QA/QC methods for grouted Drossbach duct connections in precast concrete shear wall panels – case study: new 12-storey building in Auckland

H. Rowden, V. Patel
Beca Limited (Beca), Auckland, New Zealand.

F. Galvez, R. Hudson & D. Dizhur
DIZHUR Consulting Limited (Dizhur), Auckland, New Zealand.

ABSTRACT

This paper explores the issues and limitations of grouted Drossbach duct connections, and investigates the quality assurance/control (QA/QC) methods used in the construction monitoring of a new 12-storey building in Auckland. The QA/QC methods are examined, including who was responsible for QA/QC, how this was monitored, and how evidence of compliance was demonstrated.

During construction, early investigations of the project's grouted Drossbach duct connections found areas of defective work. This ranged from low-density grout and air voids, through to partial and fully ungrouted Drossbach ducts. Reliance on current industry practice and long-standing industry QA/QC methods proved to be ineffective at consistently identifying these construction defects, as has been suspected and demonstrated in the past.

Beca Limited (Beca) worked closely with the Main Contractor to develop a more reliable QA/QC system to increase confidence in workmanship and the identification of defective work. DIZHUR Consulting Limited (Dizhur) was engaged to conduct ultrasonic scanning to provide an independent review of workmanship. Off-site grouting tests were undertaken to refine the grouting process, with sample panels being grouted, scanned, and dissected to identify issues and to verify the outcomes of the ultrasonic scanning. In addition to comprehensive contractor QA/QC documentation, a mix of invasive and non-invasive inspection techniques were used. These included pilot hole drilling, localised break-out of suspect areas, and ultrasonic scanning and post-processing performed by Dizhur.

The above saw an improvement in construction quality, with identified defects being successfully remediated, providing increased confidence to the Principal and Engineering team monitoring the work.

1 INTRODUCTION

Grouted Drossbach duct connections have been used in New Zealand's precast concrete construction industry for more than 50 years (Freeman, 2021). Following the 2010/2011 Canterbury earthquakes, brittle failures were observed in some grouted Drossbach duct connections for precast concrete wall panels, resulting in industry recommendations for more robust detailing of this connection type (Seifi, 2018). The SESOC Interim Design Guidance document (SESOC, 2013) provided improved design and detailing guidance for these connections, with provisions for their consideration in the seismic assessment of existing buildings later being incorporated into Section C5 of the Engineering Assessment Guidelines (NZSEE, 2018).

In addition to their documented poor performance in past earthquake events, construction defects have been found during various investigations of grouted Drossbach duct connections. Between 2014 and 2020, Fraser Thomas Limited and Concrete Structures Investigation Limited conducted investigations on more than 1500 grouted Drossbach duct connections from 22 different sites across New Zealand (Freeman, 2021). These sites ranged from buildings that are two to 12 storeys in height, with commercial offices, residential apartments, hotels, and retail typologies represented. Sample sizes of approximately 4 - 15% of the total number of Drossbach ducts in the structures were investigated, with a median value of 21% of the investigated ducts (per site) discovered to be defective. On one site, 100% of the investigated ducts were determined to be defective. The discovery of such cases led to SESOC's 'Grouted Connections' Task Group being established in early 2020, followed by the release of three Guidance Documents (SESOC, 2022) for grouted connections and Drossbach ducts. Whilst concerning, the above is not necessarily surprising considering, historically, the construction industry has had very little in the way of robust QA/QC methods for the grouting of Drossbach duct connections. The principle of injecting grout into an entry tube at the bottom of the duct until grout discharges from an exit tube at the top of the duct has been proven to be an unreliable and inadequate method of verifying grouting quality. Additionally, the lack of external visibility of Drossbach ducts means that defects in these connections are often difficult to detect.

Examples of construction defects in grouted Drossbach duct connections include inadequate grout filling of ducts, starter bars having insufficient length to satisfy the lap splice provisions of NZS 3101:2006, or the lack of some starter bars all together. Other defects include micro-cracking or low-density pockets in the grout, through to water ingress at the base of precast concrete wall panel connections. The above issues can arise for several reasons and are often the result of shortfalls in construction quality control processes (SESOC, 2022). Inadequate grout filling of Drossbach ducts can occur due to improper grouting techniques, leaks due to inadequate sealing of gaps along the joints between precast elements, and obstructions to entry and exit grout tubes. Starter bars of insufficient length, or missing starter bars, are typically the result of these being bent over or cut off and removed to enable the installation of precast elements when tolerance issues are encountered. Low-density grout pockets can also be caused by improper grouting techniques that lead to entrapment of air within the grout mix. Other external factors affecting the grouting operator have been found to cause issues, such as complacency in workmanship, distractions, or operator competency.

If present in a large enough number, these defects can result in the inability of grouted connections to reach their calculated design capacity. Experience from past earthquake events has shown that horizontal spliced joints often form a critical interface along which failure can occur (Steinbrugge and Degenkolb, 1969). Given the common use of grouted Drossbach duct connections in the primary lateral load resisting systems (LLRS) of reinforced concrete (RC) buildings incorporating precast elements, the implementation of appropriate QA/QC methods during construction is crucial to ensuring the structural integrity of these connections is maintained, and to prevent primary lateral load paths being compromised.

2 CASE STUDY

In mid-2021, Beca Limited (Beca) commenced the structural construction monitoring for a new 12-storey building located in Auckland. The main structural form of the building consists of a relatively regular structural steel frame supporting insitu concrete floor slabs, with a full-height central atrium. The building's primary lateral load resisting system (LLRS) is structural steel moment frames in one direction and 250mm thick perimeter RC shear walls oriented in the perpendicular direction. The RC shear walls were formed using precast concrete panels connected via vertical grouted Drossbach duct connections and insitu concrete stitches. All precast panels were doubly reinforced, with a single row of well-confined central Drossbach ducts cast into the bottom of each panel. Despite their jointed nature, the shear walls were designed and detailed to behave as equivalent monolithic elements. As such, the global lateral strength and stiffness of the building is heavily reliant on the structural integrity of the grouted Drossbach duct connections. Due to the previous industry issues noted above, the structural importance of these connections was highlighted to the Main Contractor at the start of the project. The Beca Engineering team emphasised the need for a sound QA/QC system to provide confidence in workmanship and the identification of defective work.

2.1 Grouting methodology

Establishing a reliable grouting methodology was identified as being important to minimise the potential for defective work. A number of parameters need to be controlled during the grouting process, including the workability of the grout, the grout flow rate, and the size and location of the entry and exit grout tubes.

Prior to grouting works commencing on site, the Main Contractor and relevant Subcontractors coordinated a detailed methodology for grouting of the project's Drossbach duct connections. This included demonstrating that appropriate experience and qualifications were held by the site team supervising these works. A high-level summary of the initial panel-to-panel grouting methodology is provided below; noting, this methodology assumes that panel erection has already taken place, with the panel being plumb, propped and shimmed appropriately:

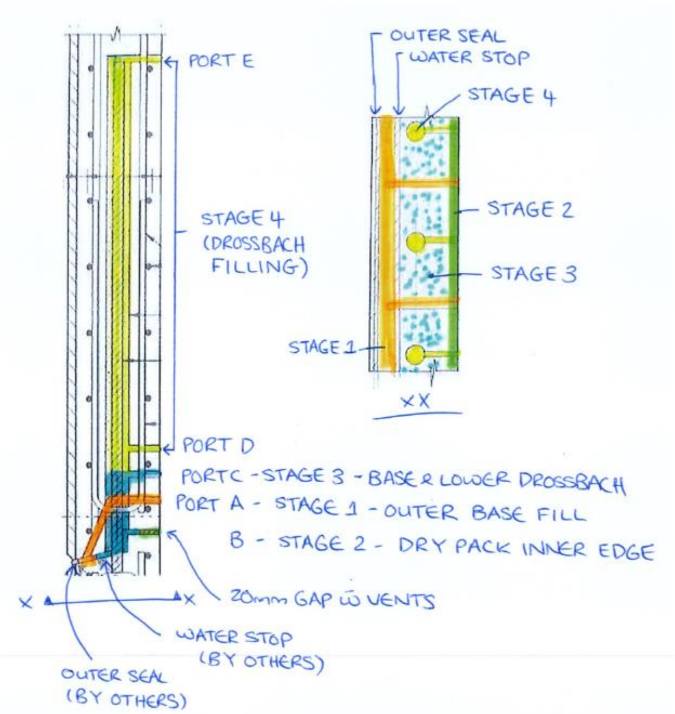


Figure 1: Diagram showing stages of grouting methodology

Stage 1: Grout between sealed outside panel edge and water stop by injecting via port 'A' (refer Figure 1 above).

Stage 2: Seal inside and side edges of panel base with dry pack grout (including forming nominally spaced grout ports / air vents in the dry packed perimeter).

Stage 3: Flood panel base and lower Drossbach ducts by injecting via port 'C' at one end of panel. Once grout discharges freely from the adjacent 'B' and 'C' ports, cap these and continue to the end of the panel, ensuring all ports have been capped and grout tubes folded and sealed.

Stage 4: Fill the remainder of each Drossbach duct by injecting grout via port 'D' (entry grout tube) until grout discharges from port 'E' (exit grout tube), following which the grout tubes at port 'D' and 'E' shall be folded and sealed.

2.2 Pull testing of grouted starter bars

The above methodology was used to grout 12 sacrificial starter bars (four of each starter bar size – DH20, DH25, DH32) into Drossbach ducts in a precast concrete test panel, with these bars then pull tested to assess the structural integrity of the grouted connections. A hydraulic jacking device was used to subject the starter bars to an axial tension load equivalent to 100% of the bar yield strength, with this tension load maintained for a minimum duration of 5 minutes without bar movement. This ensured both strength and stiffness of the grouted connections was considered, including bond stress-slip effects. All 12 sacrificial starter bars passed these pull tests, deeming the connection detailing and proposed grout material to be sufficient.

2.3 Initial ultrasonic scanning investigation

Whilst the results of the pull tests indicated the connection detailing and proposed grout material were sufficient, grouting workmanship still needed to be assessed. The Contractor's initial proposal of a verification method for grouting quality was that if grout was visible discharging from the exit tube at the top of the Drossbach duct, then the entire duct must be filled. Based on previous industry findings, this crude method of QA was considered to be an inadequate and unreliable indicator of grouting quality. Instead, ultrasonic scanning was proposed to be conducted on a random sample of the project's initial (basement level) permanent works Drossbach ducts. This would assist in verifying the adequacy of both the grouting methodology and the quality of the grouting workmanship. DIZHUR Consulting Limited (Dizhur) was engaged to conduct this initial ultrasonic scanning investigation, for which a total of 12 Drossbach ducts across 3 panels were randomly selected for scanning. This represented a ~5% sample of the total number of Drossbach ducts in the basement area.

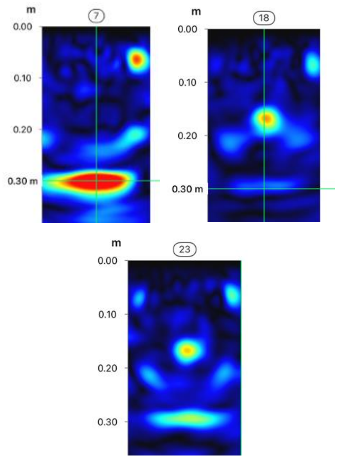
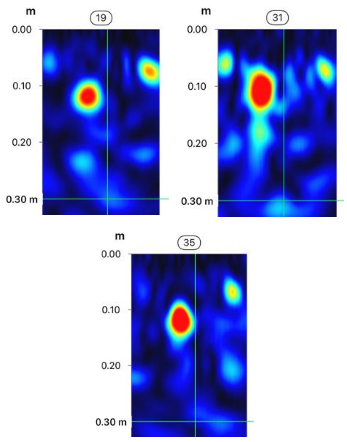
2.3.1 Ultrasonic scanning technology/background

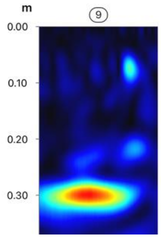
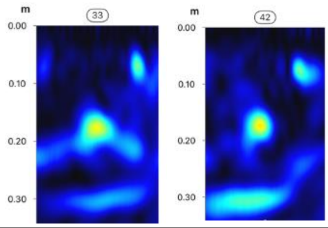
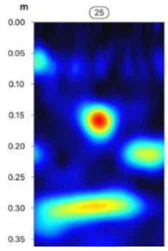
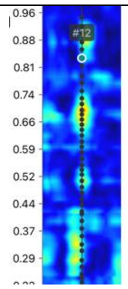
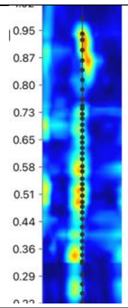
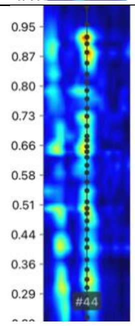
The ultrasonic scanning performed by Dizhur was undertaken using a wireless ultrasonic tomography scanner. Scans producing horizontal cross-sectional images (tomograms) of the panel were taken at small discrete vertical increments, allowing a detailed picture of the inside of the panel to be obtained. Prior to scanning of the grouted Drossbach ducts, calibration scans of empty Drossbach ducts were undertaken to provide a reference point for the imaging intensities of air, reinforcing steel and concrete specific to the project materials. Each Drossbach duct was scanned twice to provide assurance of the accuracy of the results. When potential defects were detected, an additional post-scan analysis of the suspect areas was performed to determine a confidence level associated with the results.

2.3.2 Ultrasonic scanning investigation findings

The outcome of Dizhur's initial ultrasonic scanning investigation was that, of the 12 Drossbach ducts scanned, four ducts were identified as likely having low-density grout or micro-bubbles, and two ducts were identified as likely having air voids (refer Table 1 below). The reported confidence level for each scan provides an indication of the level of confidence in the result held by the engineer analysing and post-processing the data. These confidence levels are based on the intensity and horizontal/vertical extent of the defect readings in the tomograms. The relative intensity of the tomograms is a result of the contrast in ultrasonic wave velocity through adjacent scan cross sections. More significant defects, such as large air voids, produce more contrasting cross sections and, consequently, more intense defect readings. Similarly, less significant defects, such as low-density grout or micro-bubbles, have less intense defect readings due to these being more similar to the fully grouted cross sections. As seen in Table 1, a defect in Duct #2 was identified with a very high confidence level (~ 90%). This was due to significant air voids causing a high intensity reading. This high intensity reading can be seen in Table 1 as bright red readings with sharp edges. Duct #1, #4, #9-#11 were reported with moderate confidence levels (~60%) as the produced tomograms were less intense, with readings ranging from yellow to orange, and with more gentle boundaries indicating the likely presence of less contrasting defects such as low-density grout or micro-bubbles. All remaining scans were deemed to have no air-related defects due to the mostly blue readings indicating solidly filled Drossbach ducts.

Table 1: Results of initial ultrasonic scanning investigation

Duct #	Defect (including vertical location)	Confidence level	Selection of tomograms	Tomogram orientation
1	Low-density grout or micro-bubbles: 0.38 m 0.61 m 0.77 m	60%		Horizontal
2	Air voids: 0.34 – 0.43 m 0.55 – 0.59 m 0.81 – 0.85 m	90%		Horizontal

3	No air voids detected	-		Horizontal
4	Low-density grout or micro-bubbles: 0.35 m 0.60 m	60%		Horizontal
5 - 8	No air voids detected	-	-	-
9	Air voids: 0.46 m (10 - 20 mm vertical length only)	75%		Horizontal
	Low-density grout or micro-bubbles: 0.64 m 0.7 m 0.8 m	60%		
10	Low-density grout or micro-bubbles: 0.71 m	60%		Vertical
11	Low-density grout or micro-bubbles: 0.51 m	60%		Vertical
12	No air voids detected	-		Vertical

2.4 Investigation of suspect Drossbach ducts

Following Dizhur's initial investigation, it was agreed that targeted pilot hole drilling would be undertaken to further examine the potential defect areas indicated by the ultrasonic scanning. Prior to drilling, the inside face of the panels were surveyed using Ground Penetrating Radar (GPR) to map the inside layer of panel reinforcement, ensuring a clear path for the drill bit to the surface of the relevant Drossbach ducts. For calibration purposes, pilot hole drilling was initially conducted on reference areas deemed by the ultrasonic scanning to be free of defects. During several of the targeted drilling runs, visible forward lurching of the drill was witnessed after the drill bit penetrated the metal skin of the Drossbach duct. The visible movement and audible sound transitions of the drill allowed those present to track the drill's progress through the different materials, i.e., through the concrete in the panel, the metal Drossbach duct skin, and the grout (or void/defect) in the Drossbach duct itself. Following this targeted pilot hole drilling investigation, it was clear that there was a correlation between the witnessed drilling anomalies and the ultrasonic scanning defect readings for Duct #2 and #9. As such, it was decided that a more detailed invasive investigation of these Drossbach ducts was required to determine the extent and potential cause of the issues.

The Main Contractor proposed a methodology to locally break back the face of the panels to expose the relevant Drossbach ducts, following which the metal skin of the ducts was carefully cut and peeled back to reveal the state of the undisturbed grout within.

2.4.1 Duct #2

Duct #2 was found to be only partially filled with grout (refer Figure 2 below). Peculiarly, the surface of the starter bar in the exposed Drossbach duct was coated in what appeared to be grout residue, however, this residue was not present on the inside surface of the unfilled portion of the Drossbach duct. It is speculated that this starter bar was likely coated in residue from earlier concrete works, with the site team failing to clean the surface of the bar prior to installing the precast panel above. Following this, a breakdown in the grouting QA processes on site likely resulted in the failure of all grouting stages to be completed for this particular Drossbach duct.

2.4.2 Duct #9

Duct #9 was exposed to reveal what appeared to be pockets of low-density grout (refer Figure 2). Sika NZ Limited (Sika) was contacted for comment on these pockets, to which they responded noting that these micro-bubbles were to be expected for the product being used (SikaGrout-212 NZ), and that these were a by-product of a chemical reaction caused by the shrinkage compensating additives in the grout. Most importantly, Sika noted that the presence of these micro-bubbles would not reduce the material performance of the high strength grout product, and that these micro-bubbles would also have been present in the grout work for the starter bar pull tests conducted earlier in the project.

Figure 2: Duct #2 exposed showing partial grout filling (left), Duct #9 exposed showing apparent low-density grout / micro-bubbles in red clouded areas (right)

3 OFF-SITE GROUTING TESTS

Whilst the discovery of Duct #2 being partially unfilled was of concern, it was important for the Beca Engineering team to ensure that this issue was not caused by unidentified flaws in the grouting methodology. As such, it was decided to undertake a number of off-site grouting tests to interrogate the methodology further.

3.1 Pump speed / grout flow rate testing in Perspex tubes

As noted above, grout flow rate is an important parameter to control during the grouting process. The grout pump used by the grouting Subcontractor to fill the Drossbach ducts had variable speed settings, producing grout flow rates of 3 - 5.75 L/min. It was speculated whether higher flow rates had the potential to cause air entrapment within the grout mix, resulting in reduced grout quality. To assess this potential effect, a test setup was created to observe the Drossbach duct filling process at the ‘low’, ‘medium’ and ‘high’ speed settings. Perspex tubes were used to simulate Drossbach ducts, with starter bars placed inside and the tubes then filled in accordance with the project grouting methodology. The transparent nature of the Perspex tubes allowed the grout behaviour to be examined throughout the entire filling process (refer Figure 3 below). Whilst there were no major concerns with any of the tested grout flow rates, it was found that pumping at the ‘medium’ speed setting (~4 - 5L/min) was optimal to prevent air bubbles forming in the injected grout. Although the smooth inside surface of the Perspex tubes did not exactly imitate the corrugations on the inside of the Drossbach ducts, the likelihood of air-related defects forming due to turbulence / mixing effects caused by these corrugations was deemed to be low for the range of grout flow rates being used.

Figure 3: Grout flow rate test setup with Perspex tubes

3.2 Pump speed / grout flow rate testing in sample panel

In addition to the Perspex tubes, a sample precast panel with similar sized Drossbach ducts was grouted at each of the pump speed settings. After one week of grout curing, Dizhur conducted ultrasonic scanning on six of the filled Drossbach ducts. These scans predicted low-density grout in four of the ducts and air voids in one duct. Upon dissection of the panel and scanned Drossbach ducts, the predicted defects were not readily apparent. This could have been due to these air-related defects being set back from the cut / exposed grout face, or due to false positives caused by mis-calibration of the ultrasonic scanning equipment. This outcome highlights the importance of communicating the inherent uncertainty involved when using these complex investigative technologies. Similar to the outcome for the Perspex tubes, the dissected Drossbach ducts showed no significant differences in grout quality between those filled at the different pump speed settings.

3.3 Discovery of hollow pockets

Despite no defects being discovered within the filled portions of the dissected Drossbach ducts, a common air-related defect was found at the very top of several of the ducts (refer Figure 4 below). The sample panels were constructed with the exit grout tubes projecting from the side of the Drossbach ducts, approximately 50mm below the top of the ducts. This meant that the Drossbach ducts were unable to fill right the way up with grout, forming hollow pockets at the top. Whilst this may not seem overly significant due to the starter bars having already terminated and been fully developed at this level, the relatively large diameter of the Drossbach ducts compared to the panel thickness means that a number of these hollow pockets forming side-by-side will reduce the effective cross-section of the panel considerably, creating a plane of inherent weakness.

Figure 4: Hollow pocket below top of Drossbach duct (note: jagged line in grout caused by panel dissection process)

Although the initial project detailing having the exit grout tube terminating flush with the top of the Drossbach duct (refer Figure 1) was theoretically sufficient to allow grout to fill right the way up to the top of the duct, failure to adequately fold and seal the entry grout tube after unhooking the grout pump could result in the entry grout tube leaching wet grout, causing the grout level in the duct to slump and form similar hollow pockets. Side-exit grout tubes also have the inherent risk of being inserted incorrectly, resulting in these projecting too deeply into the duct or being obstructed by the starter bar. As such, it was decided to adopt top-exit grout tubes (refer Figure 5 below) for the project's superstructure panels.

Figure 5: Underside of top-exit grout tube (left), top side of top-exit grout tube (right)

4 REFINED QA/QC PROCEDURES FOR SUPERSTRUCTURE PANELS

Following completion of the above investigations, refined QA/QC procedures were established for the project's superstructure panels.

4.1 Precasting process

QA/QC procedures commenced with a thorough review of the precast panel shop drawings by both the Main Contractor and Beca Engineering team. Once panels were ready for casting, detailed pre-pour check sheets were completed by the precast concrete Subcontractor. This included ensuring that the diameter and length of the Drossbach ducts were correct, with the set out and alignment of both the Drossbach ducts and starter bars then checked against the required construction tolerances. The considerable length of the starter bars meant that the plumbness of all elements forming the grouted Drossbach duct connections was critical to allow smooth site installation of the panels. Checks were undertaken to ensure the entry and exit grout tubes were installed and sealed correctly, without blockages or kinks that could later restrict grout flow. Maintaining the cleanliness of the inside of the Drossbach ducts during panel casting was extremely important, with hardened concrete residue and other debris potentially obstructing the path of starter bars into the Drossbach ducts during subsequent panel installation. As a QC measure, the Main Contractor reviewed all pre-pour QA documentation produced by the precast concrete Subcontractor, and would regularly visit the precast yard to conduct pre-pour inspections of their own. The Beca Engineering team also conducted independent reviews of a sample of the pre-pour QA documentation, as well as undertaking a number of visits to the precast yard for independent pre-pour inspections.

Figure 6: Panel mould prior to casting and arriving on site

4.2 Panel grouting

Each day, prior to work commencing on site, the grouting Subcontractor would compile and verify that the relevant QA handover sheets for panel installation were completed and signed. This was an important step to avoid premature grouting of panels prior to all necessary preceding works being completed. The grouting Subcontractor would then compile their own QA documentation for these same panels, including grouting sign-off sheets and a daily operations log. The purpose of the grouting sign-off sheets was to (for each panel) record details such as completion of grouting stages, sample photos, theoretical versus actual volumes of grout usage, issues encountered and remedials. On the other hand, the daily operations log was a high-level QA document used to track the timing of the daily grouting operations and to back-check material usage. These documents would then be reviewed and signed off by the grouting Subcontractor's site supervisor. All grouting QA documentation was reviewed by both the Main Contractor and the Beca Engineering team.

4.3 Sample pilot hole drilling

Following completion of panel grouting for each storey level, the Main Contractor would use the grouting Subcontractor's QA documentation to select a minimum of 2 Drossbach ducts per panel to conduct sample pilot hole drilling on. This was done by drilling a single 12 mm diameter pilot hole approximately 20-30 mm below the top-exit grout tube to verify adequate grout filling. Particular attention was paid to Drossbach ducts that were noted as encountering issues, according to the grouting Subcontractor's QA documentation.

4.4 Investigation of superstructure panels

Once superstructure construction was underway, Dizhur conducted a second round of ultrasonic scanning on a random sample of six Drossbach ducts on Levels 01 and 03. These scans predicted potential small-scale air voids in four of these ducts with low confidence levels. Targeted pilot hole drilling undertaken in these suspect areas found no evidence of defects. Due to the low confidence levels associated with these scans, it was concluded that these were likely outliers, meaning the ducts most likely did not have air voids / defects present. Continued sample pilot hole drilling found no further grouting defects in the remainder of the superstructure panels.

5 CONCLUSIONS

- Historically, grouting of Drossbach duct connections has not been subject to robust QA/QC processes, which has led to complacency in construction practices. Construction defects have been found during numerous investigations of these connections in existing buildings, reinforcing suspicions that current industry practice and long-standing industry QA/QC methods are ineffective at consistently identifying these defects.
- If present in a large enough number, these construction defects can result in the inability of grouted connections to reach their calculated design capacity. This is of particular concern where these connections are used in primary lateral load resisting systems, where important load paths may become compromised.
- The quality of construction can be influenced by various factors, starting from the construction of the precast panel, preparation of the Drossbach ducts for grouting, and the grouting of the ducts themselves.
- There are various methods of verification that can be employed to monitor the quality of grouting, including measuring the theoretical versus actual volume of grout usage, drilling pilot holes, and/or ultrasonic scanning. Auditing of the entire process of construction is important to prevent latent issues in the grouting process, and not just auditing of the grouting process itself.
- Due to the presence of small air voids within precast concrete panels themselves, and the inherent number of variables to consider when performing ultrasonic scanning of Drossbach ducts on site, the use of ultrasonic scanning to identify pockets of micro-bubbles and air voids <50mm within grouted Drossbach ducts is unreliable.
- For the purpose of onsite QA of grouted Drossbach ducts, ultrasonic scanning by an appropriately experienced engineer is an effective non-destructive method for identifying significant air voids (>50mm).
- Although pilot hole drilling provides only a localised indication of grout filling, this was sufficient to verify the absence of the primary grouting defects encountered during earlier project investigations.
- Through increasing scrutiny on QA/QC processes and monitoring key indicators such as grout volumes used in a given day, the quality of construction can be improved through some simple changes in behaviours leading to better structural outcomes for the project.

6 REFERENCES

Brown, BJ (2021). “SESOC Task Group - Grouted Connections and Drossbachs”. SESOC Journal, 34(1): 29-34.

C5 – Concrete Buildings – Proposed Revision to the Engineering Assessment Guidelines. (2018). NZSEE.

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.

NZS 3101.1:2006 Concrete Structures Standard. (2008). Standards New Zealand.

Seifi P (2018). “Seismic Behaviour of Grouted Connections in Precast Concrete Panels”. PhD Thesis, Department of Civil and Environmental Engineering, University of Auckland, Auckland, New Zealand, 208pp.

SESOC Interim Design Guidance Design of Conventional Structural Systems Following the Canterbury Earthquakes. (2013). SESOC.

Steinbrugge, K.V., and Degenkolb, H.J. (1969). “ A Note on the Earthquake Performance of Reinforced Concrete Shear Walls.”, Bulletin of the New Zealand Society for Earthquake Engineering, 2(2), 193-198.

SESOC (2022b). “Guidance Document #1: Existing (Legacy) Buildings – Investigation and Remediation”, Precast concrete – Grouted connections and drossbachs – SESOC Guidance.

SESOC (2022a). “Guidance Document #2: New Buildings – Specification/Construction/Assurance”, Precast concrete – Grouted connections and drossbachs – SESOC Guidance.

SESOC (2022c). “Guidance Document #3: Design Basis and Worked Examples”, Precast concrete – Grouted connections and drossbachs – SESOC Guidance.