# STRUCTURAL ENGINEERING SOCIETY NEW ZEALAND (INC)

# PRECAST CONCRETE - GROUTED CONNECTIONS AND DROSSBACHS - SESOC GUIDANCE

## GD#1 : EXISTING (LEGACY) BUILDINGS - INVESTIGATION AND REMEDIATION

DRAFT ISSUE #7 - 12 NOVEMBER 2021

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# GUIDANCE DOCUMENT 1

## Existing (Legacy) Buildings - Investigation and Remediation

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### 1. INTRODUCTION

1.1. Precast concrete elements such wall panels, floor units, beams, and columns, are widely used in the construction of buildings throughout New Zealand. The CAE document "Guidelines for the Use of Structural Precast Concrete in Buildings" which was first published in August 1991 (CAE 1999), notes that precast concrete has steadily increased in use since the early 1960's, with a particular increase in the use of precast concrete for seismic resistance systems in the mid-1980's. As a result, precast concrete elements are a common feature in a large proportion of the existing buildings in New Zealand.

1.2. One of the critical aspects of using precast concrete elements within a building is the process of providing a structural connection between the element and the rest of the building superstructure. Common methods of providing structural connections include:

a) Projecting starter bars cast in to poured insitu elements

b) Welded connections

c) Mechanical connections

d) Grouted connections

1.3. Grouted connections in particular are a widely used method of providing structural connections to precast concrete elements, in particular connections to wall panels, beams, columns, and a combination of these. It is these types of grouted connection within existing legacy buildings that is the subject of this particular paper.

*Important Notes:*

*This paper specifically deals with investigation and review of grouted connections in existing building structures. It is not intended to provide guidance on design or monitoring of new grouted connections. That aspect is covered separately in companion Guidance Document #3.*

**Document History**
Prepared by : Fraser Thomas Limited / B J Holliss
Revision status : 7
Date : 12 November 2021

*It is also assumed in this paper that any investigation and assessment of the quality and effects of defective grouted connections is undertaken by a suitably qualified and experienced structural engineer. Generally this means that this work would be undertaken under the direction of a CPEng structural engineer who is experienced in the design and construction monitoring of the type of building in question.*

## 2. COMMON FORMS OF GROUTED CONNECTION

2.1. There are several different types of grouted precast concrete connection that is commonly found in existing and new buildings. The two most common types are "Drossbach Ducts" and "Proprietary Grout Sleeves".

As stated in the introductory paper by Brown (2021), grouted connections are defined and classified as the following:

**'Grouted (reinforcing) connection'**: A connection between precast concrete elements formed by a starter reinforcing bar projecting from one element into a tubular recess in the adjoining element which is subsequently filled with grout. The connection enables a generic form of reinforcement splice to be made, and the recess can be formed in different ways, using different products e.g.:

(i) **'Drossbach Ducts'** being corrugated metal ducts formed by spiral winding of thin – gauge steel sheets, commonly referred to as Drossbach ducts in New Zealand. Drossbach splices are a generic design and are required to satisfy the lap-splice provisions of NZS 3101:2006.

(ii) **'Proprietary Grout Sleeves'** being connectors used to connect ('couple') reinforcing together using a short grouted length. Grout sleeves are typically a proprietary product and should be designed to satisfy the 'mechanical connection' provisions of NZS 3101:2006.

2.2. Drossbach Ducts

The Drossbach duct system uses typically generic lengths of corrugated metal tubes that are cast into the precast concrete element. The ends of the duct are sealed off to prevent concrete from entering during the casting process, and the tubes lap with the adjacent parallel reinforcing within the precast element. Once the precast element has been constructed and placed on site with the reinforcing starter bar inserted, the ducts are pumped full with flowable high strength grout which once hardened will provide a structural bond between the starter bars and the precast element The figure below shows the typical cross section detail of Drossbach ducts being used.

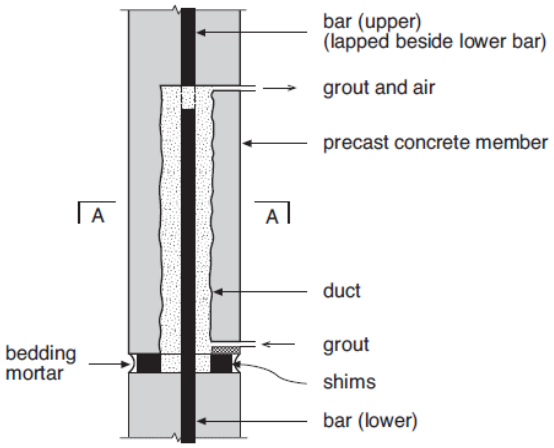


*Figure 1: Example of an early Drossbach duct joint between precast concrete wall panels (excerpt from CAE 1999)*

2.3. Proprietary Grout Sleeves

Grouted sleeve connections tend to be proprietary products and use a much shorter ribbed sleeve that is cast into the precast element with one end mechanically fixed to the longitudinal reinforcing within the element, and the other end open to insert a short starter bar from the supporting structure into, to form a grouted splice. As with Drossbach ducts, once the precast element has been constructed and place on site, it is pumped full of a flowable high strength grout or epoxy to provide a bond between the starter bar and the precast element. The figures below show a typical cross section detail of a grouted sleeve connection as well as an example of a commonly used proprietary Reid Grout Sleeve system.

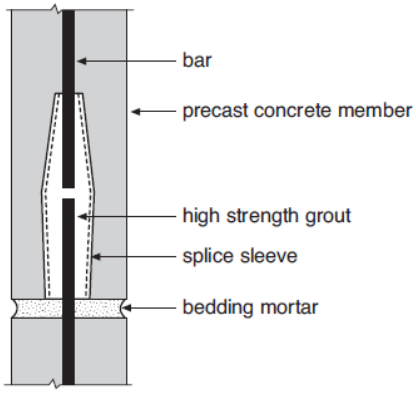


*Figure 2: Example of an early grouted sleeve joint between precast concrete wall panels (excerpt from CAE 1999)*

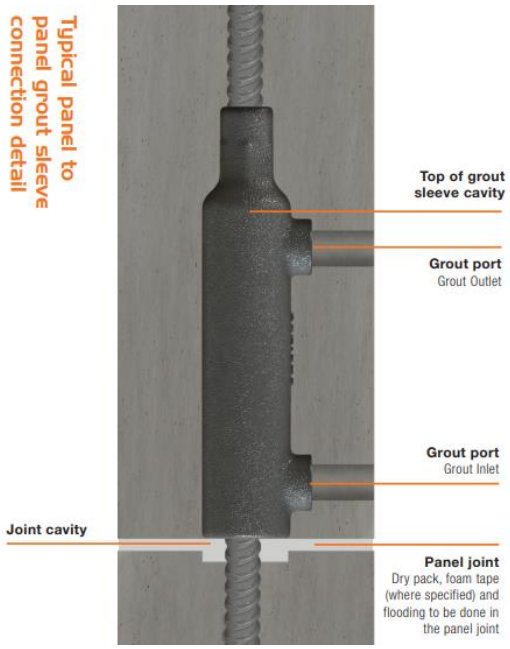


*Figure 3: Example of the Reidbar Grout Sleeve system (excerpt from the Ramsetreid Installation Guide)*

## 3. DEFECTS IN GROUTED CONNECTIONS

3.1. As with all building construction, it is possible for grouted connections within precast concrete elements to be constructed incorrectly. Because these are used to provide a specifically designed structural connection, often in a manner that contributes to the buildings primary seismic resistance system, any deficiency in the construction of these connections has the effect of reducing the structural performance of the building.

3.2. The two main forms of defective construction in grouted connections include the following:

- The duct or sleeve is either not filled with grout or inadequately filled (i.e. less than the minimum required to fully develop the tension capacity of the starter bar)
- The starter bar is either not present, or is not sufficiently long to achieve the required development length

The impacts of both types of defects on the overall structural performance of the building are described in later sections of this report.

3.3. In addition to construction defects, it is possible for grouted connections to also be defective through design errors, such as inadequate consideration being given to joint ductility, overstrength, and hinging requirements, incorrect development lengths, as well as inadequate specification of materials and components.

3.4. The focus of this particular paper is on the detection and remediation of construction related defects in grouted connections. Reports of testing by non-destructive methods has indicated possible other defects such as micro-cracking and low-density grout. However, these have not been tested or investigated in-depth as part of defects described in this paper.

## 4. INADEQUATE AND/OR LACK OF GROUTING

4.1. When Drossbach ducts and grouted sleeve based systems are not filled with sufficient grout there is a reduction in the available bond between the starter bar projecting from the supporting element, and the sleeve that is cast in to the precast element. This can lead to two common issues:

a) Reduction of the precast element's structural capacity increasing the risk of rupture and/or collapse of part of or the whole building structure

b) Introducing a route for water to enter the building envelop leading to downstream weathertightness issues and/or corrosion of the reinforcing starter bars within the duct or sleeve.

4.2. Experience from the investigation of defects within existing buildings has shown a trend of significant variations in the quality of grouting in both Drossbach duct and grouted sleeve type connections. This is often a result of shortfalls in quality control processes during the fabrication of:

a) the placement of ducts or sleeves within the precast elements,

b) the placement of grout injection and air outlet tubes within the precast elements,

c) the placement of the reinforcing starter bars,

d) sealing of voids along the joints between elements and of the grout injection tubes

e) quality of the grout mixture (i.e. amount of water added)

f) adequacy of grout placement

4.3. The existence of deficiencies in any of the above typically lead to either or both of the following two issues:

a) Reinforcing starter bars are not present within the grouted connection (i.e. were out of alignment with the ducts and therefore removed, bent over, or cut off, by the contractor to enable the installation of the precast element)

b) Grout is either not present within the grout sleeve/drossbach duct or is insufficient to provide the required development length of the starter bar. This can also require derate factors to be applied to account for low grout strength, and the presence of voids.

4.4. Deficiencies in the construction of these grouted connections can be present in several forms within a building:

a) Wide spread deficiencies in all (or the majority) of precast elements

b) Scattered deficiencies throughout the building varying from element to element

c) Whole elements with deficient connections (caused either by defective construction and/or defective design)

## 5. DEFECT EXAMPLES

5.1. Empty (ungrouted) drossbach duct

The following photo was taken using a small diameter inspection camera inserted into the top of a drossbach duct in a precast panel within an existing building. As can be seen, whilst a starter bar is present within the duct, there is no grout present within the duct void to bond it to the panel.


*Figure 4: Example photograph of a starter bar within a Drossbach duct without any grout present*

5.2. Inadequately grouted sleeve connection

The following photo shows an example of a grout sleeve connection that has been removed from a precast wall panel within an existing building, and cut in half to enable inspection of the starter bar and grout within the void. In this case the starter bar stops short of the full length of the grout sleeve, and the grout has not fully penetrated the grout sleeve void.

*Figure 5: Example photograph of grout sleeve with a short starter bar and voids within the grout*

5.3. Missing starter bar

The following two photographs show examples of missing starter bars. The first being an ungrouted drossbach duct that is also missing the starter bar. The second is of a grout filled duct that has been broken out and found to have no starter bar present.

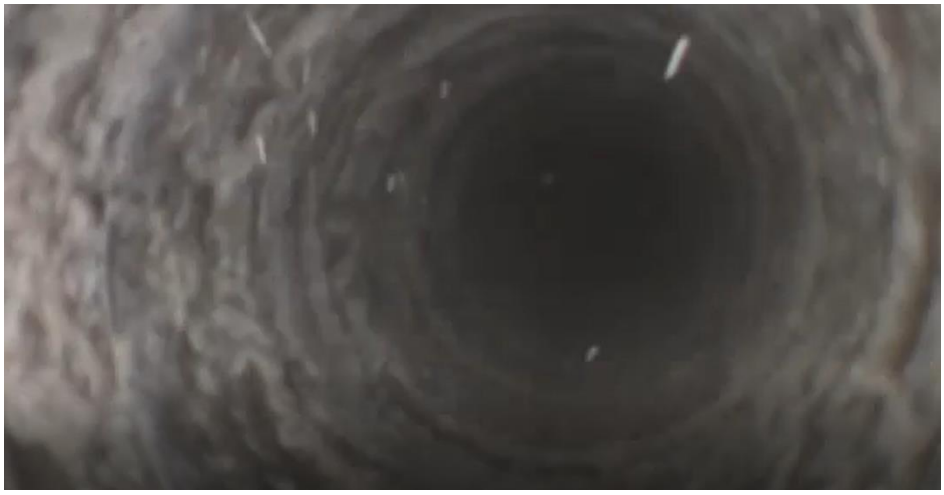

*Figure 6: Photograph of an ungrouted duct with no starter bar present within*

*Figure 7: Photograph of a grout filled duct that has been broken out and found to have no starter bar within the duct*

5.4. Water entry at base of wall

While water ingress may not be a factor required to be considered in evaluating structural performance, its impact on joint longevity i.e. durability, should not be ignored.

The following diagram shows the path that water can follow to enter the ungrouted cavity present between the top of a foundation and the bottom of a precast wall. These cavities are normally formed through the use of plastic shims placed underneath the wall panels with the intention of allowing the interface to be flooded with grout at the same time the ducts are filled. By being left ungrouted, water is able to penetrate through into the gap resulting in corrosion of the starter bar. Over time this corrosion puts the foundation at risk of spalling damage as the base of the starter bar expands. In cases where remedial grouting is undertaken, it can result in a residual loss of shear and tension capacity in the joint because of the reduced cross section area of the starter bar.

It should be noted that the remedial recommendations put forward in this paper are aimed at filling these voids with grout in order to encase the exposed reinforcing and provide it with protection from ongoing corrosion. This may not be sufficient to address weather-tightness related issues within these junctions. Therefore, it is recommended that advice regarding weather-tightness of exterior wall panel junctions is also obtained when considering remediation of defective wall connections.

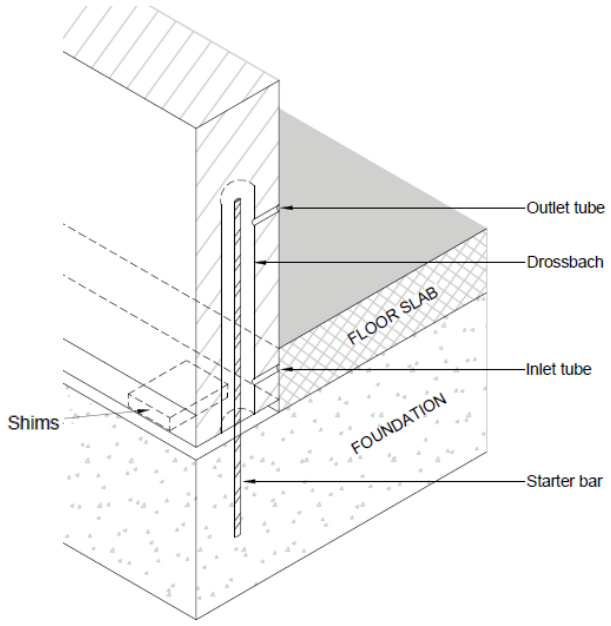


*Figure 8: Diagram showing the potential water entry into an ungrouted void between a precast wall and the top of the supporting foundation*

5.5. Concrete shrinkage cracks

Another type of defect that has been observed is shrinkage cracks in the concrete element typically running parallel to the embedded ducts or sleeve. These cracks have been observed in cases where there has been minimal concrete cover over the embedded drossbach duct or grout sleeve, and in cases where there is minimal or no transverse reinforcing on one or more sides of a grouted connection. In these cases, the assessing consultant needs to consider whether the cracks could result in a reduced splice capacity, in particular with regard to reduced confinement.

## 6. FORENSIC INVESTIGATION

6.1. Steps for Starting an Investigation

The process of investigation proposed by this paper uses the following sequence of actions, with each step in the process described in more detail in the following sections.

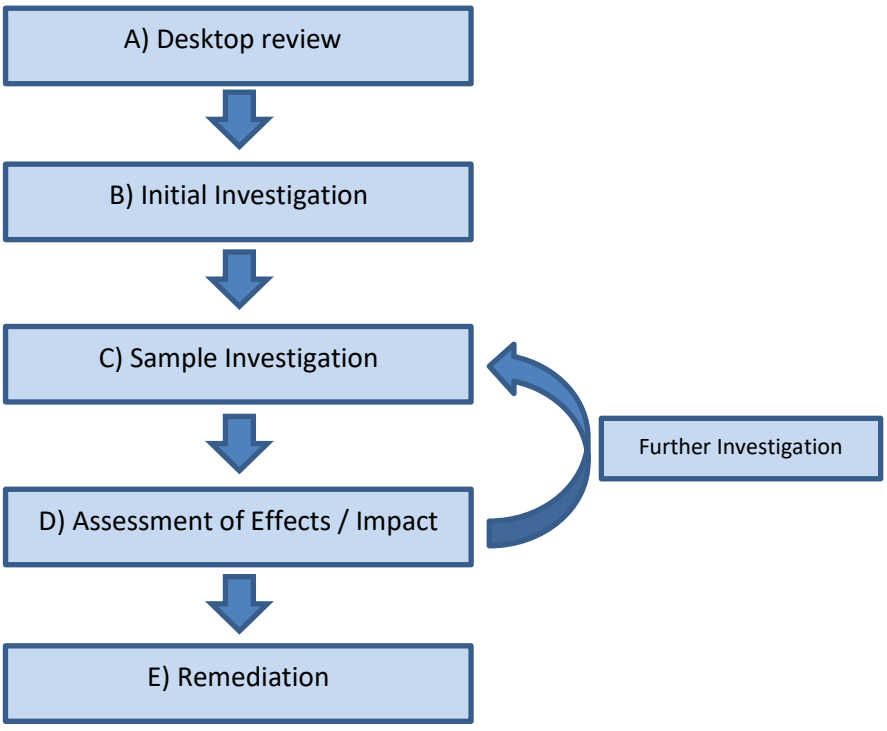


*Figure 9: Investigation process flow chart*

6.2. Desktop Review

The first step in determining whether an investigation of the grouted connection within a building will always start with a desktop review of the buildings original structural documentation including structural drawings, specifications, shop drawings, and inspection records, in order to determine:

a) The type of grouted connection used
b) Where connections have been located
c) The reliance of the building structure performance on the grouted connections

The most common method of obtaining the original structural documents is through a property file request to the Local Authority. However, additional documentation, in particular inspection records as-built plans, and precast shop drawings, are often not present in the property files in which case the property owners' records and the records of the original design engineer may be of assistance.

If available, a review of the inspection and quality control records should also be undertaken in order to inform the assessing consultants understanding of the level of care undertaken during construction. For example, evidence of good quality control measures and inspections during construction of the grouted connections would be grounds for the assessing consultant to have a higher level of confidence that the connections have been constructed correctly. Whereas the absence of any inspection records or quality control measures that specifically address the grouted connections should give the assessing consultant concern about the reliability of the connections.

Usually such a review would be undertaken as part of a Seismic Assessment (whether Initial or Detailed), a due-diligence review, or design of building alterations. It is recommended that such a desktop review of the grouted connections is included as a matter of course for any of these types of building assessment.

If a desktop review of the drawings confirms that grouted connections have been used in critical structural elements (which can include the attachment of secondary elements such as façade panels), and that there is a lack of evidence that a suitable level of quality control and site supervision was undertaken during construction or a subsequent review of the grouted connections, then the assessing consultant should recommend to the building Owner that an initial site investigation is undertaken as the next step.

6.3. Initial Investigation

The purpose of an initial site investigation is to:

a) Confirm that the building has been constructed as shown in the structural drawings that were obtained and reviewed as part of the previous step – in particular (with regard to this guidance document) whether grouted connections have been used as per the drawings. Where physical signs of grouted connections are unable to be observed, then non-destructive investigation

techniques may become necessary at this initial stage. Experience indicates that this would typically be carried out using GPR (ground penetrating radar) scanning as the initial step, non-destructive scanning techniques are described in more detail in later sections of this paper. This would be limited to confirming the presence of grouted connections only and would not provide information on the quantity or quality of grout within the connection itself. This later aspect is discussed in further detail in later sections of this paper.

b) Determine whether there are obvious visual defects associated with the construction of the grouted connections. These can include grout injection holes that have not been filled (allowing a visual confirmation that the grouted connection is empty of grout and/or whether starter bars are visible within the ducts), or the gap between precast elements and the supporting foundations has not been grouted (which may provide a view of the starter bar). This can also be determined by examination of the dry pack joint at the base of a wall and whether there is solid grout infill located behind it.

The visual inspection can be formed along the following lines:

a) Full visual inspection of all precast elements that are exposed and un-coated (such as wall panels within basements, carparks, and stairwells)

b) Sample visual inspection of hidden precast elements by cutting inspection holes in wall linings

The results of the visual inspection help determine whether a further inspection of the grout within the grouted connection duct or sleeve is necessary, and if so, how extensive the investigation should be.

*Important Note: At this stage it is typically necessary for the assessing consultant to provide initial advice to owner(s) explaining the background to grouted connections, potential issues, and recommendations for an investigation to be undertaken on a sampling basis i.e. a "sample investigation").*

6.4. Sample Investigation

Following the initial advice to owner(s), the next step is to plan and conduct a sample investigation of the grouted connections within the building. This is described in the following section.

## 7. UNDERTAKING A SAMPLE INVESTIGATION

7.1. This is the next level of investigation following that of the visual inspection and desktop review, in which the actual contents of the Drossbach ducts are investigated including both the starter bars and the grout.

7.2. Sample size / locations

As a generally rule of thumb, an initial sample of between 5 to 10% of the building's drossbachs is recommended for the first phase of a grout investigation.

The locations of the samples should include a selection of ducts from every level of the building, each type of precast element, and a selection of exterior and interior elements.

This is based on experience showing that the issues can vary in severity within a building. Possibly as a result of changes in site conditions, subcontractor, or methodology used during a particular buildings construction.

Where access to the grouted connections is difficult or economically challenging, then it can be appropriate to focus the investigation on the drossbach duct locations which have the highest structural demand associated with them.

7.3. Investigation Methods

The investigation of the contents of Drossbach ducts is a fairly difficult undertaking and can be carried out using a variety of methods. The two most common methods of investigation include Non-destructive techniques such as those utilizing ultra-sonic scanning of the drossbach with specialist equipment, and/or invasive methods such as physical drilling inspection holes into the wall panel followed by inspection of the duct interior using an endoscope (or videoscope).

7.4. Non-destructive Methods (NDT)

The purpose of using non-destructive testing methods is to avoid the issues resulting from physically drilling into existing concrete elements such as noise, dust, and the visual impact of the drilled holes after the investigation has been completed. However, it should be noted that removal of linings, cladding, and /or fixtures may still be necessary to gain access to the surface of the concrete element.

This is an evolving field and techniques are likely to change and improve over time. It is important that competent advice is obtained prior to carrying out the NDT to verify:

a) Suitability and/limitations of the testing technique to identify the information required;

b) Accuracy and reliability of the technique;

c) The requirements for site specific calibration of the equipment;

d) Experience and qualifications of the operator in particular with regard to interpreting data from grouted connections;

At the time of writing this paper the only method available to consultants for this type of investigation is acoustic testing. These methods use acoustic wave propagation through the material and interpretation of the return signal as it is reflected back. These return signals provide information with regard to differences in the material properties. It is important to understand that the method primarily identifies changes in material densities within the sample rather than identifying what those materials are.

One such acoustic technique includes ultrasound testing which has recently been developed specifically for use in grouted connection investigations (CSI 2017). This technique has the advantage of picking up air voids as strong signals making it an accurate method of detecting the presence of ungrouted zones within connections. The technique relies heavily on the operator having the correct training and experience to be able to undertake the testing and interpret the data obtained in a meaningful manner.

To date, acoustic techniques come with a number of limitations. One of which is that the existence of starter bars within grouted connections can only be established in ideal conditions. Other limitations concern the variability of the materials, including homogeneity, thickness and density of the grout within the void.

With regard to thick-walled grout sleeve type connections, the techniques are typically capable of detecting large voids within the grout the sleeve. However, depending on the equipment and ability of the operator it may not be sensitive enough to pick up small voids within the sleeve. Such small voids could still result in reduced capacities.

Implementation of acoustic testing is typically undertaken using one of two methodologies, depending on the engineer's discretion and the type of information being sought:

1. Detailed assessment:

   Scanning the full height of grouted connection to assess the level and quality of grout, as well as the existence of reinforcing within the duct where possible.

2. Grout level assessment:

   Where the assessment is limited to detecting the height of grout within a grouted connection.

In the latter case, it may not be possible to make a quantitative statement about the grout quality and presence of starter bar reinforcing, and defects in the lower portion of the drossbach may not be picked up.

Results from NDT investigations usually require careful offsite analysis by an experienced analyst. It is important that recorded data remains available and/or archived for future reference and used as evidence if required.

7.5. Invasive Investigation

An invasive investigation typically involves physically drilling inspection holes into a precast element in order to allow an inspection camera (endoscope/videoscope) to be inserted into the Drossbach duct to view the grout and reinforcing starter bar within.

The following provides an example of the activity sequence for such an investigation:

1. **Contractor/builder:**

    a) Remove wall linings from the precast concrete walls to be investigated

    b) Label each wall panel by Block / Level / Unit / Gridline

    c) Drill a 25mm diameter inspection hole at a 45deg angle into the top of the drossbach duct

        NB: the location of drossbachs can generally be found based on the existing injection/air ports in the wall. However, in some cases the duct may be located offset from these ports and multiple investigation holes or location by scanning may be necessary, to achieve an accurate location.

    d) Clean out all dust from the drilled hole

    e) Notify the engineer which walls are available to be inspected

2. **Engineer:**

    a) Insert an endoscope inspection camera into the inspection hole

    b) Run the camera down the hole to the top of the grout

    c) Record the depth from hole to the top of grout

d) Record the height from floor slab to inspection hole

e) Record the depth to grout on the wall panel

f) Record the site measurements in a spreadsheet (example provided below)

**3. Further Steps:**

a) Breakout to determine starter bar presence in grouted ducts

b) Extract a grout sample to test for strength and density

c) Check for consistency and voids

The invasive method described above comes with its own limitations when compared to alternative NDT methods. These include:

a) Limited ability to pick up defects arising from variability in the quality of grout, i.e. voids within the grout core and/or changes in density and quality within the grout

b) Limited ability to identify whether starter bars are present within the as-built connection unless the starter bar is visible above the top of the level of grout

c) Reinstatement of the drilled holes is necessary on completion of the investigation, this typically involves a using a contractor who is experienced in concrete repairs. The repaired patches of wall are usually visually apparent on completion of invasive testing. In contrast, NDT methods have the advantage that holes generally not required, and only need to be drilled where needed for calibration and remediation where defects are identified.

d) In cases whether the grouted ducts are difficult to locate then multiple holes may be needed as more of a trial and error method for locating the connections may play out. NDT methods can be used for the precise location of the ducts instead.

The following photos provide examples of invasive investigations in two different investigations:

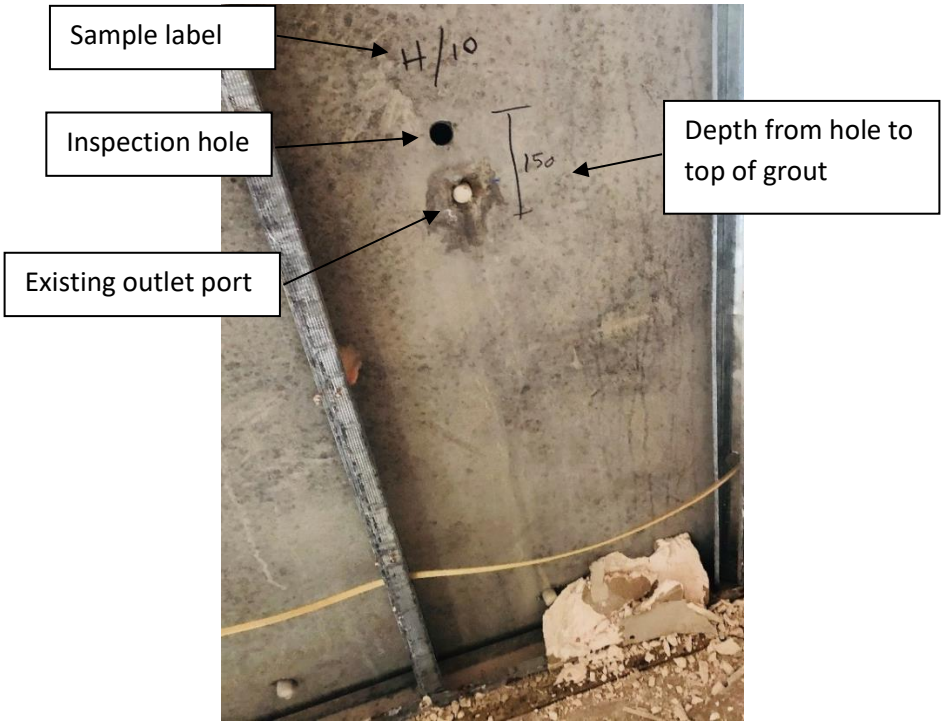


*Figure 9: Photograph showing an onsite investigation of a Drossbach duct*

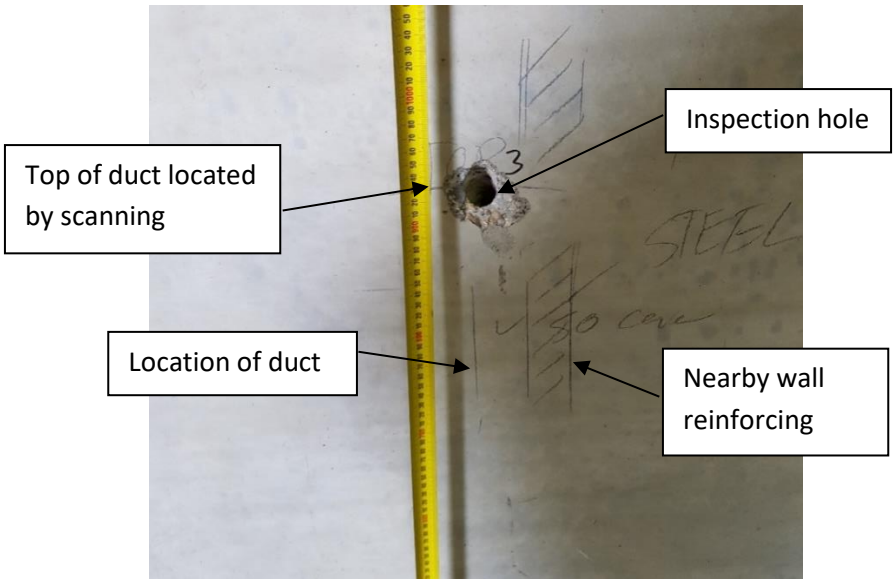


*Figure 10: Photograph showing an onsite investigation of a Drossbach duct where the duct was partially blocked by the vertical reinforcing within the precast wall*

7.6. Limitations of Invasive Investigation

When investigating grout sleeve type connections, the invasive method can be of limited application. Due to the characteristically thick walls of these types of connection it is not usually practical to drill an inspection hole into the sleeve component unless it can be lined up with the original outlet port. Furthermore, drilling through the wall of the grout sleeve may compromise the integrity of the grout sleeve. In cases where the outlet port can be found and used as a guide to drill the inspection hole, the holes naturally need to be of a small diameter and drilled on a horizontal plane. This can then make the insertion of an inspection camera more difficult and the measuring of existing grout levels (unless found to be completed grouted) to be almost impossible.

For these reasons, it may be more practical and accurate to adopt non-destructive scanning techniques when investigating grouted sleeve connections.

7.7. Recording results

An accurate record of the investigations at any level whether visual, non-destructive, or invasive, are essential for the purposes of the subsequent process of assessing the results and determining the appropriate remedial works.

Typically, once an inspection has been completed it will be difficult to obtain subsequent access, particularly if wall linings removed in the process have since been reinstated.

Therefore, the following records are recommended to be taken as a minimum:

- Location of the element within the building
- Location of existing grout injection / air release tubes observed (height from floor and plan location)
- State of the existing grout injection / air release tubes prior to invasive investigation (i.e. plastered, uncovered, poorly filled, etc)
- Photographic record of the exposed precast element prior to invasive investigation including wall and duct references notated on the element
- Measurements of the location of drilled holes for invasive investigation (height from floor and plan location)
- Photo or video record of the condition inside the grouted connection duct (or other record data if using NDT scanning)
- Measurement of the depth from the outside of the element to the inside of the duct
- Measurement of the depth from the outside of the element to the top of the grout
- Record of whether starter bar reinforcing was observed within the duct

The following table is provided as an example of how this information can be recorded consistently both on site during the measure, and in the office.

| Level | Grid | Wall | Duct No. | Starter Bar Diameter (mm) | Height to Inspection Hole (mm) "A" | Depth to Grout (mm) "C" minus "B" | Approx. Height of Grout (mm) "D" | Minimum Development Length (mm) | % of Development | Classification |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | C | 5 | 1 | 20 | 740 | 200 | 540 | 620 | 87% | Inadequate |
| | | | 2 | 20 | 740 | 930 | 0 | 620 | 0% | Empty |
| | | | 3 | 20 | 740 | 50 | 690 | 620 | 111% | Adequate |

Where "C" is the measured length from the face of the panel to the top of the grout within the wall that is modified by "B" which corrects the measurement to subtract the diagonal component of the measurement (noting that the modifier "B" needs to be calculated by trigonometry to adjust the diagonal length to an equivalent vertical height). Once corrected, "D" can be calculated from subtracting "B" and "C" from "A".

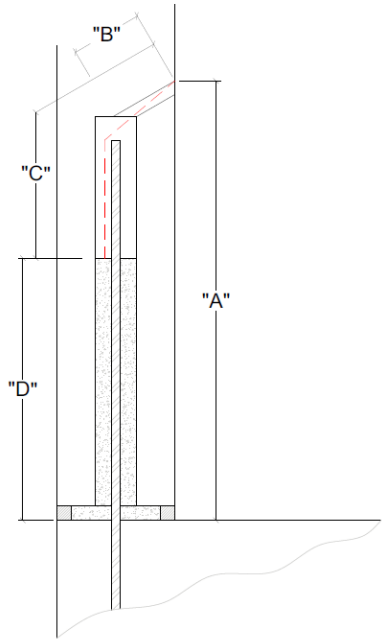


*Figure 11: Diagram showing how the height of grout within a duct can be measured via an inspection camera inserted into an inspection hole in the top of the duct*

## 8. ASSESSING THE EFFECT / IMPLICATIONS

8.1. The underlying purpose of the review and investigation is to assist in making a decision on whether there is sufficient cause for concern to require either a larger scale investigation, or remediation of the grouted connections.

8.2. Essentially, on completion of the sample investigation a decision needs to be made that:

a) There is sufficient confidence in the quality of the grouted connection construction to mean that further investigation and/or remediation is not necessary; or

b) There is sufficient concern that the quality of the grouted connections has been compromised during construction to mean that full investigation and remediation of defects is necessary; or

c) That a wider scale investigation is necessary as an intermediate step in order to determine which of the above applies.

8.3. While it is possible to use the results of the sample investigation to carry out a statistical analysis of the possible extent of any defects identified, it may not necessary provide useful or accurate information. Likewise, it may be possible to undertake detailed calculations to assess the effect that the defects identified may have on the performance of the structure. However, the likelihood of further defects being present beyond those checked in the sample investigation really comes down to a more qualitative decision on the confidence that the investigating engineer has in the quality of the grouted connection construction.

For example, if the sample investigation identified occasional shortfalls in the quantity of grout within the connections and these are spread out between wall panels, with the majority of the remaining connections in any given wall panel being adequate, then this would indicate that the construction quality is typically good, and the risk of significant defects is low.

However, if groups (or clusters) of defects are identified, and/or the defects are more significant in severity (i.e. ungrouted ducts or missing starter bars), then these should have been identified during construction if an adequate level of quality control had been undertaken. This indicates that there is a potentially high risk of similar clusters of defects, or worse, being present elsewhere in the building.

*Important Note: Grouting of these types of connections is often undertaken by a sub-contractor, and therefore the quality of work in this trade should be treated as being "decoupled" from the overall quality of the building. For example the main contractor may have implemented a high level of quality in other aspects of the buildings construction while leaving the grouted connections solely to the subcontractor to undertake. Therefore, it is possible in our experience to find defective grouted connections in an otherwise well-constructed building.*

8.4. In assessing the implications of the testing results it is also important to keep in mind that grouted connections may well be constructed correctly in terms of the consented documentation, but that does not

necessary mean that the connections have been designed correctly. For example, a Drossbach duct could be fully grouted, but still be insufficiently long to provide the required development of the starter bar. Therefore, it is recommended that any review of grouted connections within a building is done in conjunction with a structural/seismic assessment of the building design.

## 9. BUILDING CONSENTS

9.1. A common issue faced when undertaking invasive investigation of this type is whether a building consent is required or not. While the interpretation of when a consent is required may differ between territorial authorities, experience has shown that the different stages of work generally fall within the following categories:

a) Sample investigation (via drilled inspection holes or NDT scanning) – Can be carried out without a building consent

b) Patch repair of drilled inspection holes – where no defect is identified, no building consent is required as the work would generally fall within Exemption 1 of Schedule 1 of the Building Act as "general repair, maintenance and replacement of building parts".

c) Repair of defective ducts identified during the sample investigation – either a discretionary exemption (Exemption 2 of Schedule 1 of the Building Act), or building consent is typically required.

d) Widespread investigation and remediation of defects – building consent is recommended

9.2. An exception to the above is where the investigation identifies a defect that poses an immediate danger to people and/or property if left unaddressed. These situations are dealt with by Section 41(c) of the Building Act which deals with work required to be carried out urgently. However, an application for a Certificate of Acceptance is still required in these cases.

In all cases, where there is any doubt, the consenting requirements should be clarified with the relevant territorial authority prior to commencing the work.

9.3. Sample wording for an application cover letter for a Council Discretionary Exemption under Schedule 1 of the Building Act:

> *On behalf of the building owner _____, [consultancy] would like to apply for a discretionary exemption from the requirement for Building Consent, under Schedule 1 (Exemption 2) of the Building Act 2004.*
>
> *Our application is on the basis that the proposed work is unlikely to be carried out otherwise than in accordance with the building code, and further, that the nature and extent of the work is closely prescribed and well defined.*

*The proposed work would be limited to the drilling of investigatory holes in to the drossbach ducts within the precast concrete wall panels, testing the level of existing grout within the drossbach ducts, and if necessary, the placement of grout into the drossbach ducts in locations where it should have been installed during the original building construction.*

*The work shall be supervised by [consultancy] engineering staff who have experience with successful remediation of this type of work.*

*Please find attached to this letter our formal application for the Schedule 1 (Exemption 2) discretionary exemption, plans showing the locations of the precast wall panels to be investigated and if required, remediated, a detail of the investigation method, and a specification for the investigation and remediation works.*

## 10. EXTENT OF REMEDIATION

10.1. In considering the level of remediation to be undertaken there are several different approaches that can be taken, these typically being:

a) Returning the building to that state that it should have been had it been constructed in accordance with the original building consent (i.e. identify and repair all defective grouted connections to their "as-new" state). This is the most conservative approach that can be taken and likely to provide the building owners with the most assurance in regard to the quality of their building following remediation. However, providing this level of assurance usually comes with the largest cost.

b) Addressing only the connections required to ensure compliance with the Building Code. In some cases this may mean that some connections can be left un-investigated and therefore un-remediated. While in other cases, compliance with the Building Code may still require that every grouted connection in the building is investigated and remediated (i.e. depends on the amount potential spare capacity present in the buildings original design). This approach has the benefit of potentially limiting the extent of full remediation that is necessary and therefore the cost of the investigation and remediation.

10.2. In considering the second path there are several key factors that need to be taken into account:

i) The overarching requirements of these types of connection are set out in Clause 18.6.4 of NZS3101:2006 (and previously clause 4.3.6.5 of NZS3101:1995) which essentially require that vertical connections in walls meet the following minimum requirements:

(a) Transmit the required design forces, such as seismic loads

(b) Provide vertical resistance equivalent to at least 45kN per meter of wall, for example with HD16 (high tensile, deformed, 16mm diameter) starter bars in drossbach ducts this is equivalent to at least one starter bar for every 2m of wall length. For HD20 starter bars it is equivalent to one starter bar for every 3.1m of wall length.

(c) Have at least 2 vertical ties per wall panel, for example at least 2 correctly constructed grouted connections with starter bars present.

ii) While the requirements of Clause B1 may be achieved by a targeted remediation approach. There may be areas of the building where compliance with E2 (external moisture) need to be addressed as well. These can include grouted connections located around the buildings external envelope.

iii) During the process of changing a buildings use, it is necessary to ensure that a building complies with all of the current Building Code requirements for the new building use to the extent required by the Act. In these cases, this may impose a higher level of certainty being necessary for the interconnection of elements (refer to Section 115 of the Building Act).

10.3. In rare cases, it may be possible to undertake a full investigation of all grouted connections within a building, for example during extensive alterations and/or internal strip-outs. In such cases, it has typically been found to be more economical to remediate any defective grouted connections as they are identified rather than undertaking the level of assessment required to determine whether a lesser number of adequately construction connections will be sufficient to meet the performance requirements of the Building Code.

## 11. REMEDIAL METHODS

11.1. Depending on the findings from the assessment stage, several different techniques for remediating grouted connections can be adopted. The following method is set out for cases where either no grout is present within the connection, or lower levels than required are identified. This method still requires specific engineering design in order to confirm the adequacy and suitability of the repair method, the appropriate grout to be used in the remediation, and the inspection standards required to monitor the quality and completeness of the repair. Typically, it is recommended that the repair is accompanied by a PS1 by the remedial design engineer, a PS3 and quality control records by the grouting contractor, and a PS4 by the engineer undertaking construction monitoring.

*Important Note: Defects identified in regard to missing starter bars, and/or defective proprietary grout sleeve connections are significantly more complex to remediate and therefore such work must be subject to careful engineering design. Upgrading of this type is not addressed in this paper.*

11.2. If the duct has been identified as containing no or low levels of grout, but starter bars have been confirmed to be present, then the following sequence is recommended:

a) Location of the duct position by scanning, including any reinforcing that may be between the duct and the concrete surface

b) Drill a new injection hole to be drilled into the duct at a position directly above the top of the existing grout surface,

c) Drill a new hole in the top of the duct (usually this has been done during the investigation process if the invasive methodology has been adopted). This hole allows air to escape during the remedial grouting process.

d) All holes in the wall panel should be plugged and each injection hole pressure tested with dry compressed air. This process is necessary to identify whether there are any potential leaks in the wall that could result in loss of grout during the remediation. Examples of grout leaking into wall cavities and into voids underground have been encountered. Any leaks identified should be sealed and the air pressure test repeated. Experience has also shown that access to both sides of a wall being remediated is usually necessary to enable this sealing off to be accomplished.

e) The grout can then be pumped into the injection hole until it reaches the top of the inspection hole, the lower hole is blocked to prevent leaking, and the grout allowed to set.

11.3. Quality control during remediation

Quality control methods still need to be carefully specified and monitored during the remedial process. In most cases, the same quality control measures recommended for new construction are equally appropriate for remedial works. Typically these involve the following, and are discussed in more detail in the companion Guidance Document #2.

a) Contractor records of duct location and testing (including pressure testing)

b) Contractor records of grout preparation, batching, and volumes used

c) Compression testing of grout samples prepared on site

d) Monitoring for grout leaks

e) Verification of final grout levels on completion (made easier by the use of larger diameter inspection holes in the top of ducts

An example specification for remedial grouting is provided in the Appendix to this report.

## 12. REFERENCES

*Brown, B. J. (2021). "SESOC task group – Grouted connections and drossbachs. Section 1: Introduction/scope", SESOC Journal, 34(1), 29-34.*

*Centre for Advanced Engineering. "Guidelines for the Use of Structural Precast Concrete in Buildings", Second Edition (1999)*

*Freeman, J. (2021). "Observed defects in grouted duct precast panel connections in New Zealand and the potential performance implications, SESOC Journal, 34(2), 66-75.*

*Guidance Document #2: New Buildings – Specification/Construction/Assurance*

*Guidance Document #3: Design Basis and worked examples*

*Methodology developed by Concrete Structures Investigations Ltd (CSI) in in cooperation with Callaghan Innovation, Daniel Traeger, Research and Development Leader, Concrete Structures Investigations Ltd, 2017.*

**APPENDIX A: EXAMPLE DROSSBACH REMEDIATION SPECIFICATION**

1. Grouting Methodology Requirements:

The following items set out further requires that must be followed by the contractor during the remedial grouting process. This method assumes that the contractor is experienced and competent in grouting works and the products that have been nominated.

We note that all of the following steps shall be read in conjunction with the relevant product datasheets and supplier instructions.

The following shall also be read in conjunction with the Architectural drawings and specification.

**a) Concrete Preparation**

The concrete substrate shall be thoroughly clean, in a good sound condition and free from dust, loose material, surface contamination and materials which reduce bond. Concrete surfaces shall be generally level (within given tolerances) and shall not be laid to a gradient, so grout flows to the lowest end.
Use oil free air to blow clean out dust from the duct and drilled holes.

Air test each wall panel once all ducts have been identified to ensure pressure can be built prior to pumping to avoid grout loss from panel. If leaks are identified then they shall be sealed using an epoxy mortar. After setting, the panel shall be tested for leaks again to confirm that the leaks have been sealed.

**b) Grouting Products**

Flowable grouting shall be carried out using Sikagrout 215

Drypacking/hole repairs shall be carried out using either Sikagrout 212 or Sikadur UA

**c) Preparation**

Working space shall be clean and tidy with no obstructions.

Record the substrate, ambient temperature and relative humidity. Check pot life information on bag or in the product data sheet and allow for climatic conditions e.g. high / low temperatures & humidity.

External applications shall be adequately protected. Do not apply grout in direct sun, windy, humid or rainy conditions, do not apply grout if there is a risk of frost within 24 hours in unprotected areas.

Make sure feeder/breather holes are not obstructed and can allow the escape of air.

Calculate the required volume for the application and calculate the consumption of the product and make sure there is enough material on job site for the work.

**d) Mixing**

Mixing shall always be carried out in accordance with the recommendations contained in the latest product data sheet (PDS).

Do not use water beyond the stated maximum and minimum limits.
In determining the mixing ratio, the wind strength, humidity, ambient and substrate temperature and shall be taken into consideration. For best results only mix full bags.

Set up grout mixing area with adequate ground/slab cover close to task area.

Place minimum recommended water ratio in mixing container. All water shall be accurately measured.

Progressively add powder whilst mechanically mixing using low speed (maximum 500 rpm) electric drill.

Add more water if required to suit the desired consistency and flow properties but not exceeding maximum dosage. Mix in total for 3 minutes or until the material is homogenous.

Let mixture sit undisturbed for a further 3 minutes to allow any excess air entrapment to escape.

**e) Pumping**

All care shall be taken by the contractor to prevent bleeding as the sand separates while it is under pressure which can cause a blockage. It is recommended checking the compatibility of the pump equipment and grout before application.

The contractor shall be experienced in the preparation, operation, and cleaning of the pump.

SikaGrout is pre-mixed in the normal way, placed into the hopper and pumped through a hose to the point of application.

The pump machine and ancillary equipment shall be of adequate capacity for the volumes to be applied.

All moving parts, fittings and hopper shall be inspected for cleanliness and damage before use. Any hardened material shall be removed. The equipment shall not leak. The hose or pipe shall not have any dents or kinks and be long enough to reach from the pump location to the point of application. It is advisable to use the shortest hose length available to reduce the risk of blockage. Always consult with the recommendations provided by the machine manufacturer.

The Contractor shall keep full details and records of the type of machine and equipment used for the project. This information shall be provided to the Engineer, when requested.

**f) Curing**

Protect the fresh material from premature drying. Cure exposed area with proper curing methods for 3 days or spray with appropriate curing compound once the grout starts to stiffen. Suitable curing covers include jute and water, plastic sheets or other suitable membranes

**g) Records**

Grouting contractor to provide specific QA record forms for all grouting work completed, these are to be supplied upon completion unless otherwise requested.

**h) Grout Testing**

The contractor shall produce grout test cubes at the beginning of every second batch of grout mixed, and commission compressive testing of the cubes.

i. Only cube moulds are to be used. They must have been calibrated and have been treated with Formol or similar release agent. Sika generally uses moulds of size 50mm x 50mm x 50mm

ii. Ensure that the grout does not have excessive air entrainment. Ensure again grout has been mixed with a low speed drill and allowed to site for a minimum of 3 minutes.

iii. Place the grout to the top surface of the mould and run a spatula or similar tool around the mould edges to ensure no air is trapped. Tap the cubes with a hammer or similar to further reduce air entrapment.

iv. If necessary, top up to the top of the mould again and level off with a spatula.

v. Place a heavy flat steel plate on top of the mould. Another mould will often suffice for this.

vi. Store the cubes in a suitable area, preferably at 20 degrees Celsius.

vii. After 24 hours de-mould the cubes and using a suitable marking pen write on each one a unique reference number. Ensure this reference number is written overleaf.

viii. Deliver the cubes to a suitably qualified testing laboratory where the cubes can be placed in a water bath and conditioned to the required curing temperature and tested for compressive strength on the $28^{th}$ day after casting.

ix. Two Cubes are to be produced for every second batch.

2. On completion, the contractor shall provide copies of the compressive test results, QA records, and PS3 certificate.