a) Connection at top of tendon



(b) Grout plug at bottom anchorage



(c) Reservoir at top anchorage



(d) Detail of intermediate vents in long vertical tendons

Fig 5.3 Additional connections for vertical tendons

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5.3.2.4 Vacuum grouting

If well planned and executed, vacuum assisted grouting will provide improved quality of grouting. For vacuum assisted grouting the tendon duct is subjected to a partial vacuum during grouting operation. In the order of 80-90% of the air inside the duct is removed. This partial vacuum will reduce the risk of air mixing with the grout or air being entrapped. For successful vacuum assisted grouting all connection details of ducts, vents, valves, anchorages, etc must be properly sealed to permit creating a partial vacuum and maintaining it.

To perform vacuum assisted grouting a vacuum pump, a pressure reservoir, a two-way valve, and a transparent hose are needed in addition to the standard grouting equipment. With all vents closed the vacuum pump is operated until a vacuum of 800-900 mbar is created, and can be maintained. If this is not possible, the duct system most likely has leaks which must be repaired. Once the vacuum is successfully created and can be maintained, the vacuum pump can be switched off, and grouting can be performed with all vents closed until the tendon is filled. When the grout reaches the two-way valve, the valve is operated to disengage the vacuum pump, and the grout directed to waste. Grouting should continue until the grout reaches the desired consistency at the vent. Subsequently, vents can be operated one after the other as for the standard grouting operation to expel any remaining air or bleed water at tendon high points and at anchorages.

Vacuum assisted grouting may be used for all grouting activities. However, it is considered particularly suitable for long horizontal tendons (where vents are not particularly effective to expel entrapped air), for external tendons where vents cannot be placed exactly at the high point of the tendon profile, and for grouting to repair tendons with voids.

Since vacuum assisted grouting requires the creation and maintenance of a partial vacuum, it can also be considered as quality control test to assure the proper installation and sealing of the tendon duct system before tendon grouting commences. This is quite similar to the leakage test specified in TR 47 *[17]*.

5.3.2.5 Post grouting and re-grouting

Re- or post-grouting should be carried out 30 minutes to about 1 hour after grouting of the tendon, and while the grout is still fluid, if doubts exist that the tendon has not been completely filled. An indication for incomplete filling is vents which are not full of grout, when opened 30 minutes after grouting. Grouting pressure up to 12 bar may be required.

Re-grouting is usually carried out from one end only. The vents are progressively opened in the direction of the grout flow and closed again, after air or possibly water has been expelled and some compliant grout has been pressed out of the vent.

For post-grouting of external tendons, in particular the high points, it is effective to carry this out through the vents arranged at either side of the deviator pipe at high points.

5.3.2.6 High pressure grouting

High pressure grouting is a standard procedure in some countries for strand tendons. It is performed as follows:

One anchorage is sealed with a cap, the other is sealed such that the ends of the strands protrude, usually using dry pack mortar.

Grouting starts at the anchorage with the grout cap until grout exits at the opposite anchorage vent.

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All vents are then closed and grouting pressure increased up to about 12 bar. This pressure pushes water into the interstices of the strands and drips out the protruding ends. The procedure stops when no more water exits.

This has the effect of reducing the water content of the grout and preventing bleeding or segregation.

Whilst this practice is introduced for grouts made with ordinary cement and water, it should not be necessary for grouts designed to satisfy the general requirements given in Section 3.4.

This method and its effects have been discussed and introduced for the approval of tendons with larger capacities in Germany in 1979 ***[10]***.

5.3.2.7 Grouting in cold and hot weather

- When the temperature is expected to fall below 5°C, accurate temperature records should be kept of the air and of the structures adjacent to the ducts to be grouted. No grout should be placed if the temperature of the structure adjacent to the ducts is below 3°C, or is likely to fall below 3°C during the following 48 hours, unless the member is heated so as to maintain the temperature of the placed grout above 5°C for at least 48 hours. No material in which frost or ice is present should be used, and the duct and equipment should be free of frost and ice as well.
- When grouting work has to be carried out in a very hot climate, great care should be exercised to avoid clogging of the grout and blockages in the duct. The structure should not be warmer than 35°C to prevent rapid heating up and setting of the grout. Past practice has been to use chilled water but current technology can enable the grout to be designed to accommodate higher temperatures. In extreme cases the grouting work must be done at night or early morning, when the temperature of the structure is lowest. Special grout mixes with retarder may be used after the corresponding grout suitability tests have been performed.

5.3.2.8 Cleaning of equipment and structure

- After 4 to 5 hours of uninterrupted operation, or at the end of any grouting stage, the equipment together with its accessories should be thoroughly cleaned according to the method statement and the operation manual of the equipment.
- Main seals and valves should be re-checked for their tightness.
- Manometer should be cleaned each hour according to the instructions of the operation manual.
- The threads of the nozzles should be cleaned daily and if wear is appreciable the nozzles should be replaced.
- Worn out elements such as hose couplings, valves etc. should be replaced (spare parts should be available in sufficient number).
- After removal, reusable grout caps should be cleaned.
- The structure should be cleaned from spilled grout after each grouting stage and the debris should be disposed according to the locally valid environmental regulations.

5.3.2.9 Safety requirements

When grouting operations are prepared or carried out, the locally applicable safety regulations should be observed. At least the following precautions are mandatory:

- Protective goggles or shields should be worn when working at pump, grout connections and vent points. If grout should get into the eyes, they must be rinsed

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immediately with fresh and clean water and a doctor should be consulted, as loss of sight may be imminent.
- Nose and mouth should be covered and protected against dust when working at the grout mixer.
- Rubber gloves should be worn when working with grout.
- For further safety requirements, reference is made to the applicable safety regulations on site.

5.3.2.10 Inspection, checking and tests

All grout inlets and vents should be clearly labelled.

During grouting, regular quality control checks have to be made. Grout samples must be collected from the exit of the pump, and from the vent farthest away from the mixer. The frequency of sampling is usually defined in the project specifications or requested by the Engineers.

Internal quality assurance procedures should allow for the following minimum checks:

- **Flow time:** The flow time should be checked and recorded for the first tendon to be grouted and thereafter every 2 hours at the pump. If deviations of about 20% are evident, the grouting specialist has to be called in for review and necessary action. Grout should not be modified by simply adding water without approval of the grouting specialist.
- **Bleeding and Volume Change:** One specimen per half day should be checked, but at least two per grouting stage for volume change and bleeding and the results recorded.
- **Compressive strength:** 3 specimens should be prepared for determining the compressive strength after 7 days.
- **Temperature:** Temperature of the grout constituents, the freshly prepared grout, the air and the structure adjacent to the duct to be grouted. Once daily.
- **Consistency:** Visual check of the consistency of the grout at the pump and the exit of the duct.
- **Density:** The measurement of the density at the pump and the exit of the duct stage is recommended once per half day with at least 2 per grouting stage.
- **Complete filling of the duct:** Not later than 30 minutes after grouting of a tendon, the complete filling should be checked at accessible areas such as vents, connections, caps, inlets and exposed ducts. Either visually or by tapping slightly against exposed parts, the presence of grout should be verified. The results of this check should be recorded.

  At the earliest 12 hours after grouting and after setting of the grout, all vents and inlets are opened and checked for complete filling. Vents which are not completely full, or contain air or bleed water have to be filled "by hand" with grout of the same quality. Topping up can be done, using e.g. a can or a funnel. The interior of the vent should be stirred with a wire to assist the escape of trapped air and water.

On completion of internal tendons vents should be drilled or cut back to the depth of cover the same as the reinforcement, to form a recess which should then be properly capped or sealed.

5.3.2.11 Grouting report

All grouting activities should be documented and recorded on particular quality control sheets. A grouting record must be prepared for each grouting batch, but at least one per day. The record should at least contain the following data and information: (see also Appendix A).
- identification of the project and the grouting batch

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- grout mix design
- time, when grouting operation started and was terminated and weather conditions
- material sources, brand and production date
- equipment type used for grouting
- reference to the proving or suitability tests carried out
- identification of the tendons grouted
- results of all quality control tests of the grout
- number of bags of cement used, to establish comparison with the theoretical quantity of grout for the particular batch (or alternatively, a flowmeter report)
- any particular occurrences
- personnel carrying out the grouting work
- date and signature of the grouting specialist, responsible for the work.

5.3.3 Special procedures

5.3.3.1 Grouting before or after release of formwork

In most cases, the release of the formwork has no adverse effect on the quality of the grout. Only if the release of the formwork causes a considerable movement of the tendon in the duct and the release of the formwork would coincide with the initial hardening period for the grout, grouting should be delayed until after release.

The acceptability of releasing formwork before grouting should be also checked with the structure designer as the temporary lack of bond may reduce significantly the ultimate strength of the structure in the temporary condition.

5.3.3.2 Grouting under traffic loads

Concerns have been raised that vibrations due to running traffic may disturb the setting and hardening of the grout, resulting in a poor quality. In most circumstances, vibrations are typically small to negligible. The grout strength which may be affected by vibrations is not critical, anyway, and the alkalinity providing the corrosion protection is not influenced by them. On-site testing on a bridge in Switzerland in early 1999 *[17]* seems to confirm above statements. Nevertheless, it is advisable that grouting work is scheduled in a manner that setting falls into a period of low traffic, so that risks are limited and minimised.

5.3.3.3 Measures if blockages occur

If blockages occur, they have to either be removed or the grouting procedure has to be adapted such that the tendon duct can still be completely filled with grout. Before remedial measures can be started, the exact location of the blockage has to be found.
The possibilities are as follows:

- Air and water pressure: first it should be tried to remove the blockage by air pressure, only if not successful, water pressure should be used. If the passage cannot successfully be cleared, the water cannot be expelled from the tendon. Water should not be used if there is a risk of frost.
- High pressure water jetting
- Chiselling and removing the blockage is suitable when the blockage lies near the concrete surface and the location could accurately be determined.
- As a last resort, complete removal of the tendon, cleaning the duct and replacing the tendon.

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- If none of the above methods is possible, holes have to be drilled into the duct either side of the blockage to allow grouting either side of the blockage.
- Grouting with vacuum equipment:
  Vacuum grouting can be used, if all aforementioned procedures have proved unsuccessful. This equipment sucks most of the air (up to 90%) out of the tendon duct, filling subsequently the remaining vacuum with grout. However, to create a vacuum, the duct must be airtight and an opportunity for the remaining air must be provided to ascend and escape after the grout has entered. Depending on the size of the air space, it must be re- grouted either by a second vacuum injection or filling "by hand". The vacuum pump is normally equipped with a volume meter which accurately measures the quantity of air to be replaced by the grout. The quantity of the injected grout should also be measured in order to ascertain, that the vacuum produced has effectively been filled. It must be noted that water cannot be sucked out. Therefore, the duct should not be flushed with water beforehand.

5.4 Checking of complete filling of tendons

- Visual checking of the complete filling of the accessible and often critical parts of the duct is part of the quality control checks. However, presently no generally accepted and proven methods exist to verify complete filling on site of the duct with grout after hardening of the grout. In the USA suppliers are being encouraged to provide special access holes in anchorages for borescope inspection behind the anchor head.
- The following definition of the "permissible voids" may be used: voids should generally be in the duct corrugations, cover less than 5% of the diameter of the duct, not be interconnected and no migration of water possible.

5.4.1 Before hardening

- Checking of vents, group caps, connections and drains is part of the standard quality control procedures by light tapping.
- The comparison of the actually injected grout volume with the theoretically required volume helps to avoid gross errors.
- In the UK, the so-called Oxford Grout Quality Control System test has been developed to verify the filling of the duct immediately after grouting (see Grouting Report TR47) and to measure and report on many parameters during the grouting process.

5.4.2 After hardening

Simple methods to detect voids after hardening of the grout are part of the standard quality control measures and should include:

- Visual checking of the filling at the anchorages, by light tapping against the cap or by removal.
- Checking of the filling of any exposed parts of ducts by light tapping on the duct, in particular at high points, sections downstream of the high points and horizontal sections.

Sophisticated methods should only be used if confirmed doubts exist that the filling is incomplete. Such methods, normally carried out by specialists include:

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- endoscopy (most usual and accepted method)
- sonic or ultrasonic methods
- radio-or thermography

Some of these tests are subject to interpretation and should be properly evaluated before relying on the results.

If voids are found remedial grouting may be required which is often carried out with vacuum assistance.

6 Personnel and training

6.1 Qualification and training of grouting personnel

All types of grout, whether supplied in bags as ready-mixed/pre-bagged grout or a site blended mix of dry materials are mixed with water and injected by personnel on site. Assurance of the quality of grout can only be achieved by experienced, well qualified and trained personnel. Therefore, the qualification and training of grouting personnel is of prime importance. This applies to all levels of operatives including supervisor/foreman, technician and trainees.

Whatever the particular designations of the persons responsible for carrying out the grouting operations primary importance must be given to having a systematic QA scheme in operation. Many of the main post-tensioning companies operate training/QA schemes and in some countries there are certification schemes in force.

Examples of the typical requirements for training of post-tensioning and grouting personnel are given together with items they would be expected to have achieved satisfactorily.

Staffing competence should include the following general guidelines:

6.1.1 Grouting technician/engineer

Responsible overall for the grouting operations including materials, testing and control systems. A technician or engineer who has the knowledge and experience to select or confirm a grout mix for a particular site. He is also familiar with grouting operations on site and should demonstrate the following:

1) Minimum of several years of prior experience with grouting of post-tensioning tendons. This should be documented with a list of project references.
2) He should be able to plan grouting activities from a selection of materials, grout mix design, grout testing, to planning and organisation of grouting on site, selection and operation of equipment, and execution of grouting.
3) He should have attended formal Grouting Training.

6.1.2 Grouting supervisor/foreman

The person responsible for the grouting operation on site with a grout mix previously selected by the Grouting Technician/Engineer. He should demonstrate the following:

1) He should be able to plan activities on site from grout testing, planning and organisation of grouting on site, selection and operation of equipment, to execution of grouting, and preparation of reports.
2) He should be able to train labour on site for grouting.

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3) He should have attended formal Grouting Training.
4) He should have at least one year's experience as a Grouting Operative.

6.1.3 Grouting operatives

These are persons who carry out grouting activities under the supervision and responsibility of a Supervisor/Foreman. They should be able to demonstrate the following:

1) Training on site in the activity assigned to the person on the particular project, or prior experience in the same activity, both within the past year.

This training should be specified in the project Quality Plan. The actual training programme and data should be documented, and should be signed by the instructor and the trainee.

6.1.4 Grouting training

In general it is expected that all persons involved in grouting should have had formal training which includes theoretical and practical examples of using the equipment, materials and testing.

This should include a minimum period on site as a trainee under training.

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References

[1] FIP Guidelines for Grouting 1990.

[2] Concrete Society Technical Report 47 "Durable post-tensioned concrete bridges".

[3] PTI Guide Specification "Grouting of Post-Tensioned Structures". February 2001.

[4] Bulletin officiel Marchés publics de travaux. Modalités d'application du fascicule No. 65A CIRCULAIRE No. 99-54 du 20 août 1999 instituant un avis technique des coulis d'injection pour conduits de précontrainte, délivré par la commission interministérielle de Précontrainte.

[5] EN 523 – 1997 – Steel strip sheaths for prestressing tendons – Terminology, requirements, quality control.

[6] ASTM A653 "Standard specification for steel sheet, zinc coated (galvanised) or zinc-iron alloy coated (galvannealed) by the Hot-dip process".

[7] EN 524-1-6 – 1997 – Steel strip sheaths for prestressing tendons – Test methods.

[8] ***fib*** Bulletin No. 7, 2000 : *Corrugated plastic ducts for internal bonded post-tensioning.*

[9] PTI Guide Specification "Acceptance Standards for Post-Tensioning Systems" September 1998.

[10] DIBt Communication 1979. Grouting Technology of tendons with more than 1500kN Prestressing Force.

[11] EOTA ETAG Guidelines for Technical Approval of Post-Tensioning Kits for Prestressing of Structures, September 2001.

[12] FIP Notes 1991/4 Galvanisation of Prestressing Steels.

[13] FIP Recommendations "Corrosion protection of prestressing steels", 1996.

[14] ***fib*** Bulletin No. 15, 2001: *Durability of post-tensioning tendons.* Proceedings of workshop, Ghent, Belgium, November 2001.

[15] Standard Specifications for Highway Bridges 15th edition American Association of State Highway and Transportation Officials. Washington DC 1992.

[16] prENV 13670-1 Execution of Concrete Structures, 1999.

[17] R. Lardi and L. Abt: *Schwarzwaldbrücke in Basel*, tec 21, Journal of the Swiss Association of Architects and Engineers, No, 5, 2 February 2001, pp13-20.

[18] EN 445; 446; 447; 1997 Grout for prestressing tendons. Test Methods, Grouting procedures, specification for common grout.

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Appendix A : Grouting forms

Attached are a checklist and model forms to be used on site to record the quality control testing for grout, and to confirm compliance with requirements:

A1 Typical procedures / checklist

A2 Grout test report

A3 Grouting report / cement consumption

A4 Grouting schedule / tendon identification

A5 Mix design

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A1 Typical procedures

A1.1 Site organisation

- Appoint Grouting Technician/Engineer and Supervisor/Foreman to the specific site/project early to allow proper preparation and planning of grouting and in particular selection and/or confirmation of the grout mix.
- Appoint grouting operatives, confirm their qualifications, and organise training as necessary.

A1.2 QA plan

- Prepare a Quality Plan including grouting activities, adapted to the use for the specific site/project.

A1.3 Review of project specification and contract

- What standards or specifications apply to this site?
- Are the grouting requirements and conditions specified more restrictive than those previously experienced?
- If so, can they nevertheless be fulfilled with the envisaged materials/equipment/methods?
- If not, appropriate steps must be initiated such as discussing with the responsible engineer, with the objective of getting the specified requirements modified. If this is not possible, a preliminary and approval testing program must be launched to confirm a new grout mix which meets the project specification.
- Is drinking water available on site? If not, anticipate testing of water.
- Is there a laboratory on the site with the equipment necessary to carry out required testing? If not, organise the appropriate equipment or find an outside laboratory.
- Is the cement for grouting (if supplied direct) from a reputable source and able to be of prescribed controlled properties?

A1.4 Select and confirm grout mix

- If required select an approved grout mix with a specific cement for which there exists an approval test program, done in the same region with the same material specifications with the same grouting equipment and under comparable weather conditions intended to be used on the site. Obtain a copy of the Approval Test report for the project file.
- Alternatively, propose a grout mix to comply with the particular specification.
- Prepare and execute suitability test program for the materials and equipment used on site to confirm compliance of grout properties with those determined in the approval test program. Prepare test report and include it into the project file.

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- If no approved grout mix is available, select a suitable cement and admixtures complying with the specifications and determine the mix design. After successful completion, do proving and suitability test program to confirm compliance of the grout mix with requirements.
- Inform the Engineer prior to testing. Prepare proving and suitability test report and include it into the project file.

A1.5 Confirm grout mixer and mixing time

- Preferably select a grout mixer for which the mixing characteristics and performance are known, and confirmed by testing. This will allow to choose the optimum mixing time for the selected grout mix and quantities intended to be used on site.
- If a mixer without previous experience or without known characteristics and performance is intended to be used, the mixing performance should first be determined. Optimum mixing time should be determined to assure specified grout performance in terms of sedimentation.

A1.6 Prepare site installation and materials

- Prepare particular grouting method statement for the site including materials, equipment, personnel, schedule of grouting, quality assurance measures and reporting, safety measures.
- If possible use standard method statements and check for any modifications necessary.
- Select, order, and verify proper functioning of all grouting equipment needed.
- Anticipate need for stand-by equipment for critical activities.
- Verify whether standard equipment is suitable or whether site rather merits set-up of a grouting plant.
- Order and prepare grout components (cement, admixtures) in sufficient quantities, and store appropriately. Check the weight of cement bags.
- Collect certificates for all grout constituents and confirm compliance of materials with the specification. If certificates are not available, reject materials or confirm characteristics with tests done in an independent laboratory.
- Assure water supply. Possibly, use two independent lines or reservoir with pump, so that even in emergencies a tendon can be flushed out when necessary.
- Seal all anchor heads.
- Identify/tag all grout connections and vents of each tendon, check that drains, if any, are closed. Check compliance with shop drawings.
- Check that ducts are clear with compressed air.
- Safety : Have protective goggles, masks and rubber gloves ready. Make sure you know how to get in touch with the nearest doctor/hospital. Have eye wash tools available.
- Plan sequence of tendon grouting.
- Prepare all grouting quality control forms, including "Grout Test Report"/"Grouting Report"/"Cement Consumption"/"Grouting Schedule"/ "Grout Mix Design".

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- Inform inspection organisation (Engineer).

A1.7 Carrying out of grouting

- Inform inspection organisation (Engineer).
- Ambient conditions (temperature): Are they suitable for grouting, and are they consistent with the expected range when preparing and approving the grout mix? Record them.
- Comply with safety regulations (protective goggles, eye wash tools, mask against dust, rubber gloves).
- Fit grouting nozzle to first tendon to be grouted as per method statement.
- Mix grout, check flow time, record data.
- Collect grout samples for quality control tests as required, and record.
- Grout from first connection to end of tendon in the same direction, as per method statement.
- Close first vent as soon as grout flows out at the required consistency. This applies to all subsequent vent/connections, including the vent at the anchorage/cap at the tendon end.
- Collect the issuing grout for environmental reasons, and to avoid staining of the structure.
- If pressure at inlet rises towards 10 bar, fit grouting nozzle to next already filled connection, as per method statement.
- When the tendon is full (last vent closed), maintain the pressure for one minute, close inlet opening, remove nozzle and fit to next tendon. For long tendons with several high points, vents may need to be opened again to allow accumulated air and water to be expelled.
- Check flow time for quality control testing, and record. Measure also density of grout, and record grout temperature.
- Clean grouting equipment after 4 to 5 hours uninterrupted operation.
- Check specimens for volume change and bleeding for quality control testing, and record. Prepare specimens for determining compressive strength.
- After grouting is finished, thoroughly clean all equipment, hose lines, manometers, etc.
- Check all accessible areas of tendons immediately for complete filling and top-up where necessary.
- Fill in all relevant reports such as "Grout Test Report" and sign them.
- On the day after grouting, check all connections for complete filling and top-up where necessary. Check accessible areas of tendons for filling.

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Appendix A2: Grout test report

Project/Site : .....
Part of Structure : ..... Page.....of .....

Weather : Sunshine / Cloudy / Rain / Snow
Temperature : Air ...../ Water...../ Cement...../ Grout...../ Structure..... (°C)

Materials
Cement : Supplier/Brand:
Reference to Data Sheet:
Reference to Standard:
Production Date:
Water Source :
Admixtures' Brand :

Mix proportion : Cement .....kg / Water .....litres / Admixtures
.....

Equipment/Mixer : Type :
Batch Volume : litres
Mixing Time : minutes

QUALITY CONTROL TESTING

Cable N°	Location of sampling 1)	Time of sampling	Flow Cone Time	Bleed Container N°	Initial Filling Height (mm)	Height of grout (mm)	Measurement at time (hours)	Water depth (mm)	Volume Change %	Bleed %	Compressive strength (MPa)	Density (kg/m3)
							0					
							3					
							24					
							0					
							3					
							24					
							0					
							3					
							24					
							0					
							3					
							24					
							0					
							3					
							24					

1) M = Mixer, S = Cable Start, E = Cable End

Grouting Supervisor/Foreman :
Date :
Signature :
Personnel :

Office :
Grouting Technician :
Checking Date :

Signature :

Appendix A3: Grouting report / cement consumption

Project/Site :	
Part of Structure :	Page of

Cement :	Supplier : Brand :

Daily Cement Consumption :

Date : .....

Time : From – To(hour)	00 01	01 02	02 03	03 04	04 05	05 06	06 07	07 08	08 09	09 10	10 11	11 12	12 13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	20 21	21 22	22 23	23 24	Actual Total No of sacks	Actual Total Vol of Grout (l)
No of Sacks used																										

Cable no grouted																										
Theoretical Grout Volume (litre)																									Theoretical total Grout Volume (l)	

Comments :

Grouting Supervisor / Foreman :
Date :
Signature :

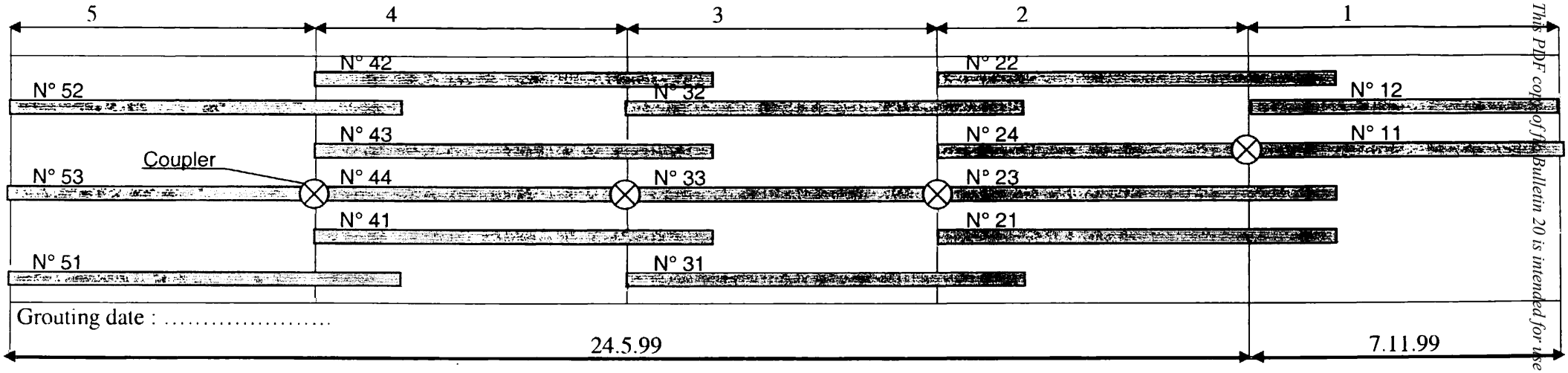
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Appendix A4: Grouting schedule / cable identification (model)

Project/Site :
Part of Structure :

Date :
Signature :

Construction Phase :



Cable N°	N°/Size of Strands	Duct Ø (mm)	Cable Length (m)	Theoretical Grout Vol (l)	Required No of sacks cement
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....

Summary :

- Theoretical No of Sacks : .....
- Reserve : .....

Total No of Sacks needed .....

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Appendix A5: Grout mix design

Project/Site : Part of Structure : Page of

Mix Design : • Cement kg • Water kg • Admixture 1 (kg or l)* 2 3 Water/Cement Ratio : W/C = ... * include liquid content into w/c
Mixing Procedure: • Batch size (l) • Mixing Sequence • Mixing Time • Mixer Type *(minutes)*

Proving Test Reference :	Report No	.....
	Date	.....
	Author	.....
Suitability Test Reference :	Report No	.....
	Date	.....
	Author	.....

Grout Materials	Supplier	Brand
• Cement • Water • Admixtures 1 2 3 ...		—

Grouting Technician : ..... Date : Signature :

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Appendix B : Test methods

Attached are suggested test methods which are compatible with the test and performance requirements for grout given in the text:

B 1 Inclined tube test

B 2 BRITE Euram 1.5m vertical strand test for bleed and volume change

B 3 Measurement of viscosity with 'scissometre'

B 4 Sedimentation test

B 5 Density test

B 6 Fluidity test

B 7 Strength test

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B 1 Inclined tube test

B 1.1 Objective

This test serves to determine the bleed properties and stability of grout which has successfully passed preliminary testing, at full scale and including the filtering effect of strands. It also allows confirmation of the proposed grouting procedures, in particular the effect of time between ending an initial grouting and starting of re-grouting on site, if specified, and equipment used on site. The intent of the test is to confirm that a duct on site can be completely filled with the proposed grout, equipment and procedure without excessive bleed of the grout.

B 1.2 Test method

In a first test phase, the bleed water and air accumulated on top of a tube filled with grout should be determined. The grout is injected under pressure and is setting such that water losses due to evaporation are prevented. In a second phase, the effect of re-grouting of a tube on bleed water and air accumulated can be determined, if such a procedure is envisaged.

B 1.3 Test equipment and set-up

- Two transparent PVC tubes, of approximately 80mm diameter and 5m long, equipped with caps at each end including grout inlet at the lower end, and grout vent at the top. The tubes should be able to sustain a grout pressure of at least 1 MPa.
- 12 prestressing strands Ø 15-16mm per tube, i.e. a total of 24.
- Grouting equipment as per the grouting method statement.
- A thermometer with automatic recording.

B 1.4 Test procedure

- The two tubes are fixed on their supports such as to avoid noticeable deflections, at an inclination of 30° ± 2° against a horizontal reference line. 12 strands should be installed in each tube. The caps are subsequently installed on the tube ends (fixed with glue), see Fig. B1.
- The grout is prepared as per the grouting method statement. Specimens should be taken from the grout mix to confirm flow time. In case of a thixotropic grout, other methods must be used.
- Grouting of first tube:
  Grout is injected into the first tube (Tube 1) from the bottom end. When the grout exits from the vent at the top with the same consistency as it enters at the bottom, the valve should be closed, and the grout pressure should be maintained at the value and for the duration specified in the method statement. Subsequently, the value at the bottom is closed, and grouting of Tube 1 is considered complete.

  The level of air, water, and any other eventual liquid on top of the grout should be measured, see Fig B1. Such eventual liquid on top of the grout can be distinguished from the grout by its whitish to yellowish colour, usually clearer than the grout. A minimum of 4 measurements of levels should be taken between 0 and 24 hours after completion of grouting, with one measurement just before re-grouting of Tube 2 is started. The following 4 measuring intervals are suggested: 30 minutes, 1 hour, 2 hours and 24 hours after grouting.
- Grouting of second tube:

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Grouting of Tube 2 should follow the same procedure as used for Tube 1, and should be done quasi simultaneously with Tube 1. At a time specified in the method statement for re-grouting, the mixing of grout in the equipment is started again, and the flow time of the grout is determined again.

Subsequently, the valves of inlet and vent of Tube 2 are opened again, and grouting is started again. This will allow any liquid accumulated on top to be replaced by grout. When grout exits from the vent on top, the valve is closed, and the grout pressure is maintained for the duration specified in the method statement. Subsequently, the valve at the bottom is closed, and re-grouting of Tube 2 is considered complete.

The time between initial grouting and re-grouting, and the duration for the second mixing activity, should comply with the grouting method statement. Typically, this time will be between 30 minutes and 2 hours.

Similar to Tube 1, the measurement of levels are done between 0 and 24 hours after completion of the initial grouting. One of the measurements should be taken just prior of re-grouting Tube 2 followed by measurements 30 minutes, 1 hour and 2 hours after completion of re-grouting.

B 1.5 Reporting of results

The following results and observations should be recorded:

- Description of test set-up.
- Grout mix design, origin and certificates of all grout constituents.
- Mixing procedure of grout.
- Flow time of grout mix before initial grouting, and before re-grouting (or viscosity of a thixotropic grout).
- Method statement for grouting.
- Measurements of level of air, water and eventual liquid on top of the grout.
- Any observations and comments on the formation of bleed or liquid, or on difficulties encountered during the test.
- Development of temperature during the entire test period.
- Photos illustrating test set-up, and details of top end of tube with air, water and eventual liquid.

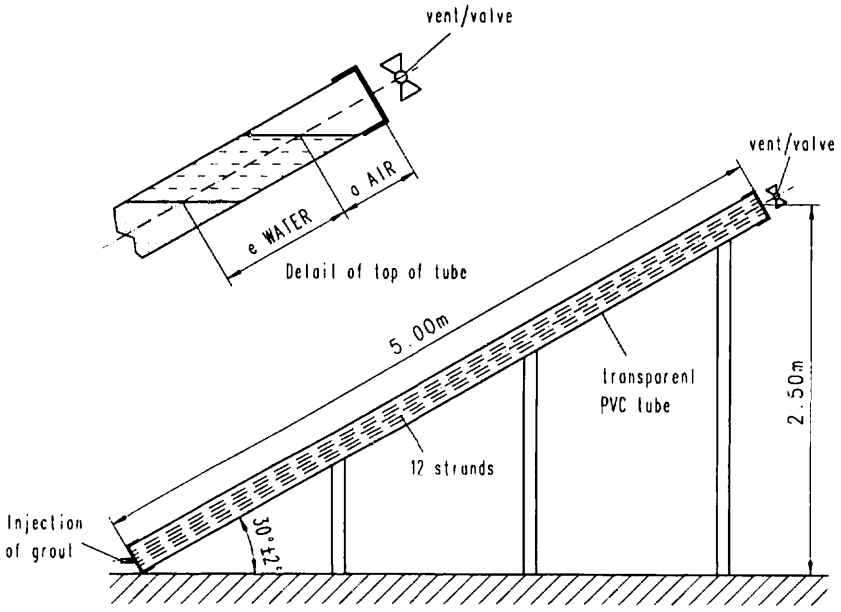


Fig. B 1 Inclined tube test set-up

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B 2 BRITE Euram 1.5 m vertical strand test for bleed and volume change

Preamble

It as been observed that the type of bleed test currently specified in most National Codes, and in the first edition of the UK Concrete Society Report TR47, fails to identify potentially unstable grouts. The important feature missing from these tests is the destabilising effect of the 'wick action' which is imposed by the presence of strands. This shortfall has been addressed by LCPC in France by the development of an inclined tube test. It has also been addressed in a BRITE Euram Project 'QA of Grouting', by the development of a 1.5m vertical test. The latter test is simpler, quicker and cheaper, and is described in this proposal.

Alternative tests are continuing to be developed, with a desire to create the simplest test that can reliably distinguish between good and bad grouts. In the USA and in the ETAG a 1m vertical tube test with a single strand to act as a wick is specified. It is not yet known if this is as discerning as the more extensive tests and it is thought that the tube should perhaps be inclined to simulate conditions in the field.

The major international prestressing specialists are carrying out trials to compare the test methods and it may be that a simpler bleeding/stability test can be introduced in the near future. However, until such tests are fully correlated and proven to detect poor quality grouts, the tests in this section are recommended.

It has also become evident that current specifications that require bleed water to be reabsorbed in 24 hours have no logical basis. If bleed water develops, reabsorption will merely create an air void.

Likewise, requirements to measure the bleed water after three hours are not necessarily relevant to modern grouts.

A specification for the bleed test is given in the following sections.

B 2.1 Equipment

The test also enables volume change to be measured.

Vertical duct of transparent material with one end sealed.

Internal diameter,	d_i	=	60 to 100mm
Height,	h	=	about 1.5m
Prestressing Strands			
Effective diameter,	d	=	about 16mm
Length	l	=	1.4m
Number of strands	N	=	sufficient to fill about 30% of cross sectional area of the duct, ie $Nd^2 = 0.3d_i^2$

B 2.2 Procedure

- Set up transparent duct in a vertical position with its open end at the top. Provide rigid fixing preferably on a concrete floor so that no movement or vibration can occur.
- Install the strands in the duct, ensuring that they are all firmly located on the base.
- Pour the grout into the duct at a steady flow rate (either from the top or using a small diameter tremie tube) to ensure there is no trapped air. Fill the duct to a height, h_o, about 10mm above tops of the strands. Put plate on to top of duct to minimise evaporation.
- Record starting time and height of the grout.
- Record height of grout, h_g, at 15 minute intervals for first hour and subsequently at 30 minute intervals until there is no further change in 3 consecutive readings. NB: The purpose of recording at intervals instead of simply taking the final value is to be able

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to follow the behaviour of expansive grouts. If, for one reason or another, the grout has been left for a time before being poured into the duct, expansion may be completed and measured behaviour will be affected. Measurements should ignore the meniscus on the grout.

- Record height of bleed water, h_w, at the same times as the grout.
- Record any inhomogeneties that may develop in the appearance of the grout as seen through the transparent duct. Examples of inhomogeneties are:
  - formation of lenses of bleed water below top of grout
  - segregation leading to areas of different coloured grout

B 2.3 Reporting of results

Bleeding is expressed as $\frac{h_w}{h_o} x\ 100\ per\ cent$

Volume change is $\frac{h_g - h_o}{h_o} x\ 100\ per\ cent$

B 3 Measurement of viscosity with 'scissometre'

B 3.1 Principle

The stiffness of thixotropic grout is measured by use of a torque meter and a cross-piece vane which shears the grout when rotated.

B 3.2 Apparatus

The apparatus comprises:

- 1 support
- 1 vane with a depth and diameter of 38mm
- 1 calibrated spiral spring
- 1 cog-wheel drive fitted with a dial graduated from 20 to 300
- 1 manual control screw
- 1 pointer linked to the vane
- 1 pointer scale

B 3.3 Mode of operation

Let the grout rest at least 30 seconds.

Plunge the vane vertically into a zone away from the sides until the top is level with the surface of the grout.

Steadily turn the vane, without nudging, until shearing is complete (when the needle returns) and note the maximum deviation indicated by the dial/meter.

Repeat a further time.

B 3.4 Reporting of results

The viscosity of the grout must be between 120g/cm^2 and 200g/cm^2 immediately after mixing and remain at 200g/cm^2 for the duration of injectability.

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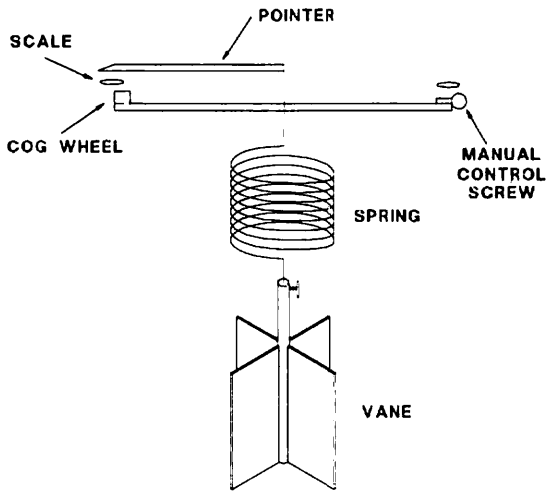


Fig B 2 Scissometre test set-up

B 4 Sedimentation test

B 4.1 Principle

The sedimentation is measured as a percentage difference in density of the grout between the samples taken from the top and bottom of the test cylinder.

B 4.2 Apparatus

A transparent graduated cylinder 60 mm to 100 mm internal diameter and approximately 1 metre in height.

B 4.3 Test procedure

Place the cylinder on a horizontal surface free from shocks or vibration. Fill it with grout (either from the top or using a small diameter tremie tube) to the top and seal the cylinder to prevent evaporation. At least 24 hours after filling the cylinder remove the grout column intact from the cylinder. Take two samples from each end of the grout column of approximately 50mm length. Keep the samples immersed in water. Measure the density of each of the four samples by an approved method.

B 4.4 Reporting of results

Sedimentation is the variation in the density of the sample from the top compared with the density of the sample from the bottom, expressed in percent. The variation of the density of the second top sample compared with the density of the second bottom sample shall also be reported.

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B 5 Density test

B 5.1 Principle

The density is measured as the ratio of weight to volume in both the fluid and the hardened state.

B 5.2 Apparatus

The apparatus comprises suitably calibrated equipment for weight and volume measurement.

B 5.3 Reporting of results

The method of sampling, measuring weight and volume, the equipment used and the density determined shall be reported.

B 6 Fluidity test

B 6.1 Principle

The fluidity of the grout, expressed in seconds, is a measure of time necessary for a stated quantity of grout to pass through the orifice of the cone, under stated conditions.

B 6.2 Apparatus

The following apparatus is required for the test:

(a) Cone — A cone as shown below. It shall be robust and manufactured from materials not reactive with any materials specified.

(b) Sieve — The sieve aperture shall be 1.5 mm and the sieve shall be fitted as shown in Figure B3, and shall be removable.

(c) Stopwatch — The stopwatch shall be accurate to 0.2 s in 60 s and shall show time to 0.1s.

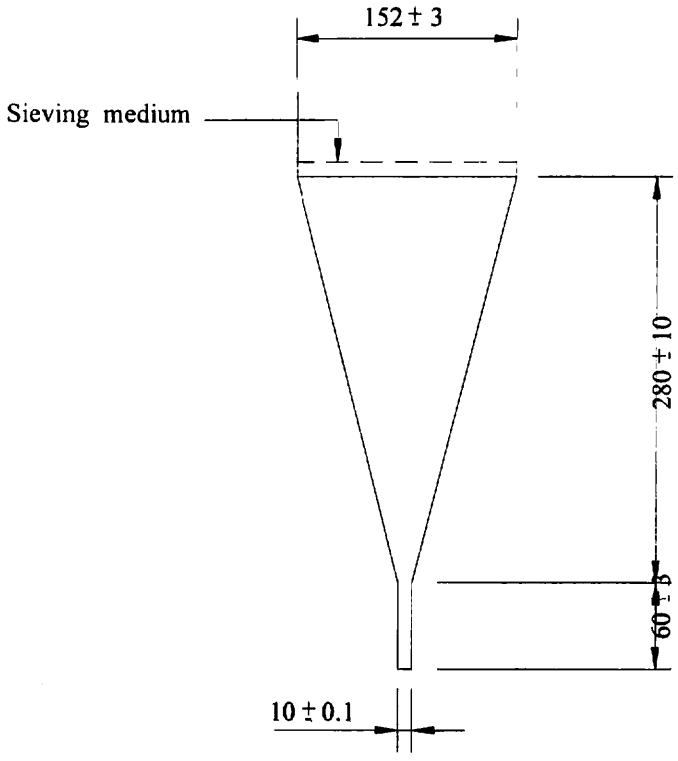
(d) Cylinder — A graduated cylinder of minimum 1 litre capacity and diameter in the range 60mm to 150mm.

B 6.3 Test procedure

Mount the cone with its axis vertical and its largest diameter uppermost. Fix the sieving medium at the position indicated in Figure B3. During the test prevent the cone from vibrating. Place the cylinder under the cone outlet. All surfaces of the cone shall be clean and shall be dampened so that the surfaces are moist but without free water. Close the lower cone orifice.

Pour the grout through the sieve to fill the conical section of the cone. Pouring shall be sufficiently slow to prevent the build-up of air in the grout in the cone. Open the lower cone orifice and at the same time, start the stopwatch. Measure the time taken to the nearest 0.5 s to fill the cylinder to 1 litre. The presence of lumps on the sieve shall be reported. For Suitability Testing, three tests shall be carried out, the first immediately after the grout is mixed and the remaining two tests at the estimated time to grout a duct or a minimum of 30 minutes after the grout is mixed. The grout shall be kept agitated while awaiting testing.

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All dimensions in millimetres
Dimensions are internal

Fig B 3 Cone for fluidity test

B 6.4 Reporting of results

Report the time to the nearest 0.5 s. Report also the presence of lumps.

Report the result as the average of the times determined in the second and third tests, separately from the result of the first test. Report the average time to the nearest 0.5 s.

For Acceptance testing, the test shall be performed on grout from the mixer at the start of grouting of each duct and every two hours after that.

B 7 Strength test

B 7.1 Principle

The strength is measured in tests on cubes or cylinders or prisms according to relevant National Standards.

B 7.2 Apparatus

The apparatus comprises suitably calibrated equipment for load application.

B 7.3 Reporting of results

The strength is expressed as the load at failure divided by the loaded cross-sectional area of the specimen.

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Grouting of tendons in prestressed concrete

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Appendix B: Test methods

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