Stabilisation of an historical building

Active settlement compensation using Soilfrac® (compensation grouting) during tunnelling below the main train station of Antwerp

Site Report 61-29 E

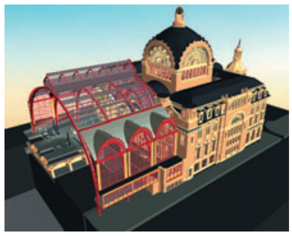
Zusammenfassung

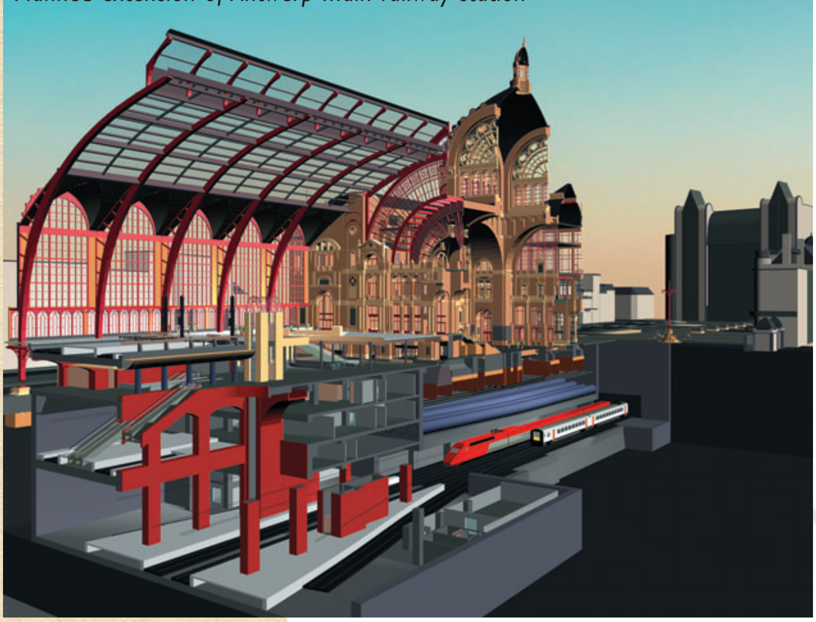
Es ist geplant eine Teilstrecke der Bahnlinie Brüssel – Antwerpen – Amsterdam weiter auszubauen, wodurch auch ein Umbau des Bahnhofs Antwerpen zur Hochgeschwindigkeitsstrecke notwendig wird. Der historische Kopfbahnhof muß dazu untertunnelt werden. Zur Vermeidung von möglichen Setzungsschäden und um bleibende Setzungen während der Tunnelvortriebsphasen zu kompensieren wird das Soilfrac®-Verfahren angewendet. Auf diese Weise ist es möglich, daß – nach einer Vorstabilisierungsphase und ausreichender Vorspannung des Bodens – bestimmte Bauteile während des Tunnelvortriebs kontrolliert stabilisiert und gehoben werden können.

En résumé

Dans le cadre de la transformation de la ligne de chemin de fer Bruxelles – Anvers – Amsterdam, une adaptation de la gare d'Anvers pour le passage de trains à grande vitesse était nécessaire. On a donc réalisé un tunnel sous la gare terminus d'époque.
Afin de diminuer l'effet des tassements pendant la phase d'exécution de la galerie, on a utilisé le procédé Soilfrac pour la compensation simultanée des tassements. On s'est assuré que, après les travaux préliminaires, et un précontrainte suffisante du terrain, les soulèvements contrôlés de l'ouvrage pourraient ultérieurement être réalisés sans dommage.

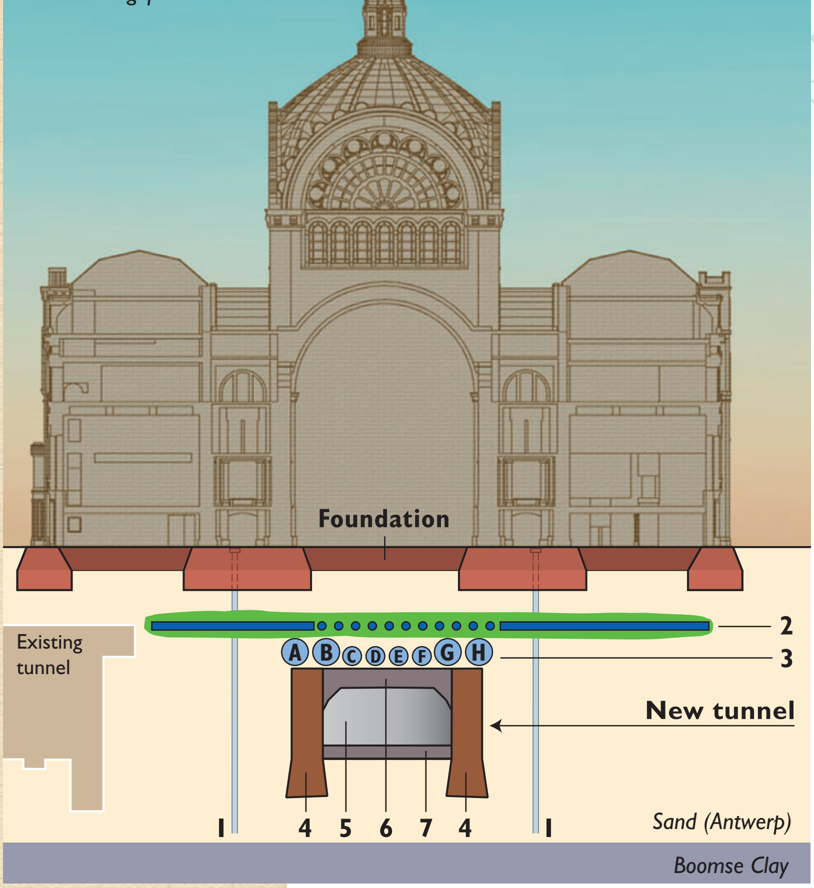
The special project…





Planned extension of Antwerp main railway station

Picture: Eurostation, Brussels



Cross-section of railway station and building phases

Description of the project

Since 1999 stabilisation works to the main train station of Antwerp have been ongoing whilst tunnelling works are being carried out under the building. The 70 m high building complex was built between 1899 and 1905 as a terminus station. The Belgian railway company NMBS is extending the high-speed railway line from Brussels via Antwerp to Amsterdam. Tunnelling has been chosen to allow ordinary and high speed trains to pass through.

The tunnel was built using the proven "Belgian tunnelling method". This technique involves constructing a pipe umbrella roof, followed by lowering of the ground water table, excavation by hand of 15 m deep tunnel retaining walls and finally the remaining excavation and lining of the tunnel roof.

Scope of works

Calculations and experience gained from previous projects estimated the total expected settlements to be between 60 mm and 120 mm considering all construction phases. Deformations of this magnitude, with steep tangential inclinations on the edge of the depression, normally lead to considerable damage to structures. Highly stressed foundations i.e. tower footings with soil pressures > 800 kN/m^2 result in additional technical challenges for the control and stabilisation systems.

In order to avoid such damages, the Soilfrac® method was used for settlement compensation during various tunnelling phases. Use of this method ensures, that after a pre-stabilisation phase and sufficient pre-stressing of the soil, a controlled active settlement compensation can be performed during tunnelling works. The allowable settlement and tilting for the critical construction phases was limited to 5 mm and 1:2000 respectively.

1 Wells for groundwater lowering

2 Soilfrac® borings and injections

3 Pipe umbrella roof (diameter 2.5 m–3.0 m)

4 Tunnel retaining walls

5 Excavation

6 Lining of tunnel roof

7 Tunnel base

The Soilfrac® method…

Installation of Soilfrac® borings

Boring works

The 45 m long horizontal Soilfrac® borings were carried out from vertical shafts.

The boring and injection works were performed in dense sands which are found below the tunnel, down to a depth of 20 m. The "Boomse" clay containing sea silt exists below the dense sands.

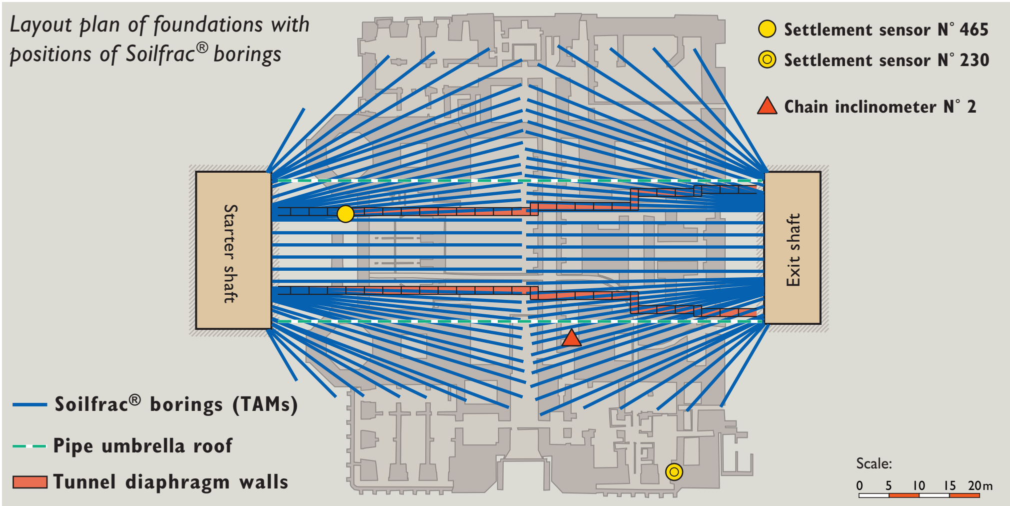
A boring accuracy of <1% had to be maintained in all directions, because of various obstructions in the soil, whose locations were not exactly known, i.e. footings, sheet piles and wells.

Contact Grouting

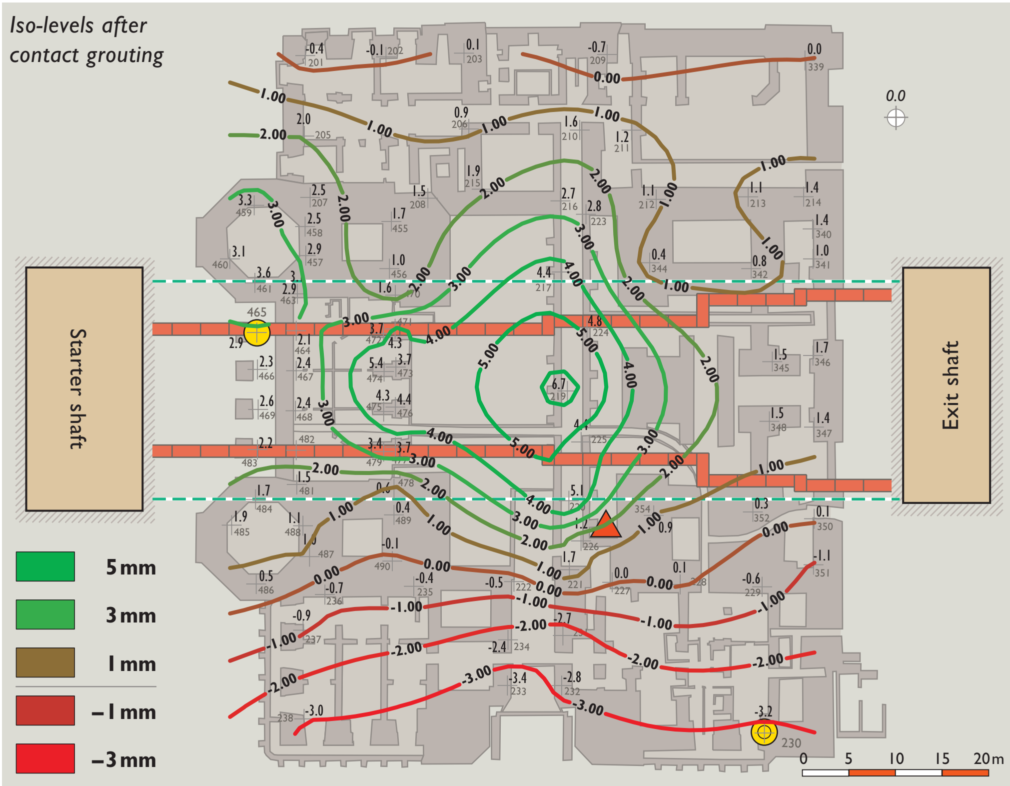
After the boring and sleeve pipe installation, a contact grouting and stabilisation program for the footings was started.

The injection was stopped after several grouting steps and a contact settlement compensation between 2 and 5 mm. In total, several thousand single injections were necessary.

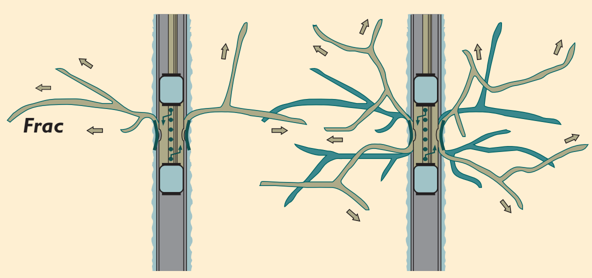
Settlements up to 3 mm were recorded outside of the injection area due to groundwater lowering.



Layout plan of foundations with positions of Soilfrac® borings



Iso-levels after contact grouting



Single injection **Multiple phase injection**

Soilfrac®-principle

The Soilfrac® method has been applied successfully by Keller Grundbau for several decades to minimise settlements in connection with tunnelling and to re-level existing buildings.

Packers are installed inside sleeve pipes (TAMs) and a defined volume is injected though single valves. This sequence is repeated in several injection phases in order to provide controlled active settlement compensation of buildings, after the contact grouting phase and the pre-stressing of the soil has been completed.

Surveying and control…

Installation of a crack thickness measuring device

Measuring systems

Eight different measuring systems, each equipped with highly responsive sensors, were installed prior to any works on site to monitor the change in levels and deformations.

The measured data was assessed, controlled and evaluated by means of computers.

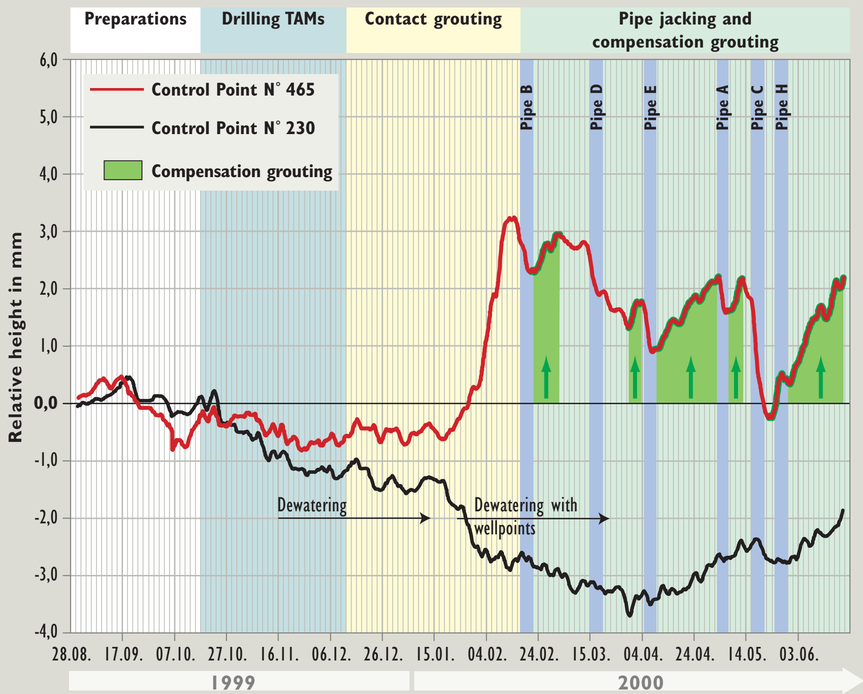
The following equipment was used:

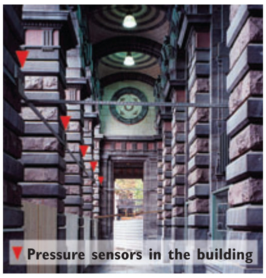
Levelling:	
• **pressure and temperature sensors**	**93**
• **extensometers**	**18**
• **measuring points for accurate levels**	**114**
Displacement control:	
• **automatic and optical crack thickness measuring devices**	**67**
Tilting control:	
• **automatic vertical chain inclinometers**	**68**
• **automatic horizontal chain inclinometers**	**120**
Total measuring devices	**480**

Pressure settlement sensor

An automatic water levelling system was installed to control the changes in levels. This system does not use the usual displacement transducers, but pressure transducers (system GeTec) having a high accuracy. A long term system accuracy < 0.3 mm was achieved in spite of the very difficult site conditions.

Levels of representative measuring points (water levelling system)

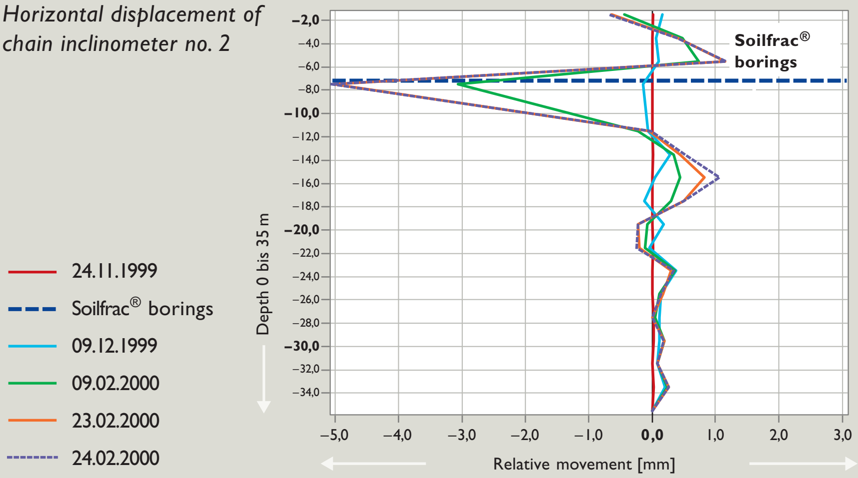




Pressure sensors in the building

In order to control the deformation of the tunnel sides, vertical chain inclinometers down to 35 m were used with a distance of 2 m between the sensors.

Horizontal displacement of chain inclinometer no. 2



Installation of a vertical chain inclinometer

Pipe jacking and active settlement compensation…

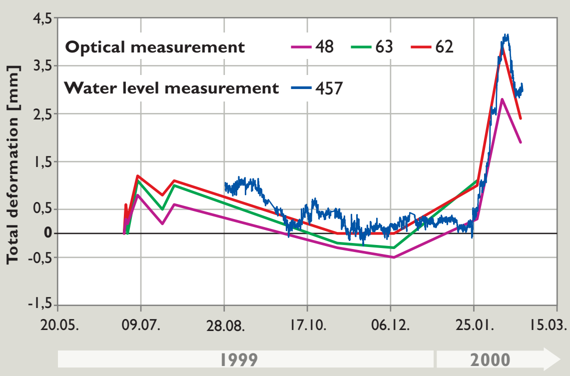
Pipe jacking and compensation grouting

After the contact grouting had been completed, eight pipes with diameters of 2.5 m and 3.0 m were installed by jacking. No obstructions were encountered and maximum settlements of 4.0 mm were recorded.

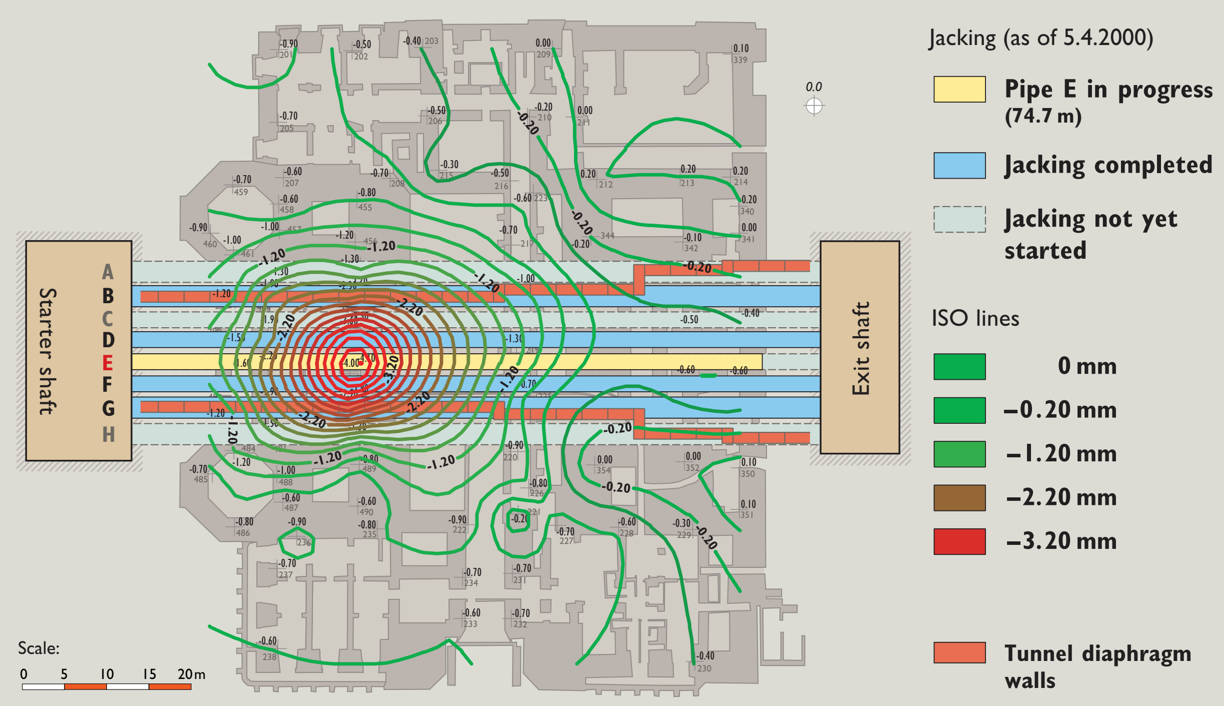
Compensation grouting followed every pipe jacking operation. In this way loose zones were stabilised immediately and footings underwent active settlement compensation up to their original level.

A comparison of ordinary levelling with the water levelling system confirmed the settlements and active settlement compensations.

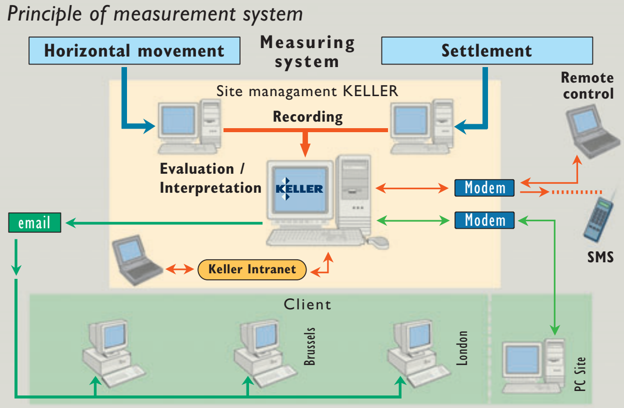
Comparison between optical levelling and the water levelling system



Iso-levels during pipe jacking (pipe E)



Principle of measurement system



After pipe jacking A and H had been completed, the excavation of the 15 m deep diaphragm walls was started by hand.

All measuring systems were monitored online during the injection and pipe jacking works in order that any necessary compensation grouting could be carried out at any time.

Additionally critical values were sent via cellular phone as SMS messages to ensure a permanent control and a quick response during difficult phases.

Client
NMBS (Belgian railway company),
Koningin Astridplein 27 · B-2018 Antwerp

Main contractor
TV (J.V.) A.C.S. Tunnel (CEI Construct · MBG · Jan De Nul · Votquenne · Smet Tunnelling),
Excelsiorlaan 16 · B-1930 Zaventem

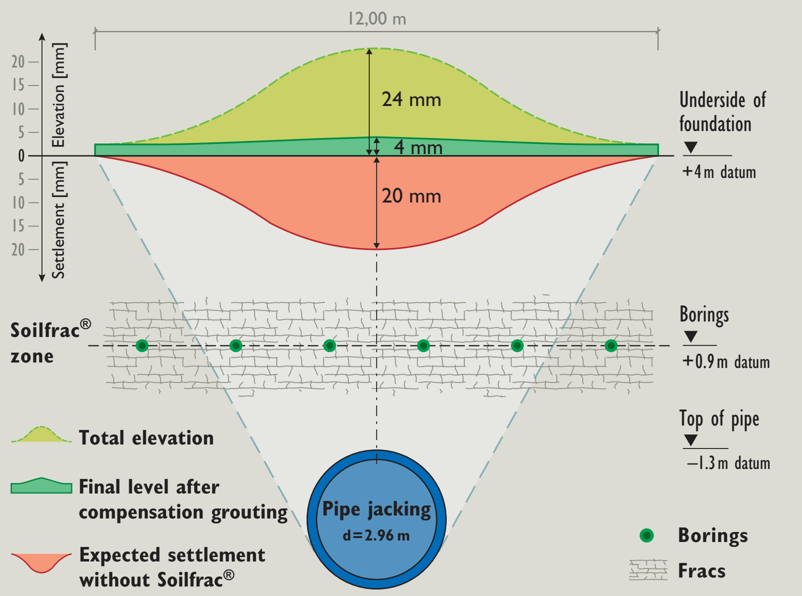
Design engineer
Eurostation, Brogniezstraat 54 · B-1070 Brussels

Consultant
Seco, Aarlenstraat 53 · B-1040 Brussels

Work carried out
- borings approx. 3 500 m
- injections approx. 530 m^3

Period of execution
August 1999 – April 2001

Settlements / active settlement compensation

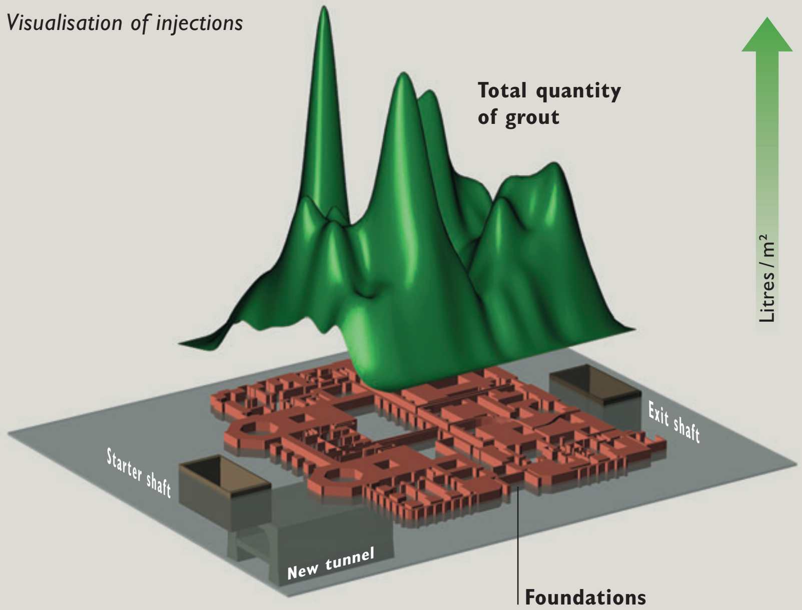


It was calculated that due to the construction of the pipe umbrella roof 20 mm of total settlement was expected. The purpose of Soilfrac® was to compensate for the settlements immediately, ensuring that the specified values were not exceeded.

A total settlement compensation of 24 mm was achieved by implementing many single injections during pipe jacking and the construction of the diaphragm walls.

After this construction phase had been completed and the settlement rate reduced to zero, an overcompensation of approximately 4 mm took place compared to the initial level. Critical deformations did not occur at any time.

Visualisation of injections



During the course of the works thousands of single injections were executed. All injection data was saved and evaluated regularly. The distribution of the injected quantities displayed large differences. In areas of highly stressed main footings considerably larger quantities were necessary.

An advantage of utilising sleeve pipes (TAMs) was that the manchette injection valves could be used more than once.

With the application of both, Soilfrac® and comprehensive control systems, it was possible to execute the tunnelling works without disturbance or damage to the existing buildings.

Photos:
Volker E. Jahr, Köln

Keller Grundbau GmbH
Head Office and Overseas Division
Kaiserleistr. 44 · **D-63067 Offenbach**
Tel. +49 69 8051-0 · Fax +49 69 8051-244
E-mail: Info@KellerGrundbau.com
www.KellerGrundbau.com

Berlin · Bochum · Bremen · Dorfmark · Garching · Leipzig · Maintal · Renchen · Wien

Executing branch
Bochum
Mausegatt 45–47 · **D-44866 Bochum**
Tel. +49 2327 804-0 · Fax +49 2327 804-31
E-mail: Bochum@KellerGrundbau.com