PROJECTBUREAU NOORD/ZUIDLIJN

AMSTERDAM NORTH/ SOUTH LINE

INDEPENDENT OPINION ON THE FEASIBILITY OF COMPENSATION GROUTING

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Executive Summary

The Amsterdam North/ South Metro Line is under construction. It involves underground tunnels passing beneath built up areas of the city. A risk assessment has been conducted by Adviesbureau Noord/ Zuidlijn (ABNZL) and compensation grouting has been selected as a means of mitigating the impact of induced settlements on identified vulnerable buildings.Projectbureau Noord/Zuidlijn (PBNZL) acts as the Employer for the project. ABNZL acts as the Project Engineer. Saturn is the tunnelling and compensation grouting contractor.

Concern has been raised about the feasibility of using compensation grouting on the project, given the presence of very soft soils, high water tables and piled buildings. PBNZL have therefore asked for independent expert opinion on this issue from a team comprising Professor Mair of Cambridge University and the Geotechnical Consulting Group (GCG). The team has long experience of the use of compensation grouting, dating back to its original development as a formal application of the observational method and its first use in Europe in 1992-3. This report presents the opinion of the team on the general feasibility of compensation grouting for the Amsterdam North/ South Line. The report is primarily based on a review of the Mitigation Measures Stage 2 Redesign Report (Document Ref 4.2/FK-600 6765 dated 03-04-06). All buildings designated in the Stage 2 Redesign Report for mandatory compensation grouting have been considered, except for buildings in the Pijp area where further work is in progress to develop the compensation grouting scheme.

It is our understanding that the general ground conditions at the areas of compensation grouting comprise Made Ground over very soft Holocene clays and silts, overlying a medium dense sand sequence that is itself underlain by firm marine silty clay and clays. The medium dense sand sequence is of particular relevance to this report and can be subdivided into three strata: an upper sand layer (called the Eerste zandlaag, unit 13 in the Geotechnical Basis Report), an intermediate sandy clay or sandy silt layer called the Allerod (unit 14 in the GBR) and a second (lower) sand layer called the Tweede zandlaag, unit 17 in the GBR. The buildings to be protected are typically old masonry structures on wooden piles driven 0.5m into the upper sand layer (Eerste zandlaag, unit 13). The twin 6.5m outer diameter tunnels are mostly in the second sand layer (Tweede zandlaag, unit 17) and are to be constructed with Mixshield TBMs capable of good volume loss control. Compensation grouting is to be within the Allerod (unit 14) or first sand layer (Eerste zandlaag , unit 13).

Our opinion is summarised as follows:

Compensation grouting is the controlled injection of grout at a level between the tunnels and the building to be protected, in order to compensate for tunnelling induced settlements as they occur. In this way, the protected building never experiences damaging differential movements or distortions. For compensation grouting to be feasible in principle, the following factors must be applicable.

- The ground conditions must be conducive to compensation grouting. When grouting is carried out in soft or lightly overconsolidated clays, the process of grout injection induces large positive pore pressures which subsequently dissipate leading to consolidation settlements. Compensation grouting is only efficient if the heave induced by grouting is much larger than the consolidation settlement associated with grouting. An analogous situation can occur in loose silts or clayey sands, where grouting can induce a tendency for collapse of the soil fabric. Inspection of the information available to us on the general ground conditions of the target grouting strata (Eerste zandlaag, unit 13 & Allerod unit 14) indicate that they are not in these problematic categories and would be conducive to compensation grouting. This opinion is strongly reinforced by the significant and sustained pre-heave that has been induced beneath some of the protected buildings as part of the compensation grouting preparatory works.

- Preparatory works for compensation grouting must be implementable without inducing unacceptable damage to the protected buildings, taking into account the presence of cohesionless soils and a high ground water table. Any movements that occur must be small so as not to induce damage to the building before the compensation grouting works are active. For the configuration of the North-South line, preparatory works are shaft sinking, drilling and installation of grout tubes. Established methods exist for carrying out these activities while limiting the associated ground movements. It is our opinion that it is generally feasible for compensation grouting preparatory works to be carried out without damaging the protected buildings. This opinion is supported by monitoring information provided to us which indicates that preparatory works have been completed with only small movements occurring. However, it is important to stress that preparatory compensation grouting works must be carefully designed and executed. Particular importance should be placed on stringent site supervision during these works.

- Grouting must be able to control the movement of buildings founded on piles. There is the possibility that grouting very close beneath end bearing piles could cause lift of some piles relative to adjacent ones. However, this risk can be mitigated in a well designed scheme and compensation grouting should be feasible for the situation in Amsterdam where the piles are founded on a stiff sand layer that would spread the effects of grouting. Possible mitigation

measures are discussed in our report. The proposed compensation grouting scheme already addresses this issue by maximising the cover between the grout tubes and pile toes, and by pre-treating the grouting zone to develop a stiffer block within which subsequent grouting is carried out. If necessary during subsequent stages of work, further mitigation measures are also available including the use of grout mixes that induce hydro-fracture and distributed heave, adjusting the grouting pattern and injection volumes. The full scale trial at Rotterdam and the successful pre-heave at some building locations for the North/ South Metro demonstrates that compensation grouting beneath pile toes is feasible.

- A satisfactory level of redundancy should be built into the compensation grouting design. This would be reflected in the extent of the mandatory grouting zone, maximum spacing between grouting tubes and number of grouting layers adopted. The level of redundancy is also closely linked to the experience, workmanship and maintenance provided by the grouting contractor. There is no established rule for the acceptable level of redundancy, and this must be chosen to reflect the project's risk strategy and maintenance regime. We can only comment that the maximum spacing of grout tubes proposed, and the use of a single layer of grout tubes, is similar to configurations successfully used in other projects. We can also highlight that the compensation grouting technique is inherently flexible in that if larger volume losses than expected occur during tunnelling, then more grout is simply injected concurrent with tunnelling to compensate for the larger settlement as it occurs.

We have reviewed case histories of compensation grouting application in similar soils and ground water conditions. Relevant successful case histories are available from Bologna, Perth, Antwerp and London, which are documented in our report. These confirm the general feasibility of the method in similar ground conditions to those North/ South line compensation grouting locations considered in this report.

We have also reviewed pre-heave monitoring records for compensation grouting preparatory works completed so far. These confirm the general feasibility of the method by demonstrating heave and control of piled buildings, rapid response to grouting, longevity of the induced heave and satisfactory performance of the installed instrumentation.

We conclude that, with appropriate application and planning, compensation grouting is feasible for the North/ South Line.