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Topic

UNDERGROUND AND ENVIRONMENT / TUNNELLING METHODS

Title

Urban contracting and the environment

Author

ITA WG Underground and Environment; V. Roisin, T. Braaten, W. Dietz, M. Legeais, J. K. Lemley, T. Romanowski, J. Van der Linden

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Abstract: -

Résumé: -

Remarks: During this meeting the following articles have been presented:
* Exposé introductif: L'entrepreneur face aux difficultés d'exécution de travaux souterrains en milieu urbain, V. Roisin
* Experiences from Drilling and Blasting Operations in Two Norwegian Towns, T. Braaten
* The Influence of Environment Protection on Planning and Execution of Tunnelling Projects in German Cities, W. Dietz
* Réalisation de parkings souterrains à Paris à l'aide de parois moulées exécutées à l'hydrofraise, M. Legeais
* Tunnelling Action in New York City, J. K. Lemley
* Construction of an Underground Railway in Warsaw - Man Environment Protection, T. Romanowski
* Problèmes de reprise en sous-oeuvre lors de travaux souterrains à Bruxelles, J. Van der Linden

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"URBAN CONTRACTING AND THE ENVIRONMENT"

"LES MARCHES DE TRAVAUX EN SITE URBAIN ET L'ENVIRONNEMENT"

JOINT OPEN SESSION ITA/NOT

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EDITORIAL

Victor Roisin

Le Symposium de Varsovie, organisé en mai 1983 par la NOT à l'occasion de l'Assemblée Générale Annuelle de l'AITES et consacré au thème "Travaux Souterrains — L'homme et l'Environnement", constitua une occasion pour étudier en séance publique les problèmes associés aux marchés de travaux en site urbain.

Le rapport général et les six communications qui y furent présentées, et qui font l'objet de la présente publication, mirent en évidence les contraintes multiples avec lesquelles un entrepreneur impliqué dans de tels travaux est confronté.

Il est évident qu'en site urbain les procédés et les moyens à mettre en œuvre pour l'exécution de travaux souterrains requièrent une coordination particulièrement attentive entre tous les protagonistes de la construction. Les maîtres d'œuvre, les architectes, les ingénieurs conseils, les administrations locales, les services publics doivent former avec les entrepreneurs choisis des équipes cohérentes dont la responsabilité est de mener à bien les travaux dans le respect des cahiers des charges, mais aussi en recherchant toutes les solutions susceptibles d'améliorer la protection de l'environnement. De telles opérations présupposent une concertation permanente et constructive avec les populations, concertation génératrice d'options ouvrant la voie au succès final.

Un corollaire à cette approche pluridisciplinaire des problèmes, réside dans la définition sans équivoque des tâches et des responsabilités dans la mise en œuvre des actions nécessaires pour conserver et si possible améliorer la qualité de l'environnement.

On touche là un aspect important du problème. Faut-il se contenter de conserver l'environnement ou ne faut-il pas saisir l'occasion fournie par les travaux pour l'améliorer.

L'entrepreneur joue ici pleinement son rôle de réalisateur capable de fournir des services comme d'éclairer les maîtres d'œuvre sur le coût des solutions techniques relatives non seulement à l'ouvrage souterrain proprement dit mais aussi aux ouvrages auxiliaires affectés par les travaux tels que les égouts, les galeries techniques, etc.

Les détournements provisoires envisagés par l'entrepreneur peuvent, par exemple, déboucher sur des solutions définitives représentant un apport important dans la politique de modernisation des réseaux des services publics.

Doivent aussi être pris en considération les frais d'exploitation tels que l'éclairage et la ventilation.

Le coût des dispositions évoquées constitue, bien entendu, un facteur important de la décision quant à l'adoption ou au rejet de ces mesures. Mais ces coûts directs ne représentent qu'une partie de la question et il y a lieu d'étendre l'analyse financière à l'ensemble des problèmes économiques associés à de tels travaux.

En effet, il est bien connu qu'un environnement peut être profondément altéré par des solutions techniques, avantageuses en elles-mêmes au niveau des coûts, mais dont les conséquences financières peuvent s'avérer très préjudiciables pour les habitants.

Les exemples sont nombreux ou l'adoption de la méthode à ciel ouvert a détruit la vie commerciale dans des artères précédemment florissantes. Le recours à la tranchée ouverte comme solution définitive peut encore avoir en milieu urbain des conséquences économiques considérables en altérant la valeur d'utilisation et donc la valeur vénale des immeubles qui la jalonnent. Ces deux exemples montrent qu'il y a lieu d'étudier les aspects économiques de la protection de l'environnement, à la fois pendant la durée du chantier et à titre définitif.

Ainsi donc on ne peut que recommander le recours à des études socio-économiques globales, élément important dans l'élaboration des budgets pour la protection de l'environnement.

On ne saurait trop insister non plus sur l'intérêt d'une concertation la plus large possible au moment de l'établissement des avant-projets qui intègre aussi l'entrepreneur dont l'expérience est susceptible d'apporter un éclairage bénéfique sur les problèmes relevant de sa discipline.

Victor Roisin
Secrétaire Général AITES

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UNDERGROUND AND ENVIRONMENT / TUNNELLING METHODS

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Exposé introductif: L'entrepreneur face aux difficultés d'exécution de travaux souterrains en milieu urbain

Author

V. Roisin

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Remarks:

L'entrepeneur face aux difficultés d'exécution de travaux souterrains en milieu urbain

V. Roisin

L'entrepreneur se trouve lors de la construction d'un ouvrage en milieu urbain devant un nombre important de contraintes, qui résultent bien entendu de l'implantation de l'ouvrage au milieu de la ville, de la nature de l'ouvrage souterrain — métro, passage routier, parking, infrastructure de bâtiment, galerie technique — comme aussi de la plus ou moins grande proximité d'ouvrages existants.

On trouve en tête de ces contraintes l'obligation de maintenir pour les personnes et les véhicules, une circulation satisfaisante durant toute la durée des travaux. Il faut, en effet, assurer un accès aisé aux habitations par des passerelles prévues, non seulement pour les piétons mais aussi pour les véhicules automobiles dont la présence pourrait être essentielle sur place: pompiers, ambulances, déménagements, fournisseurs de combustible (mazout, charbon), etc. Il faut évidemment maintenir l'accès aux immeubles où s'exerce des activités professionnelles et commerciales. A l'heure actuelle, on n'imagine plus d'éventrer pour plusieurs années une rue où sont installés de nombreux magasins de détail, ce qui signifierait la ruine des commerçants par suite de la désaffectation de la clientèle pour une zone de la ville où la circulation et le parking sont très difficiles.

De plus, il faut se préoccuper du trafic destiné à transiter dans les quartiers bouleversés par des travaux exécutés à ciel ouvert et il faut assurer la fluidité de la circulation.

V. Roisin est Secrétaire Général de l'AITES.

L'imagination des entrepreneurs est donc mise à épreuve et c'est ainsi que l'on assiste, dans les travaux urbains à ciel ouvert à un découpage en phases successives, au travail sous platelages temporaires, à l'installation de viaducs provisoires, à l'établissement de détournements.

L'injection dans une circulation déjà contrariée, de nombreux et lourds camions transportant à vitesse réduite les produits de démolition ou de terrassement peut aussi provoquer une congestion du trafic.

A l'entrepreneur donc d'établir si possible des circuits spéciaux pour ses camions et de planifier leur introduction dans la circulation, par exemple en évitant les heures de pointe. A l'entrepreneur aussi de proposer des procédés pour rétablir le plus vite possible la circulation dans son intégralité d'où la méthode "cover-and-cut" à ne pas confondre avec la méthode "cut-and-cover", la première comportant la réalisation des parois du pertuis suivie par la construction de la dalle supérieure et par le rétablissement immédiat de la voie de circulation, le terrassement du stross s'effectuant ensuite en phases avec la construction des structures internes et du radier.

De plus en plus les administrations imposent à l'entreprise l'adoption d'une méthode complètement souterraine telle que la réalisation de pertuis de tunnel à partir de galeries blindées classiques, le procédé pouvant être amélioré par la réalisation des dalles supérieures à l'aide de tubes poussés dans le sol et remplis de béton après introduction d'une armature. Une autre méthode souterraine déjà largement utilisée est celle du bouclier avec ses nombreuses variantes: bouclier à front de taille ouvert dans les terrains secs et résistants, bouclier à air comprimé dans les terrains pulvérulents gorgés d'eau, bouclier à la bentonite dans les terrains à faible résistance et gorgés d'eau, machine de creusement à plateau rotatif équipé de molettes dans les roches non aquifères ou injectées, etc.

Les entrepreneurs ont ainsi été amenés à développer des méthodes et des machines de plus en plus performantes et de mieux en mieux adaptées aux conditions du milieu urbain. La sécurité de la circulation va de pair avec sa permanence avec comme conséquence pour l'entrepreneur l'obligation de prévoir la signalisation adéquate — panneaux indicateurs et marquages routiers — d'installer des clôtures de chantier et des glissières de sécurité, d'assurer la protection des piétons et des véhicules par des ouvrages provisoires tels que auvents, pertuis provisoires, etc.

Les surfaces de roulement doivent encore être maintenues en parfait état de propreté et débarrassées des terres tombant des camions ou entrainées par les pneumatiques, comme des boues bentonitiques, fatales pour l'adhérence des véhicules.

A noter encore que dans les grandes opérations urbaines, l'entrepreneur a généralement l'obligation de constituer une petite équipe d'ouvriers qui se consacrent sous le conduite d'un technicien responsable au maintien de la circulation.

Un autre type de contrainte pour les édificateurs est l'obligation

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d'assurer la permanence du fonctionnement des câbles, canalisations et installations diverses des Services Publics. Cela implique le support de ces câbles et canalisations au-dessus des fouilles ouvertes, le détournement éventuel des égouts, la pose éventuelle de canalisations ou de câbles provisoires.

En milieu urbain, les édificateurs ont à faire face à de nombreuses obligations en ce qui concerne les pollutions de toute nature: gaz d'échappement, poussières, bruits, vibrations.

On est ainsi amené par exemple à remplacer le battage des palplanches par le fonçage par vérins, à procéder à des démolitions à l'éclateur plutôt qu'à l'explosif, à pourvoir de silencieux les compresseurs à air comprimé et les marteaux, à remplacer des pieux battus dans le sol par des pieux forés. Les travaux de nuit font aussi l'objet de règlementations très strictes: interdiction de fonctionnement pour les machines bruyantes, restrictions quant à la circulation en rue des engins lourds, coupures planifiées des circulations routières et ferroviaires (métro, trams, trains).

Les procédés de construction utlisés par l'entrepreneur pour la réalisation d'ouvrages souterrains en site urbain doivent aussi être choisis en fonction des contraintes locales.

Comme de tels ouvrages se trouvent souvent très proches de constructions importantes, parfois vétustes, parfois de caractère monumental, il faudra sélectionner des procédés qui assurent la stabilité de ces édifices. On fera donc appel à des techniques de reprise en sous-œuvre, pieux Méga, pieux aiguilles, rempiètements en tranchée blindée, injections, pour conforter ces bâtiments. Quant aux ouvrages souterrains proprement dits, ils seront donc réalisés en faisant appel à des procédés qui n'altèrent en aucune façon l'environnement.

D'où le recours à des écrans non déformables — paroi raide du type paroi moulée, écran en pieux sécants, écran exécuté en tranchée blindées, etc. — à la mise en œuvre d'un rabattement qui n'affectera pas la nappe aquifère à l'extérieur de l'enceinte — recours à la réalimentation de la nappe extérieure, injection d'étanchéisation pour constituer un horizon imperméable au niveau de la base de l'enceinte, prolongation de l'enceinte jusqu'à un horizon imperméable à l'aide d'injections classiques ou par un diaphragme réalisé en jet grouting, etc.

Il y a lieu encore d'éviter la consolidation des sols par des vibrations, ce qui exclut le recours au battage au bénéfice des procédés par forage ou par fraisage — hydrofraise par exemple.

La congélation des sols est en terrain de mauvaise qualité — par exemple sable fin peu compact et saturé — une technique qui appliquée avec les précautions voulues permet de réaliser des pertuis souterrains sans perturber l'équilibre du massif et sans affecter ni les voiries ni les immeubles voisins.

Enfin, il faut mentionner une nouvelle fois le bouclier qui, sous ses formes modernes — bouclier à la bentonite, bouclier à extension, etc. — a permis de réaliser des tronçons de tunnel pour métro dans des villes à tissus urbains très serrés et cela sans provoquer de tassement préjudiciable.

Pour terminer cette brève revue des problèmes auxquels doit faire face l'entrepreneur appelé à réaliser un ouvrage souterrain en milieu urbain, il faut rappeler que le succès d'une telle opération est conditionné par la qualité de la collaboration entre tous les protagonistes de la construction, à savoir:

- le client — administration ou client privé;
- l'ingénieur conseil et l'architecte;
- le bureau de contrôle technique mandaté par les assureurs;
- les services publics;
- la police locale;
- les représentants des populations riveraines;
- et last but not least, l'entrepreneur général.

L'entrepreneur sur qui se concentre en finale les responsabilités de bâtir se trouve en présence d'un challenge particulièrement lourd.

Il lui faut respecter un cahier des charges impératif, respecter toutes les obligations de résultat et particulièrement celles relatives à la sauvegarde de l'environnement, respecter ses prix et respecter son délai final et éventuellement les délais partiels: Il lui faut encore s'accommoder du voisinage éventuel, d'autres chantiers qui ne sont pas contrôlés par lui, cas fréquent lorsqu'un long tunnel de métro par exemple est adjugé en plusieurs sections attribuées à des entrepreneurs différents.

La réalisation de tels travaux va donc requérir la mise en place, au sein de l'entreprise, d'équipes de première qualité, pour mener à bien l'exécution comme pour imaginer des solutions satisfaisantes aux nombreux problèmes locaux qui se présentent dans ce type d'ouvrage, comme pour réagir rapidement en cas de problème — une venue d'eau par exemple.

On dit que l' "Union fait la Force" et ceci est particulièrement vrai pour les travaux souterrains entrepris au cœur de nos villes.

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Experiences from Drilling and Blasting Operations in Two Norwegian Towns

Author

T. Braaten

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Remarks:

Experiences from Drilling and Blasting Operations in Two Norwegian Towns

Tore Braaten

Résumé — L'auteur décrit certains des problèmes auxquels un Maître d'Œuvre est confronté dans la construction à l'explosif d'ouvrages souterrains en site urbain, à l'aide de deux exemples: la centrale électrique de Mesna, construite sous le centre de la ville (environ 154 GWH) et un parking à Fredrikstad, également au centre de la ville, avec un volume total excavé de 40 000 m³. La proximité immédiate d'immeubles a imposé des limites très strictes quant aux vibrations résultant du creusement à l'explosif et le recours à certaines modifications de cette méthode. D'autres mesures ont été prises pour limiter le bruit et la pollution de la nappe phréatique.

In Norway, as in other countries, increasing land prices and growing restrictions on the use of cultivated areas and parkland result in a need to exploit underground spaces, for a variety of purposes. Examples include air-raid shelters, parking areas, swimming baths, sports facilities, sewage and waterpurifying plants, refrigeration rooms and oil- and heat-storage. In many cases, a double function is achieved, such as parking combined with storage, etc. Such constructions are often sited in town centres, and construction work must be carried out within a commercial or residential area with little rock coverage, and short distances to buildings and streets.

Full-face drilling has gained greater acceptance in Norway in recent years, due to its ability to process increasingly harder rocks, and improved possibilities for carrying out stabilizing work in front of the machine. However, a large number of tunnels and caverns are constructed every year, using conventional methods, in other words, drilling and blasting. Frequently, these projects are so small that full-face drilling is uneconomical, or the geometry of the cavern is such that is not feasible. The only method of excavation thus possible, in the hard types of Norwegian rock, is drilling and blasting. I shall proceed to describe two such projects, in which our company has been engaged as the the main contractor, firstly the Mesna Power Plant in Lillehammer and secondly a parking hall in Fredrikstad.

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Mesna Power Station, in Lillehammer

Lillehammer is a small town in southern Norway. The Mesna River runs through Lillehammer, and has been exploited for many decades, to produce hydroelectric power. At present, there are four small power stations using the wa..r system, and all have components of considerable age. The present total yearly output is about 110 GWH.

Development of the new Mesna Power Station will replace the existing power stations. The project enables the utilisation of a 350-m head. The new power station is, in contrast to its predecessors, completely enclosed by rock, under the town centre, and the yearly output is estimated at about 154 GWH.

The Contract includes the following operations within rock:

The driving of:

- a 900-m long access tunnel, cross-sectional area 28 m², downward gradient approx. 1:8;
- various transport tunnels, cross-sectional area 18 m², varying downward gradients, total length approximately 200 m;
- an inflow tunnel, cross-sectional area 18 m², upward gradient 1:8, length 900 m;
- an emergency exit tunnel, cross-sectional area 16 m², upward gradient 1:8, length approximately 200 m;
- an outflow tunnel, cross-sectional area 18 m², horizontal, length 1800 m;
- an inflow shaft, 45°, dia. 5.4 m, length approximately 360 m;
- an emergency exit shaft, dia. 4.8 m, length approximately 150 m;
- a power station hall, approx. 7000 m³;
- cuttings, channels, etc. approx. 12 000 m³.

Both shafts are drilled with a raise drilling machine while all tunnels are excavated by drilling and blasting.

The rock, found here, is of a sparagmite type and consists of alternating layers of sandstone and clay mudstone. The sandstone layers make 2/3–3/4 of the total rock mass. This type of rock has proved to be very resistant to water penetration, and has behaved favourably with respect to stability.

Parking Hall in Fredrikstad

Fredrikstad is a small town east of the Oslofjord, the site is located within a small highly built-up rocky mound in the town centre. The parking hall consists of three halls

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with common access and connecting tunnels.

Each hall has a cross-sectional area of 120 m^2, and a length of 120 m. Access and connecting tunnels have a cross-sectional area of 40–50 m^2. The total volume excavated is 40 000 m^2 in the caverns, and 6000 m^3 cutting for the access. The distance from the contour of the halls to the nearest houses is generally in the order of 10–14 m, occasionally dropping to only 2.5 m.

The type of rock in this area is a medium to coarse-grained granite, with little cracking. In some places, the granite is cut through by narrow, rather cracked diabase intrusives.

Requirements for the Execution of the Work and Problems During Construction

Limiting of tremor from blasting

There are no norms for how much tremor can be tolerated by different types of buildings and constructions in Norway. There are, however, several consultant firms and research institutes who have studied the problem of tremor, for a number of years. They usually evaluate every project, and set maximum limits, according to the type of building, the state of the foundations and probable consequences.

Strict requirements were made with respect to tremors. Generally, they should not exceed 100 μm or 30 mm/sec, at any place measured at the foundation or on the construction.

Even stricter limits applied to:

- The old power station, pipelines etc., which were in use.
- Several houses.
- Main railway.
- Two factories

In these cases, the maximum acceptable tremor was 50 μm or 15 mm/sec which is quite stringent.

Requirements with respect to tremors set at 100–150 μm *amplitude on nearby houses*

For the Mesna Power plant, the blasting work can be divided into two groups: cuttings and tunnels.

The cutting that offered the greatest challenge was undoubtedly that at the access tunnel, and will thus be described. The cutting, in total approx. 2000 m^3, lies very close to the existing power station, which, at the time of blasting, was in full use. Otherwise, the blasting area was surrounded by buildings. To meet the maximum level of 15 mm/sec, the amount of explosive per detonator was calculated at 200 g. This proved to be totally impractical, and was therefore increased to 560 g per borehole, with a maximum of two detonators per borehole.

The drilling pattern was 0.6 × 0.8 m, where the burden was 0.6. The maximum depth of the boreholes was approximately 3 m, and the bench was divided into two. The size of each blast was therefore maximally about 22 m^3. The work took approx. 6 weeks. Figure 1 shows a longitudinal section of the cutting, and Fig. 2 shows the firing plan.

Tremors were measured using a Vibrameter, which electronically measures the vibration in two scales, 0–10 mm/sec and 0–100 mm/sec. The measurement are taken in three different places, and some typical results are shown in Fig. 3. The table shows some relatively high values. On one occasion, the powerstation cut out in one generator, but without any damage as a result. Otherwise, there was no significant damage caused by the blasting.

The major problem concerning tunnel blasting in tremors is that the amount of explosive becomes too great. It is not unusual to use 35–40 kg explosives per detonator interval, in a tunnel blast. This gives, of course, unacceptably high vibration values where the coverage is inadequate. There are various measures one can take to solve this problem, including:

- reducing the length of the borehole;
- reducing the cross-sectional area blasted;
- using the most possible detonator intervals.

All three of these remedies were used in the tunnels at Mesna. A typical drill pattern for a 28-m^3 tunnel will give a maximum of approximately 40 kg explosives per detonator interval, which is unacceptable with little coverage and small distance to buildings.

This was solved by dividing the tunnel cross-section into an upper and lower half, and blasting each half individually. The borehole length was 2 m, and the Nonel system of detonation used. The Nonel system 30 intervals, and by using delay

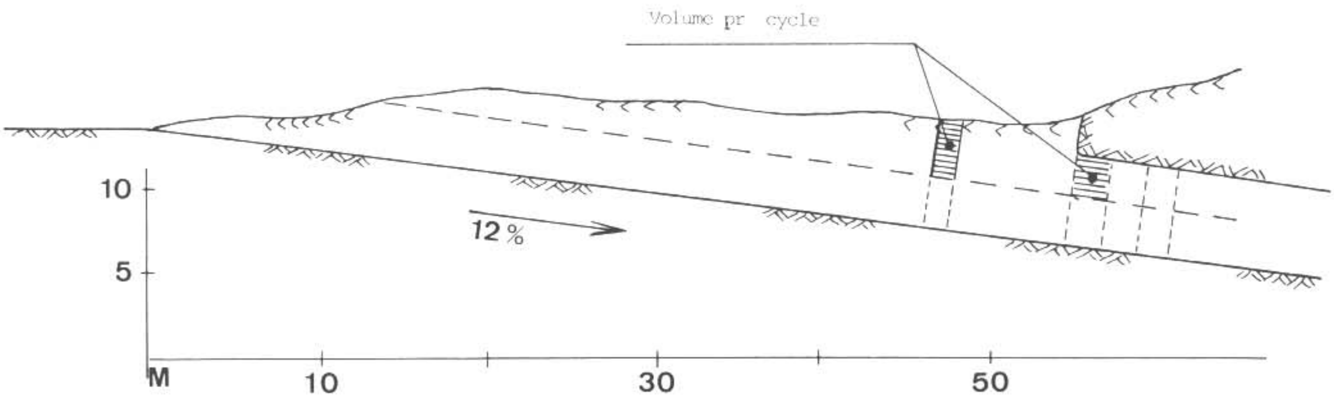

Figure 1. Mesna Power Plant. Cutting and outer part of access Tunnel.

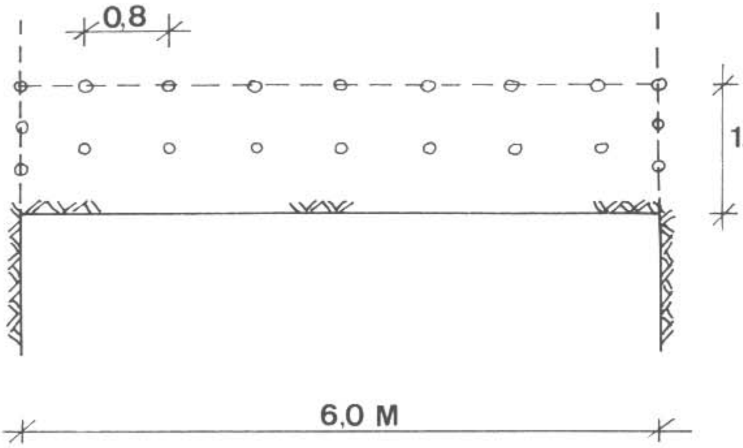

Figure 2. Mesna Power Plant. Horizontal section, typical drill pattern in cutting for access tunnel. Min. distance to wall of old power plant 3.0 m. Max. load per detonator interval 560 g, 2 intervals per borehole. Max. depth of borehole 3.0 m.

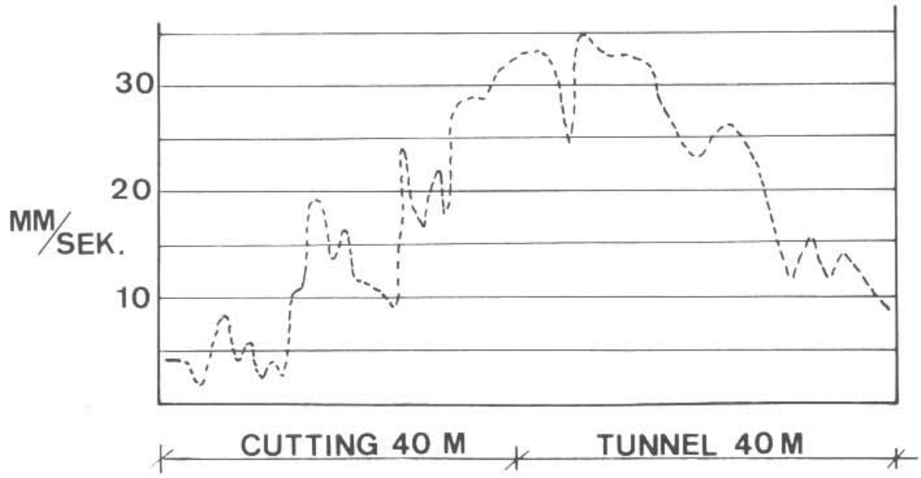

Figure 3. Vibration measurements of generator, old power plant.

elements on the detonator fuses (40 msec) a total of 60 intervals was possible. The number of boreholes was 72.

This arrangement reduced the amount of explosive per interval to approximately 2 kg.

Divided blasting was used for the first 15 m of the tunnel. Subsequently, whole blasts with borehole lengths of 2 m were used, where the number of boreholes drilled was 123 and the maximum amount of explosives was 8 kg. This pattern was employed for approximately 40 m. After this, when the distance to nearest building exceeded approximately 50 m, ordinary blast pattern and length of 4.2 m was used.

In the parking hall in Fredrikstad, the blasting of the cutting, with a bench height between 0 and 10 m, was carried out with a two-inch borehole diameter and 0.3–1.0 m between boreholes. The maximum amount of explosive per interval was 3.0 kg, and the entire blasting was carried out without exceeding the limits for tremor. Shielding against stone chippings was achieved using heavy rubber mats, and the work was done without any damage to the surroundings.

Blasting of the access tunnel was started with theoretically calculated

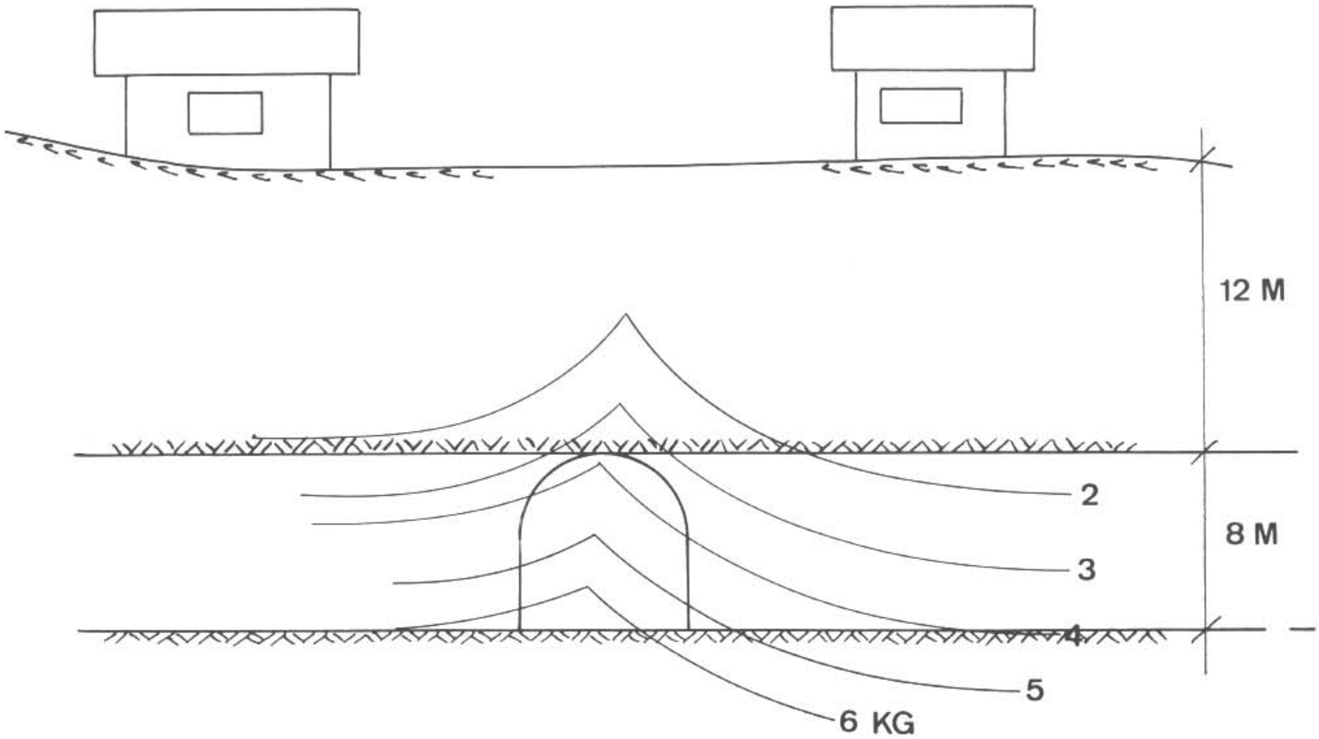

Figure 4. Parking hall, Fredrikstad. Vertical section, showing max. unit load in kg explosive per detonator interval.

amounts of explosive per detonator interval.

It was necessary to divide the cross-section into six, and use a borehole depth down to 1.2 m. The pilot tunnel, which was approximately 10 m^2, was blasted at least one borehole length in advance of the main tunnel. In spite of this, tremors in excess of the limit occurred several times, but no significant damage could be demonstrated to buildings.

There was however, some damage due to the air shock-wave from the initial blasting, which resulted in broken windows in nearby commercial buildings.

In blasting the parking-halls, the cross-section was also divided, with a pilot tunnel of approximately 25 m^2 on one side of the hall, and two to four additional blasts. The two outer most borehole rows at the contour were blasted last. The distance between boreholes at the contour was 50 cm, while otherwise it varied from 50 to 110 cm. The Nonel system with 50 detonator intervals was used.

Theoretically, it is possible to use more detonator intervals, but, due to inaccuracies in the firing time, there is a risk of overlapping, such that several intervals could detonate simultaneously, giving greater chances of unacceptably large vibrations. The charge size, borehole spacing and sequence of the detonators were adjusted continually, according to the tremor measurements obtained.

The total length of boreholes drilled, at 43 mm dia. in the tunnels and halls, was 80 000 m, which gives 2.0 m drilled per m^3 of rock. This is very high for such a large cross-section, but is necessary if tremors are to be limited.

Noise

Noise in the immediate surroundings of tunnel sites is usually due to the following sources:

(a) Ventilator fans.
(b) Transport.
(c) Loading and tipping of stone.
(d) Blasting.
(e) Compressors.
(f) Drilling.

Of these, vetilator fans and compressors give continuous noise, and are therefore the most irritating. Both of these sources, however, can be effectively damped by enclosing in insulated wooden structures. The other sources of noise are more difficult to control, but are usually a nuisance only for a shorter period, during the initial cutting and first few metres of a tunnel.

Drainage of Water from Drills and Ground Water

All water pumped out from a tunnel site is polluted with rock dust (mud) and machine oil, whether it has been used to prevent dust during drilling and loading, or it is ground water from the rock.

The authorities set increasingly strict requirements as to the purity of waste water, whether it is to be pumped directly into a river, or into the public waste system.

The lighter types of oil referred to can be removed by a relatively short period in an oil separator, but the sedimentation of the very fine-grained mud often takes a very long time. For reasons of space, it is unpractical to remove the finest mud, therefore the waste water will have a greyish colour. This rock dust has, however, no harmful effect. Oil-and mud-separator tanks must be of appropriate size, according to the amount of water being pumped out.

Stone Chipping from Blasting in Cuttings

Mats, measuring around 3 × 7 m, and made of old car tyres, were used as a covering. These were held in place over the blast by bolt-anchored steelwire-net and in addition, fishing nets with a mesh of about 20 × 20 mm, to trap smaller stones, were used.

So-called blasting-cloth (Trevira) was tried, but fishing net is, in our opinion, better, because of its elasticity, and it is also, at least in Norway, much cheaper.

This type of coverage is very effective and there was no significant damage from stones, on either site.

Contour Blasting and Stability Problems

Both sites consisted of types of rock with moderate cracking and few stability problems. To obtain a fine countour in the caverns, the two outermost rows of boreholes, at both sites, were drilled with a hole distance of 30–80 cm. To secure accurate drilling, with minimum deviation, measuring instruments were used on booms on the drilling rigs. This resulted in smooth contour and good stability in tunnels and caverns.

Summary

The completion of the two above-mentioned projects shows that one can carry out drilling and blasting in the immediate vicinity of houses, and sensitive technical installations such as operating water turbines, without causing significant damage, by means of precise but relatively simple changes from normal rock construction procedures.

These measures naturally bring about a certain cost increase, but in reasonably good rock, where cavern stabilizing expenses are not too great, one can obtain caverns which can compete economically with similar outdoor structures of, for example, steel or concrete.

One important point: Under conditions such as these described, it is self-evident that the burden on residents is great. We therefore consider it important that information, on the type and duration of the work, be available.

Before the projects were started, we produced leaflets describing the project, which were distributed to the affected households, together with various public departments and offices. In addition, the employers' agent has kept the press and the media informed of progress, and answered all communications.

We have had satisfactory results from this public relation campaign, and surprisingly few complaints have been received from members of the public.

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Topic

UNDERGROUND AND ENVIRONMENT / TUNNELLING METHODS

Title

The Influence of Environment Protection on Planning and Execution of Tunnelling Projects in German Cities

Author

W. Dietz

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Résumé: Les exigences modernes en matière de protection de l'environnement ont conduit à une mise en souterrain accrue des transports publics (métro, bus guidés). Les travaux publics ne pouvant être exécutés en Allemagne qu'avec l'accord du public, la plus grande considération est accordée à la protection de l'environnement, ce qui a conduit à une modification fondamentale des méthodes de construction. L'auteur décrit l'évolution de ces procédés et leurs améliorations successives permettant de minimiser l'impact en surface des travaux souterrains. Il mentionne également des mesures permettant de préserver l'environnement pendant l'exploitation des ouvrages.

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The Influence of Environment Protection on Planning and Execution of Tunnelling Projects in German Cities

Walter Dietz

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To improve its infrastructure and to keep up with ever changing requirements is a task for every major city. Dominating in this respect is the modernization of traffic systems for public transport but also the extension and replacement of water supply and sewage mains and road constructions.

In the course of the past 25 years each larger German city systematically developed these systems and gave public commuter transport a particular importance.

At a very early stage it became clear that modern requirements would only be met by transferring as much as possible of the new transport lines into the underground. Only in this way the scarce and valuable surface ground of inner-city areas could be saved for a more useful utilization. Existing buildings, parks and trees would not have to be touched and planners would have more freedom in laying out their network.

This decision in itself constitutes a very substantial contribution to the protection of the environment. Meanwhile 21 German cities have subway systems either under construction or already in use, where in the past almost exclusively street-bound tram and bus systems were used to deal with the increasing commuter traffic (Fig. 1).

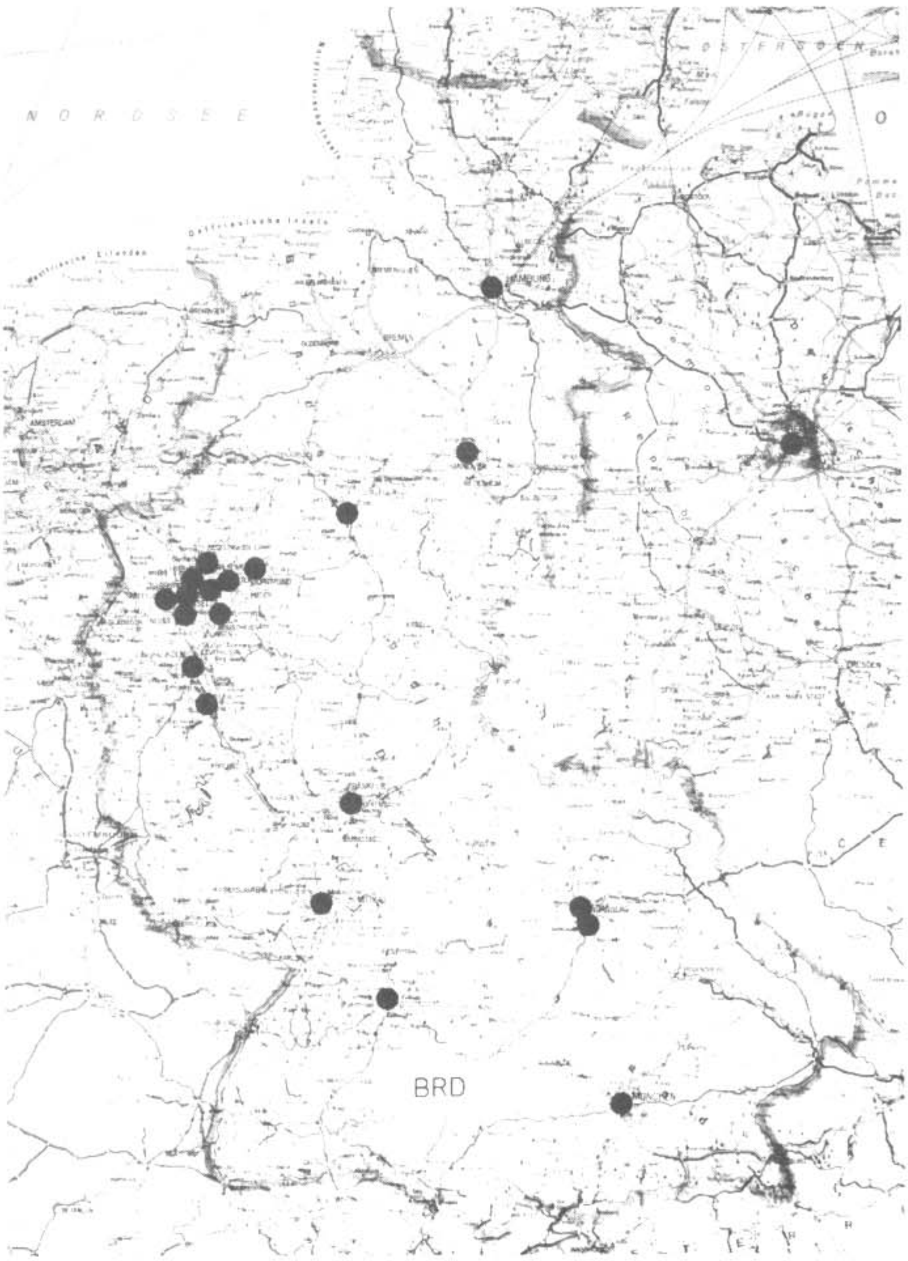

Fig. 1.

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Fig. 2.

Moreover, with the introduction of guided busses a development has started which enables buslines to be run on their own narrow tracks and thus also in tunnels. Especially for medium-sized cities which generally keep their bus systems for economic reasons, this recent development presents a chance to find solutions which satisfy environmental requirements (Fig. 2).

In Germany, public construction projects can only be executed with the consent of the directly affected neighbours. This can be a time consuming legal process. The easiest and quickest way to obtain this consent is to try to choose methods of construction and subsequent operation which give greatest possible consideration to the needs of environment protection.

In the course of time this was realized by clients and planners and led finally to a fundamental change of construction methods. Also the civil engineering contractors contributed by innovation and advance of cost-saving techniques. By consistent application and development of technological knowledge and improvement of specific details, the construction and operation methods have reached a standard which comes ever closer to reaching perfection in respect of environment protection. It is important to mention that this was not combined with economical sacrifices.

In the following, this development will be demonstrated. It should be kept in mind that tunnelling in German cities has to take place almost exclusively in the sedimentary soils of the quarternary and tertiary age and often in the presence of groundwater.

At the beginning of subway construction, underground structures used to be built in open construction trenches which were enclosed by rammed steel piles and strutting. Only where it was unavoidable, construction took place underground by application of the more expensive shield method (Fig. 3).

Cut-and-cover construction methods were always linked with long-lasting diversions for public and individual transport and also with extensive relocation of ducts and culverts.

For the time of construction, neighbours had limited access to their houses and shops and suffered from the construction noise.

The first modest steps towards improving this situation were the replacement of rammed piles by vibration reducing bored steel or concrete piles, and the partial or complete bridging of the construction trench in order to allow traffic to return as early as possible.

The logical continuation of this concept was the introduction of the so-called cover-and-cut method. Bored concrete piles and diaphragm walls are able to lead heavy vertical loads into the ground through point resistance and wall friction. In this way it is possible to construct the roof slab at an early stage and to reinstate normal surface conditions. All the remaining work up to the final completion of the construction itself can then be carried out under the protection of the roof slab and the construction trench enclosure (Fig. 4).

An increase in economy was achieved for this construction method by the incorporation of watertight diaphragm walls as permanent elements into the building.

Bored concrete pile walls and diaphragm walls have the additional advantage that because of their great rigidity horizontal deflections remain small and with them the settlements under adjacent foundations.

In groundwater-bearing strata it was tried to form water impermeable construction trench enclosures by either integrating the diaphragm walls in binding subsoil or by means

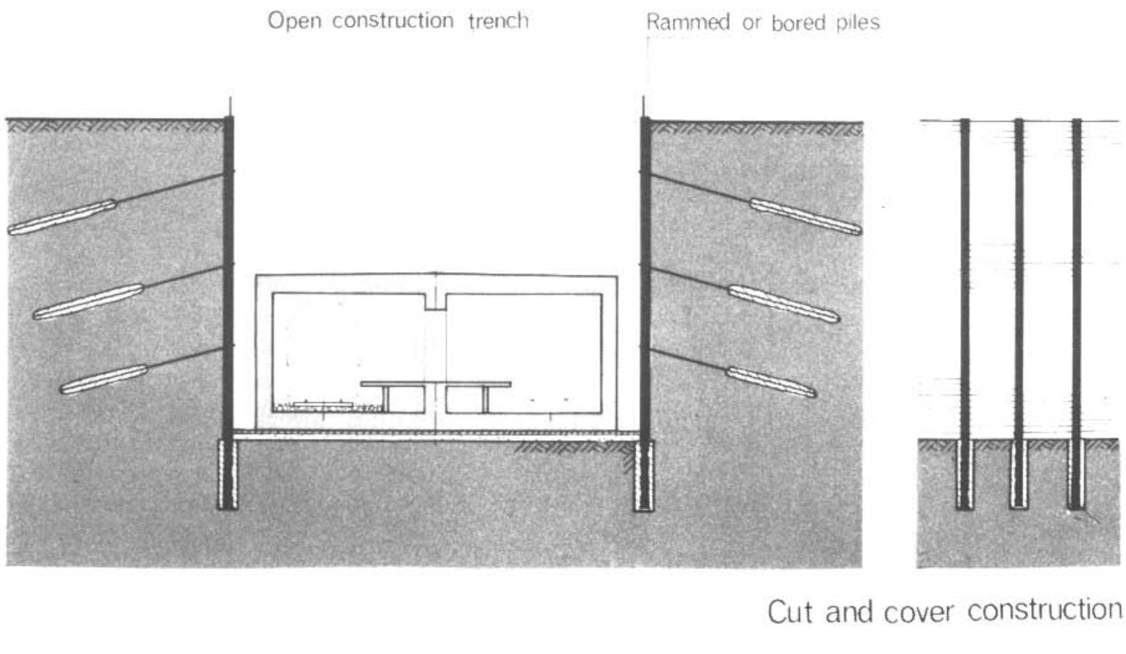


Fig. 3.

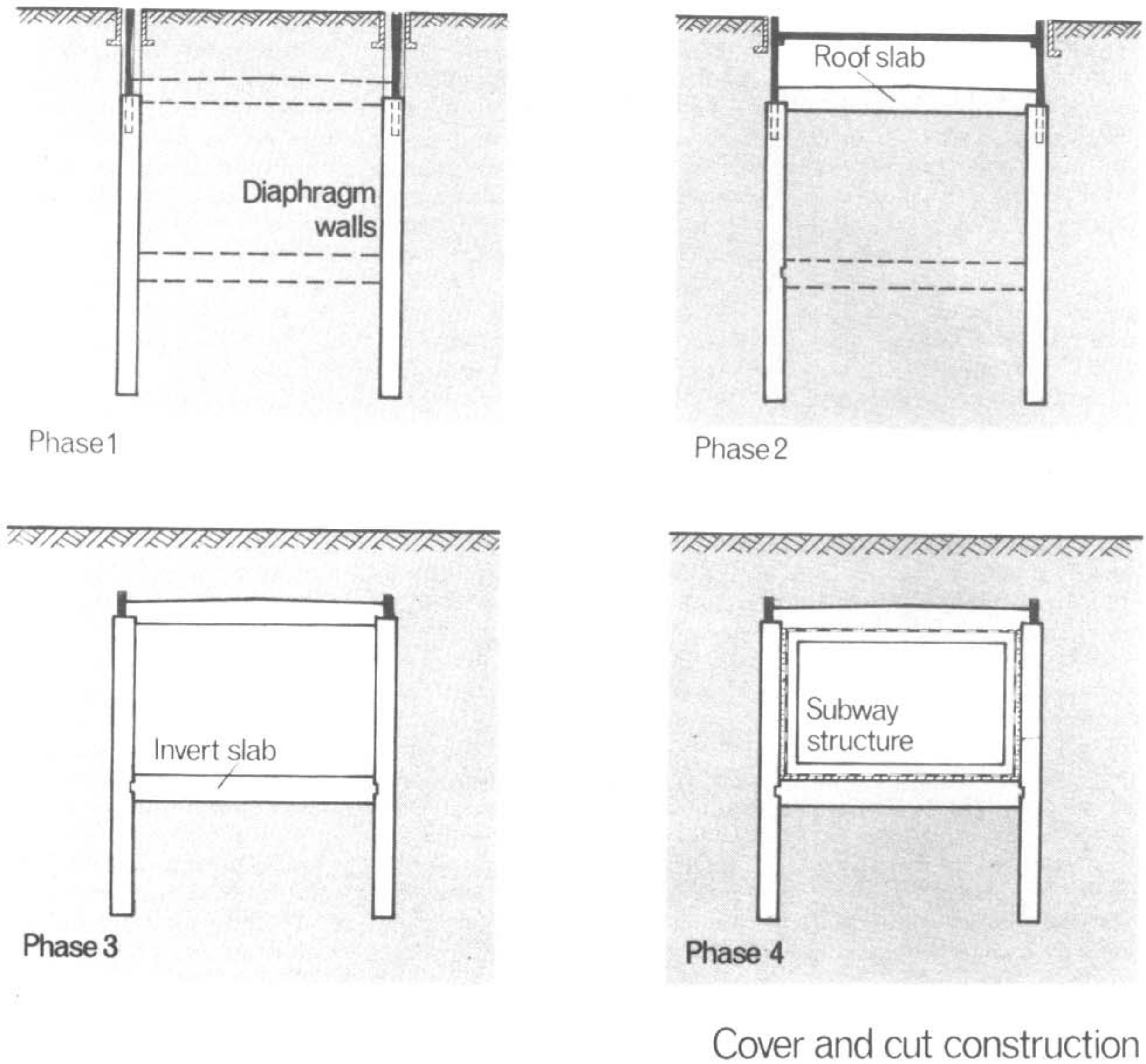


Fig. 4.

of an underwater concrete base. By this method interference with the groundwater system by large scale dewatering can be avoided — again a benificial effect in respect of environment protection. However, one has to keep in mind that these extended buildings can form a groundwater barrier which can create dead water areas.

These negative consequences, were overcome by the systematical installation of well and culvert systems which guarantee a nearly unrestricted waterflow around the underground structures (Fig. 5).

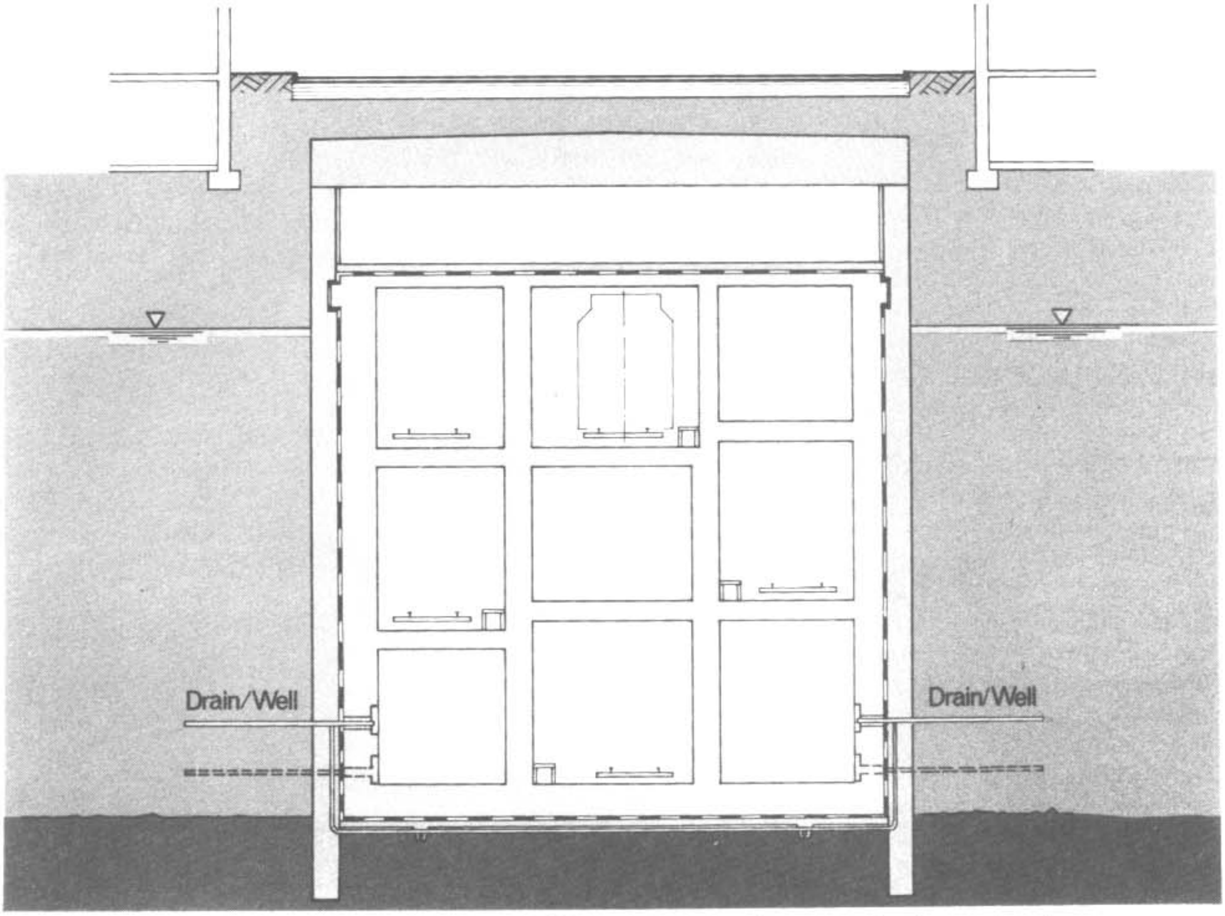
All these means eventually minimized the impact of the execution of tunnelling projects on their vicinity.

Nevertheless, the development went increasingly towards underground methods. It was decisive in this respect that after the first successes in inner-city tunnelling the New Austrian Tunnelling Method did not only prove itself to be reliable and safe but also to be flexible and economical.

It did not take long to overtake the once leading shield method and under suitable circumstances underground construction in Germany following the NATM came to similar costs or was only marginally dearer than cut-and-cover construction (Fig. 6).

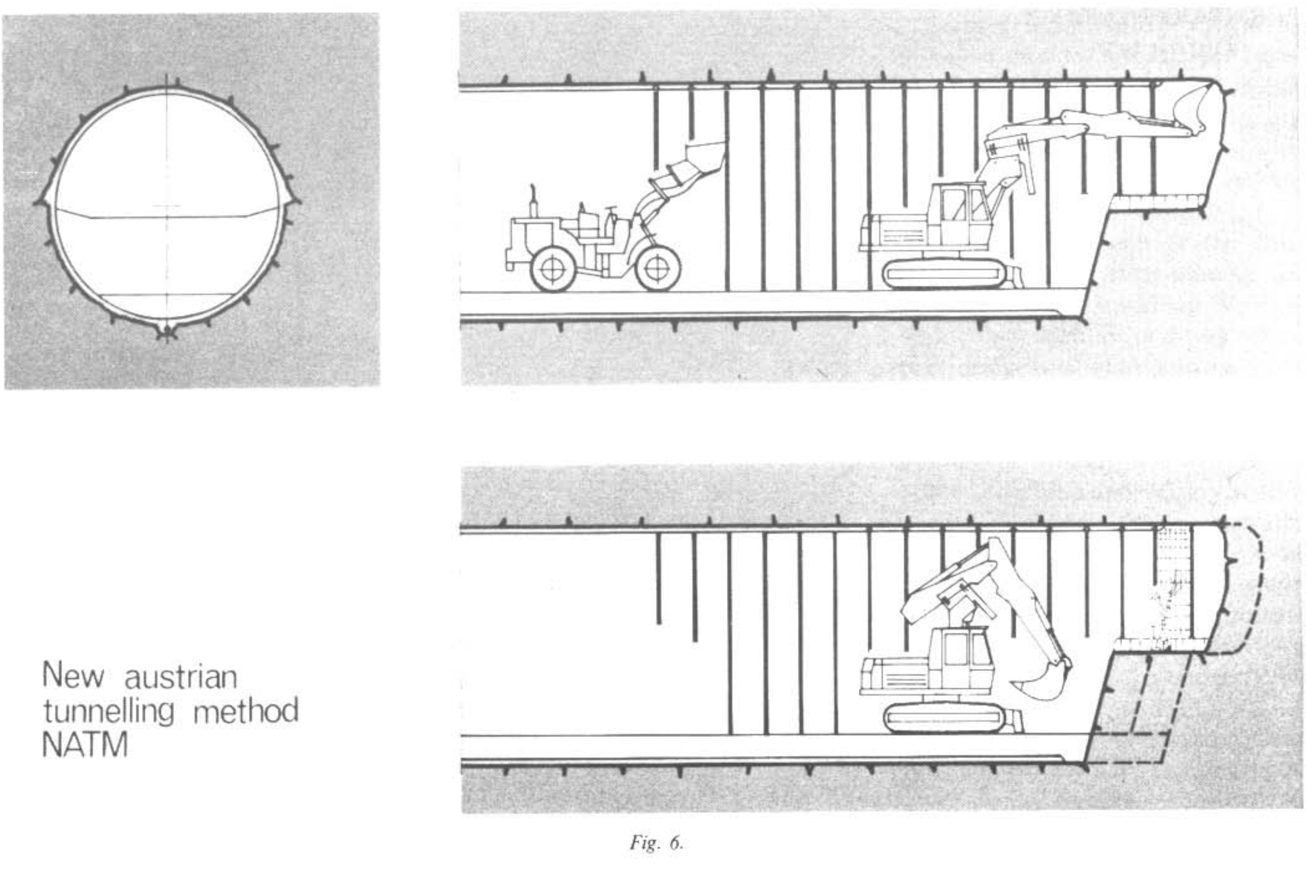
The example of the city of Munich demonstrates this development. It was triggered by the increasing sensitivity of the population against disturbances through extensive and long-lasting construction projects and made possible by the improvement of the technology and economy of underground construction methods.

At the beginning, around 1964, when work started on the subway system for the Olympic Games of 1972, approximately 70% of stations



Watertight trough groundwater culvert

Fig. 5.



New austrian
tunnelling method
NATM

Fig. 6.

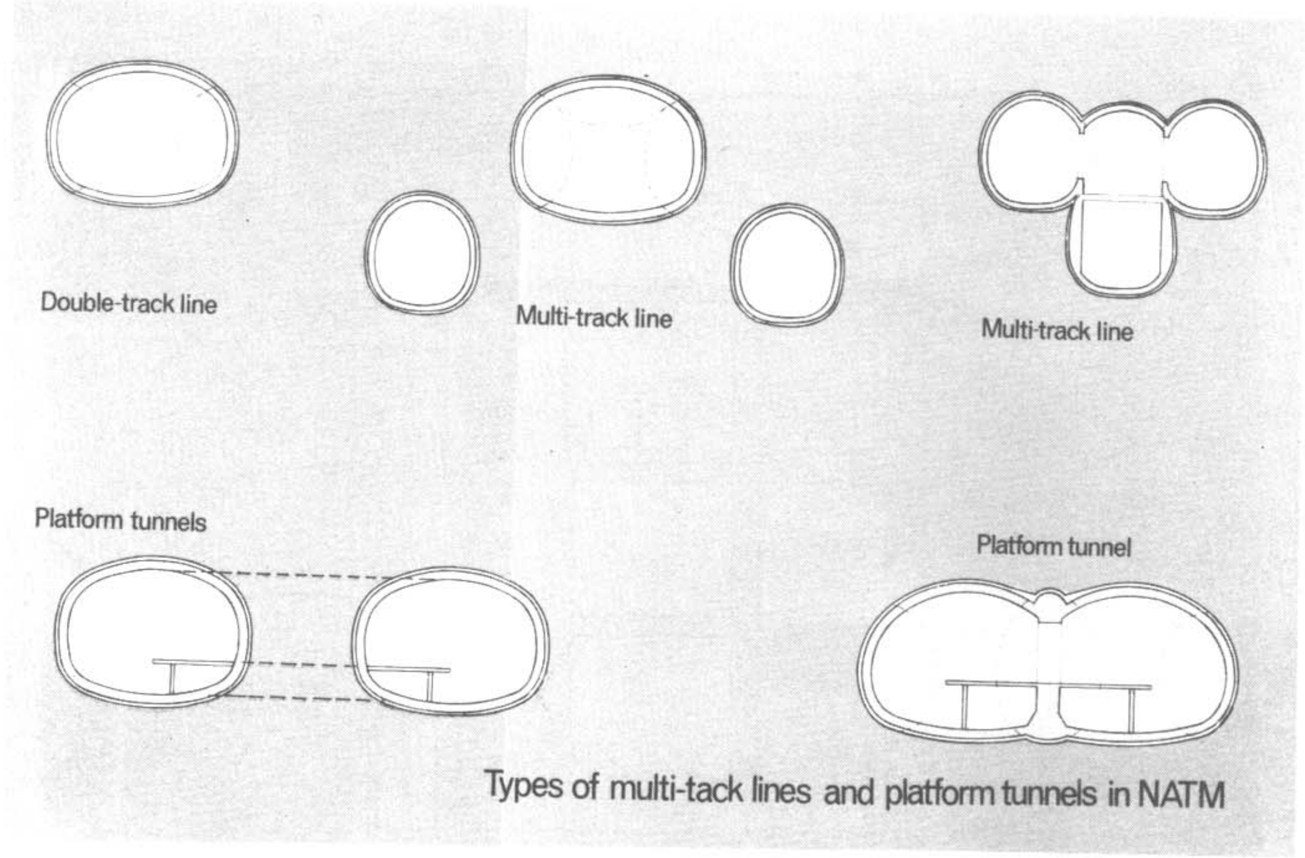

Double-track line
Multi-track line
Multi-track line
Platform tunnels
Platform tunnel
Types of multi-tack lines and platform tunnels in NATM

Fig. 7.

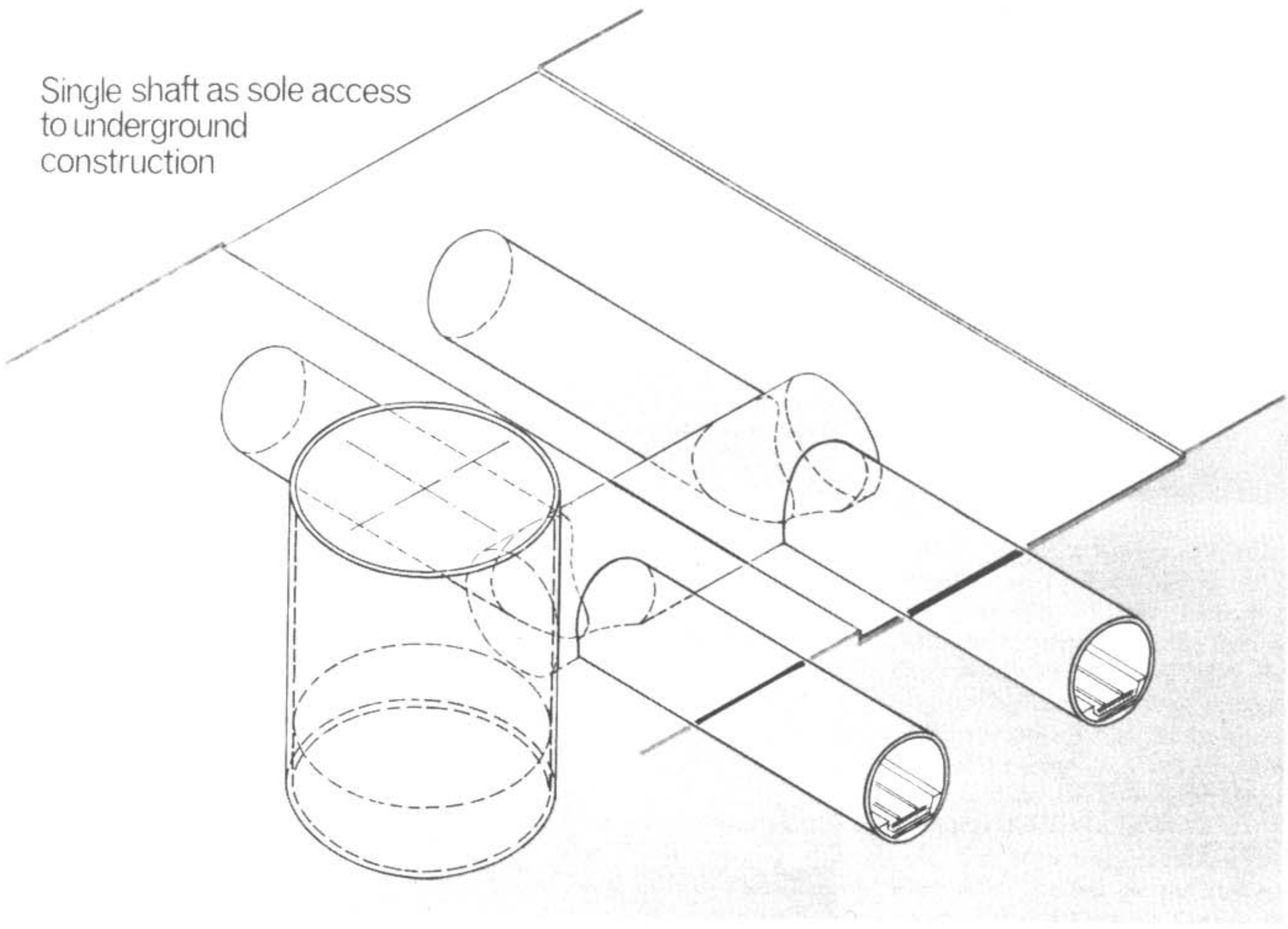

Single shaft as sole access
to underground
construction

Fig. 8.

and tunnels were built in open trenches.

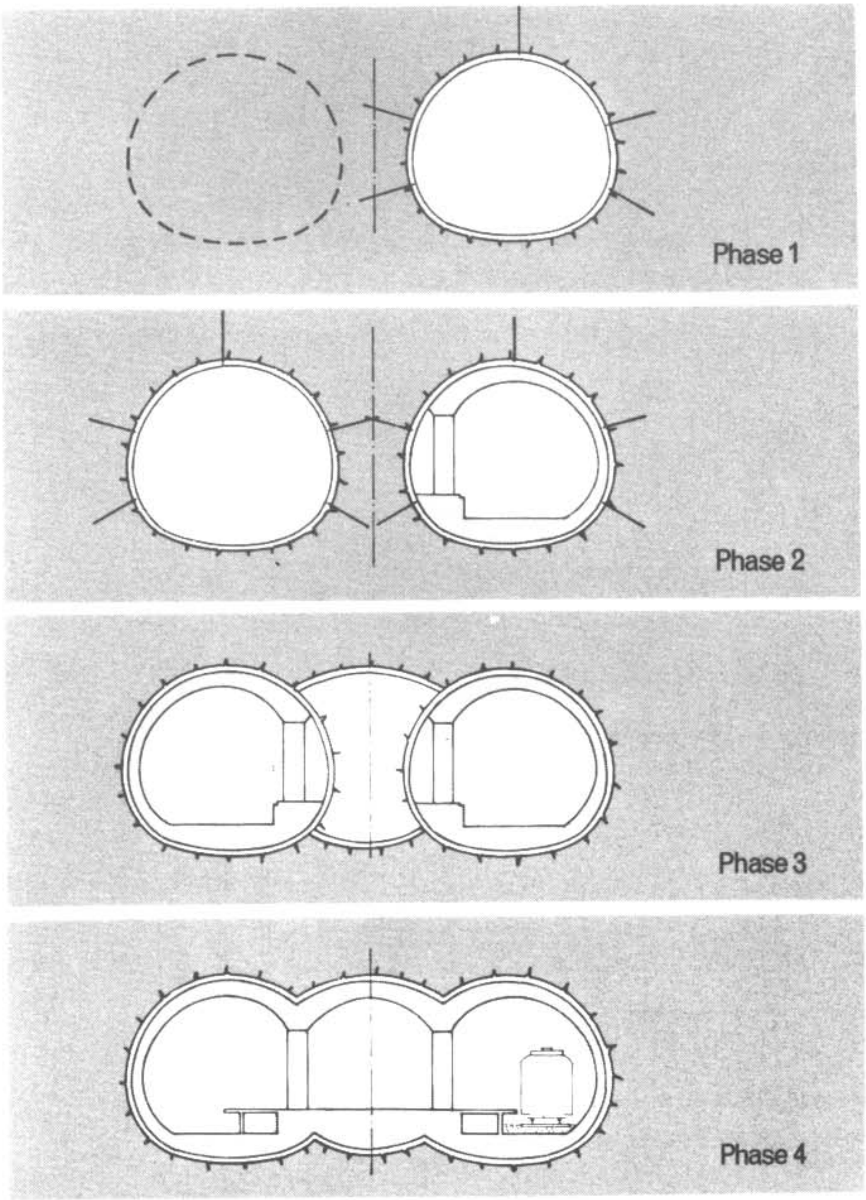
The subway projects which have been started during the last years, however, are clearly dominated by underground methods. Now 70% of stations and tunnels are built underground and only 30% remain for cut-and-cover. The situation has completely changed.

While at the beginning only single-line tunnels were driven and had greatest possible distance between each other, this distance has eventually been reduced to a minimum. Soon larger cross-sections were chosen for twin and treble track tunnels, finally also for many stations which were built either into one large cross-section or by connecting smaller ones (Fig. 7).

Only a few accesses from the surface remain, often just one single shaft, they are the only thing noticable above ground. They are also the only points where operational necessities as the vertical transport of muck and building material disturb neighbours and traffic flow.

In order to reach an ultimate protection of the vicinity, many clients, however, prohibit noise emission during night hours when — as it is common practice in tunnelling — two shifts are worked. Over and above that it is often required to install noise screens around the last remaining shafts (Fig. 8).

In constructing the tunnel itself one tries to choose a driving sequence which guarantees limited settlement on the surface. This can be achieved by early completion of the provisional lining over the full circumference of a cross-section and by stage driving of parallel headings or large tunnels which have to be excavated in sections. When large tunnels are constructed by combining smaller parallel tunnels, difficulties with stabilization can be overcome by an early installation of parts of the inner lining. In this way safety of work during driving and control of ground deformation can be optimized (Fig. 9).



Construction phases of multi-section tunnel

Fig. 9.

Very often tunnelling has to take place in waterbearing strata. One way to enable tunnelling under these conditions is groundwater lowering. This, however, causes large-area settlement and interference with the groundwater flow. In order to reduce these consequences and also the additional waterfreight which has to be managed by the sewer system, groundwater is often re-introduced into the natural system by constructing sucking wells in the neighbourhood.

Certain situations require additional efforts for ground improvement or stemming of water. This can either be achieved by injecting materials which are compatible with the groundwater or alternatively by ground-freezing.

The latest position is the construction of tunnels combining the New Austrian Tunnelling Method with compressed air in a way which previously was only known from shield drives. This universal construction method makes the inconvenient drilling of wells from alleys and streets unnecessary, it does not have to touch the groundwater and reduces ground-settlement even further. As the tunnels are generally built in shallow depths of groundwater, pressure can be kept at a level which does not endanger the personnel underground (Fig. 10).

In the meantime imporved systems of shield driving have regain ground in Germany by using bentonite to support the face, so-called bentonite

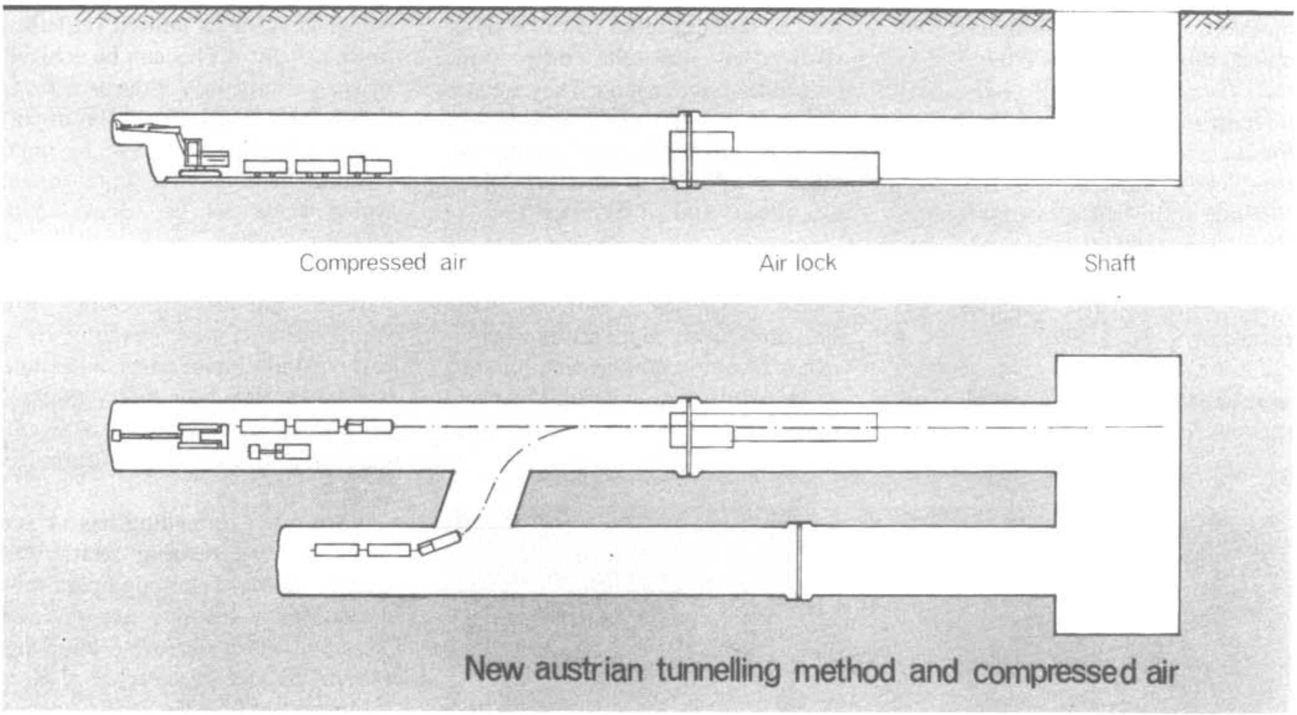


Fig. 10.

Bentonite Shield (Hydroschild)

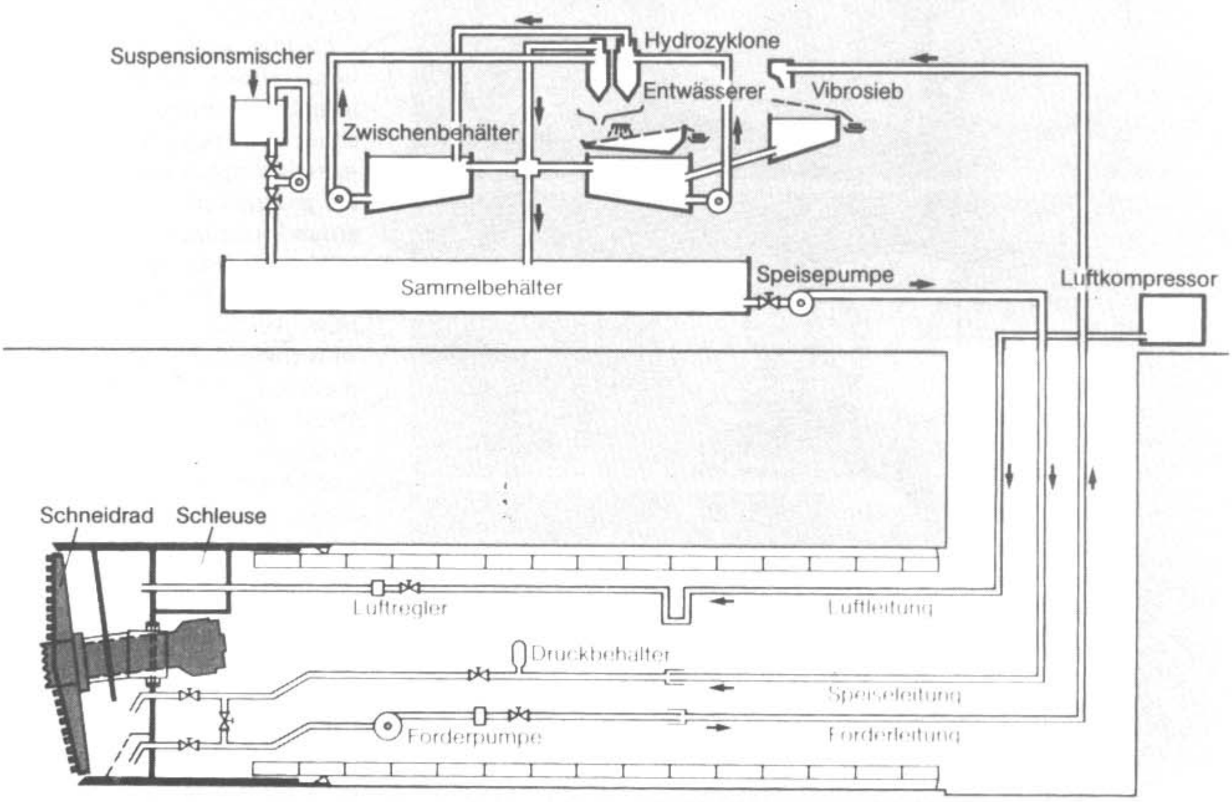


Fig. 11.

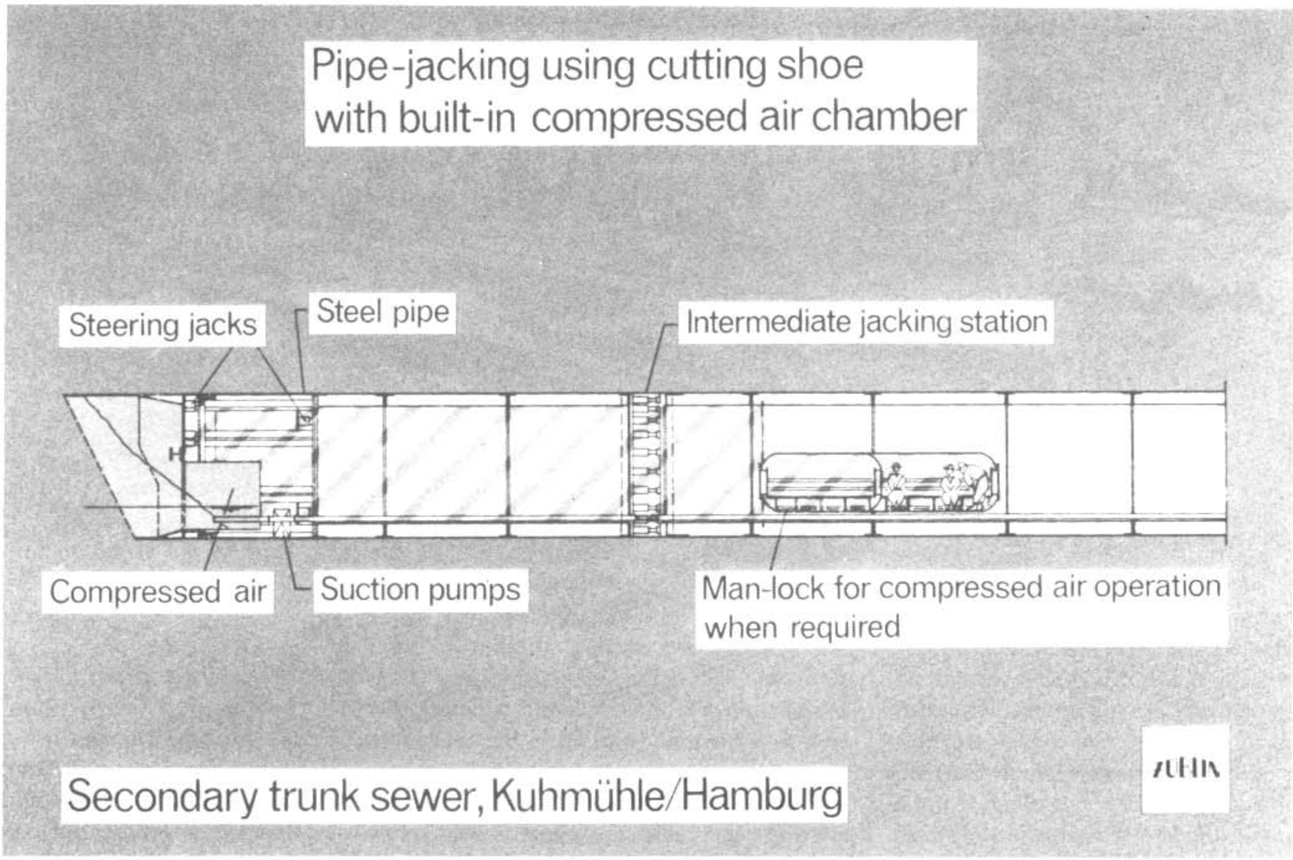


Fig. 12.

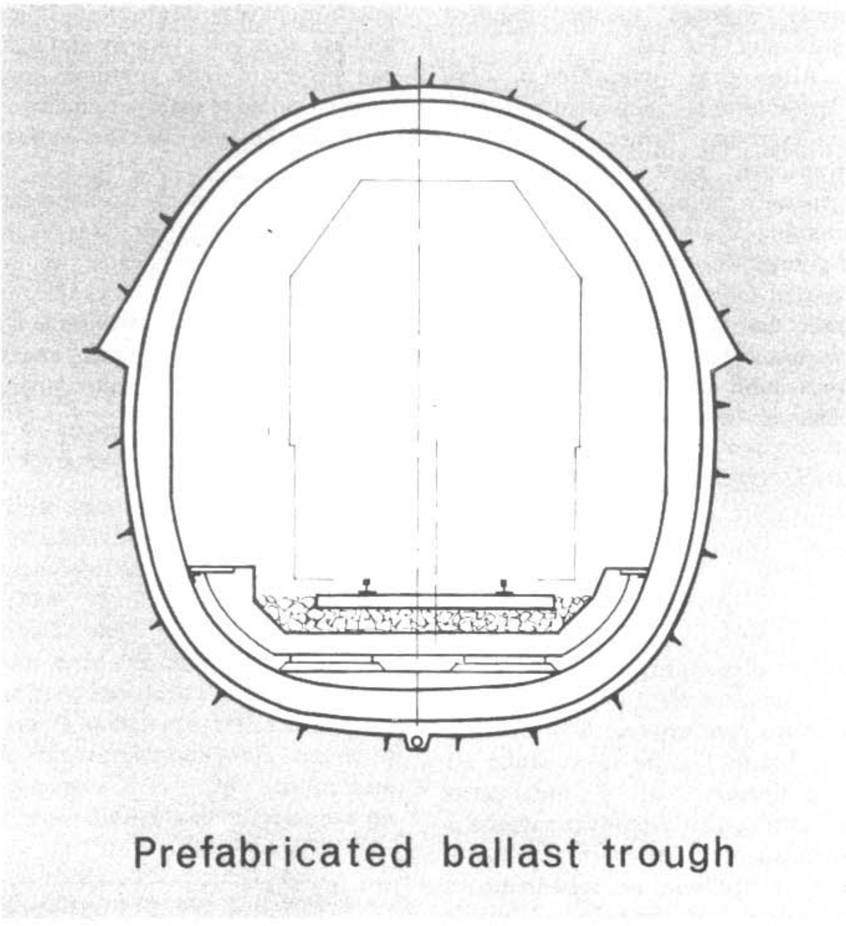


Fig. 13.

shields. This method is also characterized by very little ground deformation, protection of groundwater, working safety and economy in connection with the installation of single-shell lining with precast concrete elements or concrete pipes or extruded steel fibre concrete (Fig. 11).

Comparable in respect of environment protection is the use of a moving compressed-air chamber at the face of pipe jacking drives. In this case the crew can work under normal atmospherical conditions which is physiologically better, because the compressed air is limited to the face area (Fig. 12).

It is not surprising that development in tunnelling did not restrict itself to the protection of the vicinity of construction sites but also led to improvements of the working conditions for the people involved. They were achieved through imposing strict specifications in respect of ventilation, dust extraction and exhaust fume purification. Diesel-powered plant was often replaced by electromotors. Air tools had to give way to less noisy hydraulic equipment.

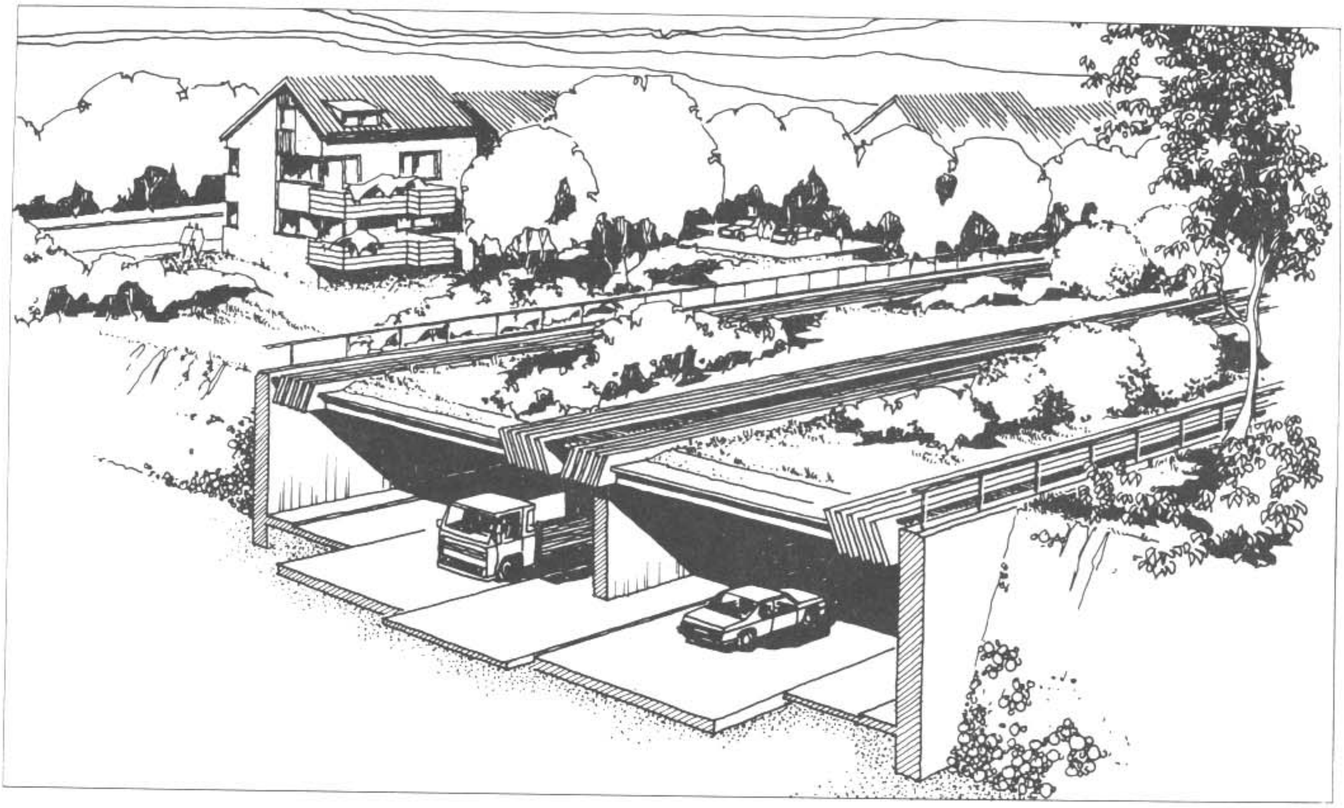


Fig. 14.

Up to now, we have restricted our report to the execution of construction projects and the problems involved. However, the environment has also to be protected after completion and under operation of the project. In various cases of the earlier projects unpleasant noise bridges existed between the tunnel and adjacent buildings despite laying the track on ballast. In the meantime, in all German cities, trasmission is, where necessary, reduced by the installation of mass-spring systems. They normally consist of heavy concrete troughs which take ballast and track and are elastically bedded on stripes of neoprene. They reduce noise emission to the required minimum (Fig. 13).

Although it would often be more desirable to lay individual transport underground rather than public transport, close limitations are generally imposed by the high running costs of ventilation and lighting. But also here tests were started in Germany with noise reduction tunnels. With these efforts were made to combine environment protection with low running costs. This can be achieved by constructing roofs with louvered apertures along the edges of the carriageway. The apertures have noise absorbing lining and are arranged in a way and light can penetrate. This solution, however, is limited to shallow tunnels and restricts the use of the surface (Fig. 14).

This report about the developments in tunnelling in Germany was meant to show to which degree we, as tunnelling engineers, are able to contribute through innovation to the protection of the environment and to the conservation of our natural living conditions.

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Topic

UNDERGROUND AND ENVIRONMENT / TUNNELLING METHODS

Title

Réalisation de parkings souterrains à Paris à l'aide de parois moulées exécutées à l'hydrofraise

Author

M. Legeais

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Open Session, Seminar, Workshop: **Open Session 1983, Warsaw: "Urban Contracting and Environment"**

Others: -

Abstract: A new boring machine has been developed to build moulded walls supports under extremely difficult conditions, avoiding any tremors and vibrations which may lead to important damages in existing surface structures. The author describes this machine - called Hydrofraise - its advantages and fields of use. He also provides examples of urban subsurface works utilizing the machine.

Résumé:

Remarks:

Réalisation de parkings souterrains à Paris à l'aide de parois moulées exécutées à l'hydrofraise

M. Legeais

Abstract — A new boring machine has been developed to build moulded walls supports under extremely difficult conditions, avoiding any tremors and vibrations which may lead to important damages in existing surface structures. The author describes this machine — called Hydrofraise — its advantages and fields of use. He also provides examples of urban subsurface works utilizing the machine.

Introduction

L'exécution de grandes fouilles dans Paris, avec traversée d'horizons durs, a amené l'Entreprise Soletanche à développer à partir de 1975 un nouvel outil de forage pour la réalisation des soutènements en paroi moulée dont le principal but est la traversée des terrains durs à la rotation (sans trépan) évitant ainsi tous les ébranlements, vibration pouvant causer des dommages importants aux ouvrages existants.

Description de l'Hydrofraise

Cette machine appelée "hydrofraise" se compose:

(1) d'un châssis dont les caractéristiques sont les suivantes: (Fig. 1)

- hauteur 15 m
- largeur 2,40 m
- poids 20 tonnes;

(2) de deux moteurs hydrauliques de 120 CV fixés au châssis. Ces moteurs supportent les tambours de diamètre 1,20 m. Sur ces tambours, sont montés les pics de forage. La geometrie des tambours et des pics est fonction de la nature du terrain (dureté, adhérence, etc). Les vitesses de rotation des tambours sont de 10 tours/min et 20 tours/min. L'épaisseur des tambours (largeur du forage) peut varier de 0,63 à 1,50 m;
(3) d'une pompe hydraulique immergée pouvant débiter 360 m^3/h de déblais et de boue, l'aspiration se faisant entre les moteurs. La pompe refoule les déblais et la boue dans un flexible 8″ vers une unité de déssablage assurant la séparation des déblais et de la boue.
(4) le châssis est équipé en tête d'un vérin permettant à la machine de travailler soit à vitesse constante soit à poids constant;
(5) enfin, le châssis est équipé d'un inclinomètre donnant au poste pilotage, l'inclinaison du châssis, à chaque instant, dans le sens longitudinal et transversal.

Cette machine est montée, soit sur une grue à chenilles, type PINGUELY GTL 165, ou un porteur type F 12 (porteur de machines de pieux battus).

Ces porteurs supportent la centrale hydraulique fournissant l'énergie aux moteurs. C'est un Power Pack Caterpillar de 365 CV.

Avantages et Emplois

La traversée en rotation des roches dures et la capacité de la machine de traverser tous les terrains (y compris les alluvions et argiles) en font un outil tout à fait exceptionnel. L'absence d'ébranlements, de chocs ou de vibrations fait naturellement recommander cet outillage en site urbain. Les exemples qui vont suivre en sont une excellente démonstration.

La réalisation des panneaux secondaires se fait par recoupement du béton déjà coulé des panneaux primaires sur quelques centimètres. Ceci permet d'éviter la mise en place des tubes joints et assure un excellent contact béton sur béton au niveau de ces joints. Associé à une excellente verticalité, cet outillage devient alors un exceptionnel outil pour l'exécution des parois circulaires à grande profondeur (réservoirs de gaz liquéfié au Japon et à Zeebrugge).

Le dessablage et la régénération en continu des boues ainsi que le contrôle permanent à la station de dessablage des caractéristiques de la boue (viscosité, densité, cake, filtrat) permettent d'avoir, en permanence, une très bonne boue de forage, qualité essentielle pour que la paroi moulée ait un bon aspect.

Enfin, la vitesse de perforation importante de 4 m^2/h à 20 m^2/h permet l'exécution des travaux dans des délais très courts, donc une diminution de la durée des nuisances en ville.

Exemples de Travaux Urbains

1. Le parking sous la Cour d'Honneur de l'Assemblée Nationale

Dans un site prestigieux, il s'agit de construire cinq sous-sols à usage de parking.

Le Palais Bourbon est situé sur la rive gauche de la Seine en face du Pont de la Concorde; la Cour d'Honneur est une cour intérieure

M. Legeais est Ingénieur Civil de l'Ecole des Ponts & Chaussées et Directeur de Soletanche Entreprise.

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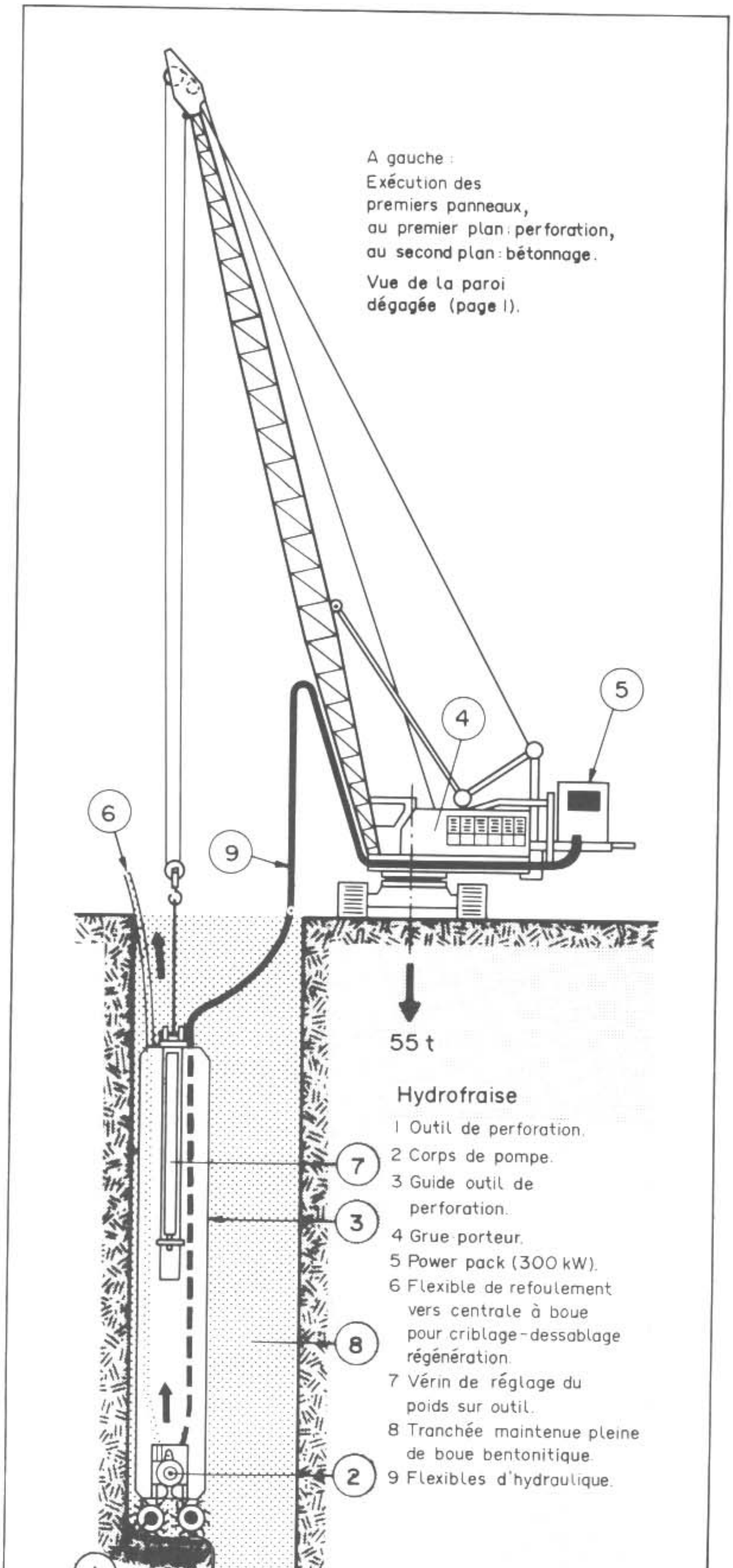

Figure 1. Schéma de l'hydrofraise

donnant sur la rue de l'Université et d'une surface d'environ 5000 m²

La solution retenue a été d'exécuter une paroi moulée périmétrale depuis le terrain naturel jusqu' à une profondeur de 48 m pour l'ancrer dans les argiles plastiques, après avoir traversé la succession des terrains suivants:

- 0–10 m: remblais — alluvions,
- 10–22 m: calcaire grossier (le calcaire grossier est un calcaire fracturé dont certains bancs sont extrêmement durs. Sa résistance varie de 50 à 500 bars,
- 22–46 m: sable du Soissonnais,
- en dessous de 46 m: argile plastique.

Le niveau de la nappe est estimé à 1 m de profondeur en période de crue (Fig. 2).

L'ancrage de la paroi moulée dans les argiles plastiques permet de réaliser une boîte suffisamment étanche pour envisager un pompage permanent, sous le radier de l'ouvrage, rendant ainsi stable la construction (la prise en compte de la totalité de la sous-pression en fond de fouille: 18 t/m² aurait conduit à des dimensionnements tout à fait prohibitifs).

Malgré la petite place et l'importante installation de chantier, le choix de deux hydrofraises pour réaliser les soutènements de cette fouille a permis:

(1) de ne causer aucun dommage aux existants pendant l'exécution de la paroi moulée malgré la traversée de 12 m de bancs durs de calcaire grossier,

(2) de réaliser à une profondeur importante en 0,63 m de largeur un soutènement étanche, le pompage définitif mis en place a été de l'ordre de 10 m³/h (ceci suppose une verticalité des panneaux très importante; déviations inférieures à 1%), la qualité des joints étant essentielle pour obtenir ce résultat.

(3) d'exécuter l'ouvrage dans un délai record puisqu'il a été exécuté pendant l' intercession des travaux de l'Assemblée Nationale entre Noël 1979 et la fin du mois de mars 1980, soit 13 semaines pour réaliser:

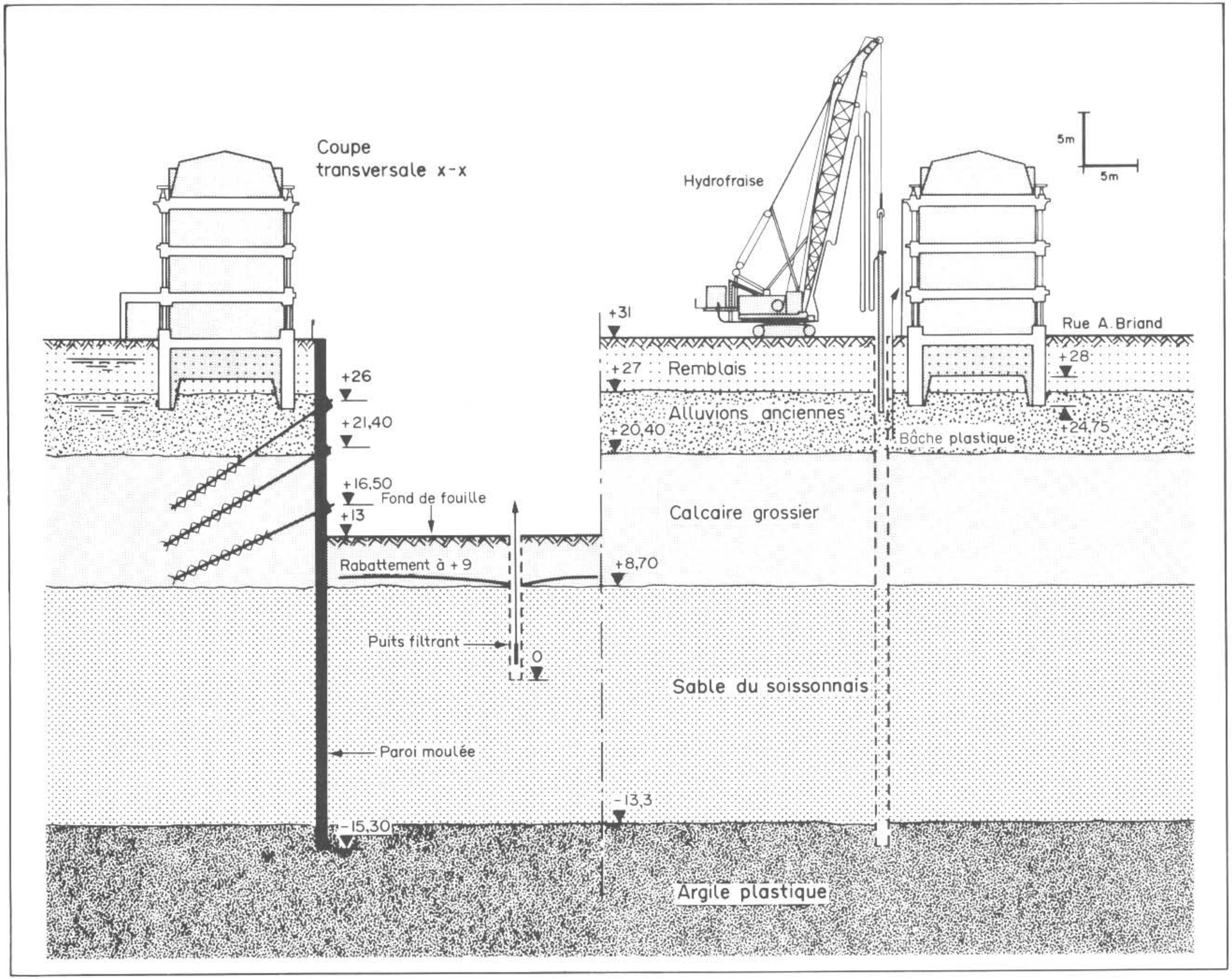

Figure 2. Coupe transversale.

Figure 3. Vue de la fouille dégagée.

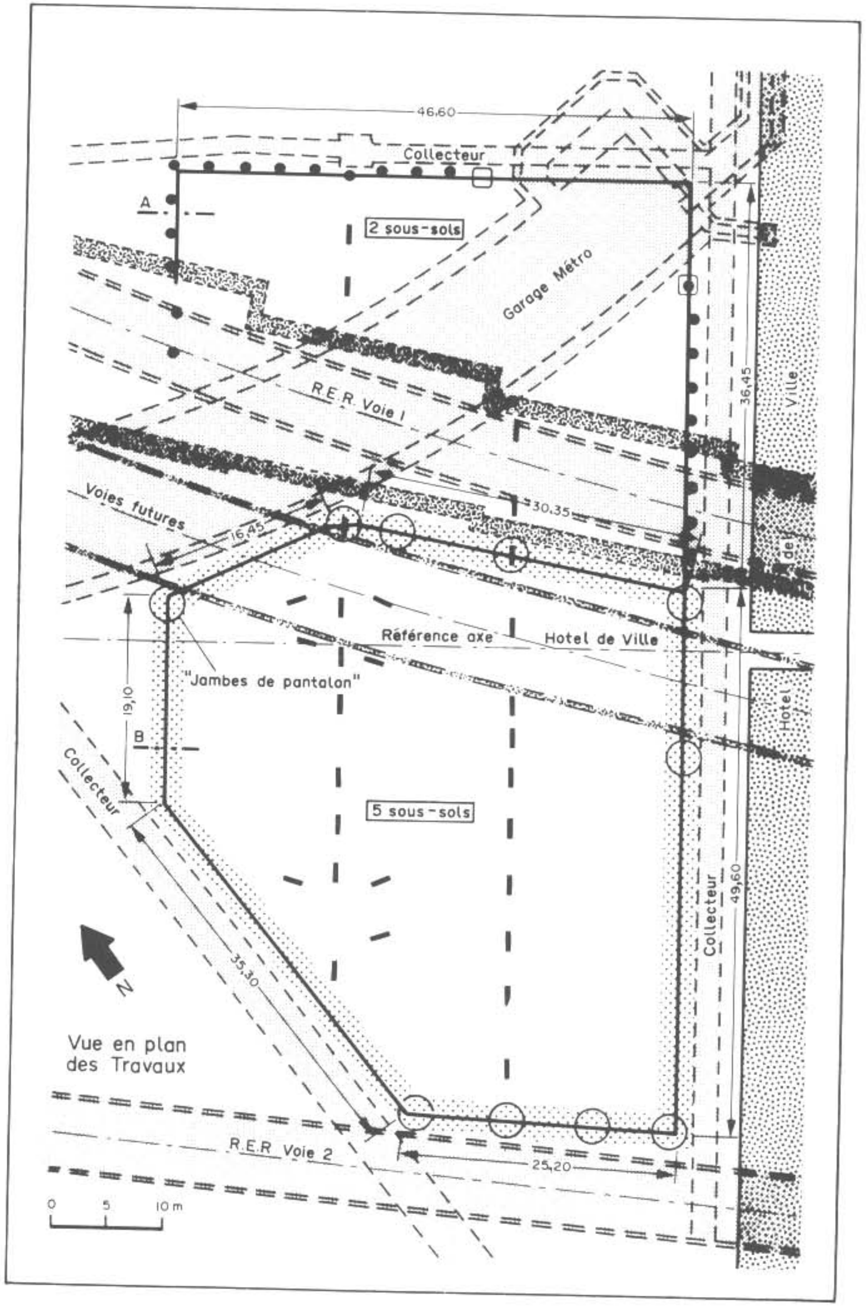

Figure 4. Vue en plan des travaux.

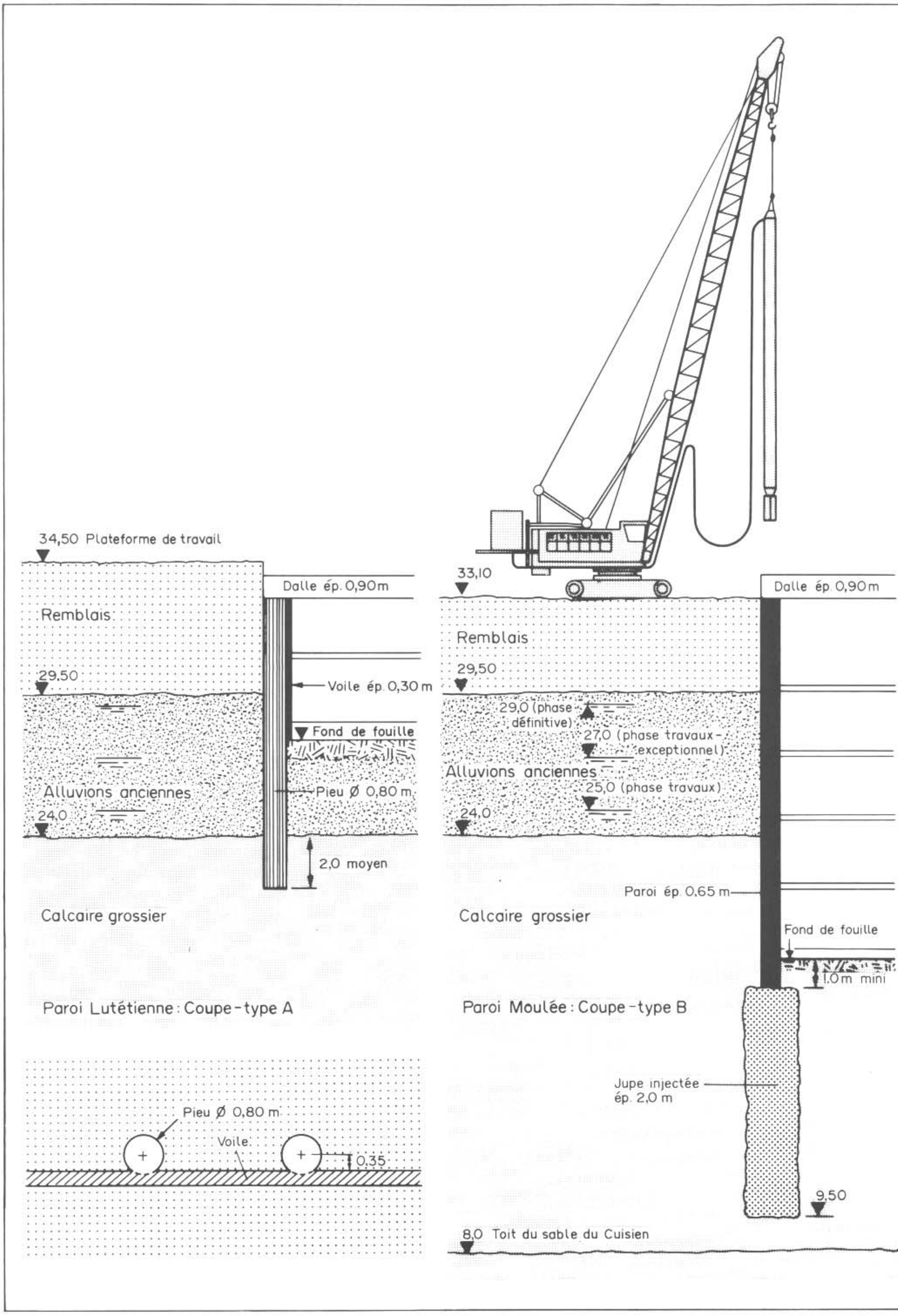

Figure 5. Paroi moulée — coupe type.

- l'importante installation de chantier,
- les travaux de murettes guides, y compris la découverte de quelques vieux murs de maçonnerie,
- la paroi moulée: 12 460 m^2 de 0,63 m d'épaisseur,
- le déménagement du chantier (Fig. 3).

2. Le parking Place de l'Hotel de Ville

Ce site se trouve en bordure de Seine sur la rive droite à quelques kilomètres de l'Assemblée Nationale.

Situé sous la place de l'Hôtel de Ville, ce parc de stationnement est implanté au milieu des ouvrages existants:

- 2 tubes du Réseau Express Régional,
- 1 voie du garage du Métro,
- 1 collecteur, des égoûts,
- tous les concessionnaires habituels: eau, gaz, électricité ... (Fig. 4).

Compte tenu de ce contexte, ce parking comprend une zone à 2 niveaux et une à 5 niveaux.

La coupe des terrains est la suivante:

- 0–10 m: remblais alluvionnaires,
- en dessous ... : calcaire grossier.

La nappe est, en temps de crue, à 4 m de profondeur.

Le fond de fouille se trouve:

- dans la partie 2 sous-sols à 6,50 m de profondeur,
- dans la partie 5 sous-sols à 15 m de profondeur.

Le terrassement a pu ensuite être réalisé à ciel ouvert, la stabilité des parois moulées étant assurée par des tirants d'ancrage (Fig. 5).

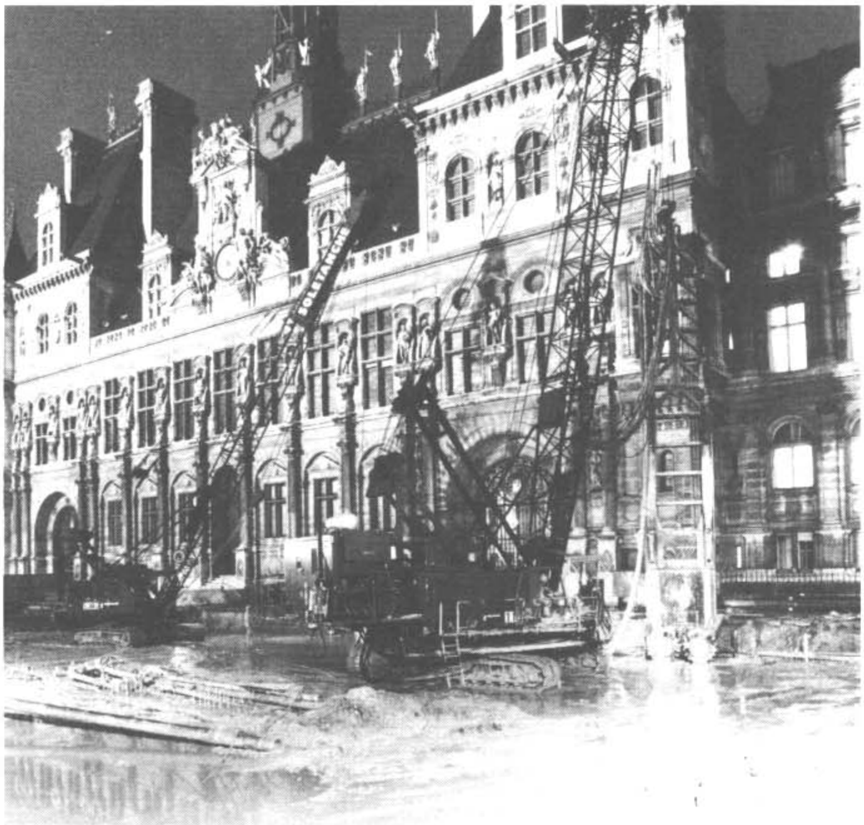

Figure 6. Vue des travaux.

Les soutènements de la partie à 2 sous-sols (pratiquement hors d'eau pour la nappe à l'étiage) ont été réalisés par une berlinoise.

Pour la partie 5 sous-sols où tous les soutènements longent des ouvrages souterrains existants, la solution retenue a été une paroi moulée à l'hydrofraise. Cette paroi ancrée de 1 m sous le fond de fouille est prolongée par une jupe injectée jusqu' à la base du calcaire grossier permettant d'abaisser le débit résiduel de pompage en fond de fouille à 30 m^3/h.

L'exécution des travaux n'a provoqué aucun dommage aux souterrains existants malgré l'inquiétude que pouvait entrainer la proximité immédiate de ces ouvrages par rapport à la paroi moulée (Fig. 6).

Conclusion

L'hydrofraise permet donc de réaliser des ouvrages de soutènements en paroi moulée dans des conditions extrêmement difficiles, en particulier là où le trépannage des couches dures aurait inévitablement causé des dommages aux ouvragres existants:

- immeubles,
- galeries de métro,
- collecteurs ...

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Topic

UNDERGROUND AND ENVIRONMENT / TUNNELLING METHODS

Title

Tunnelling Action in New York City

Author

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Abstract:

Résumé: L'auteur décrit, à l'aide de l'exemple du tunnel No. 3 d'alimentation en eau de la ville de New York (diamètre 7,3 à 6,1 m et longueur 22 km), les multiples problèmes qui se posent lors de la construction d'un ouvrage souterrain important dans une grande ville. Ces problèmes sont tout à la fois d'ordre technique, culturel, politique, juridique, et constituent autant de risques de retard pour le bon achèvement des travaux. Il insiste sur la nécessité de conditions contractuelles suffisamment souples pour être adaptées à l'évolution des circonstances.

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Tunnelling Action in New York City

J. K. Lemley

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Major projects generate major problems and opportunities; major projects in densely populated urban areas generate an additional layer of complexity — that produced by the urban environment itself. Most large metropolitan areas today are crowded, congested, 24-hr-per-day affairs in which political, geographical, ethnic, religious and other boundaries can be crossed merely by walking across a street. The contractor operating in an urban environment must plan carefully for these and other factors, and this is particularly true for large projects such as linear transportation systems and tunnels that cut through numerous jurisdictions. New York City intensifies these problems because it is perhaps the most diverse and technologically complex of the world's large cities. By examining the impact of the New York City environment on a major construction project — New York City Water Tunnel Number Three — a general appreciation can be gained of the difficulties, as well as of specific problems and their solutions, of operating in a complex modern urban environment.

As the accompanying map shows, City Water Tunnel Number Three, Stage 1, begins at the Hill View Reservoir in the adjacent city of

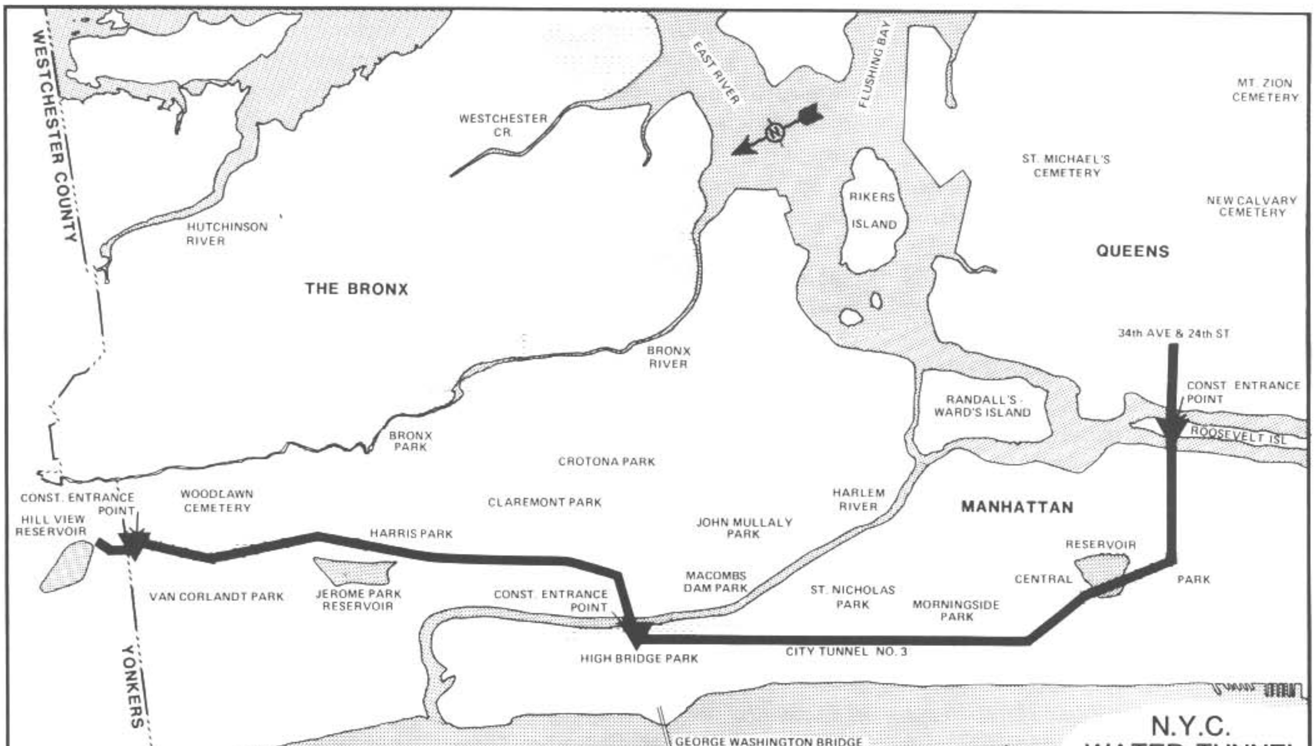

Fig. 1.

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Yonkers and cuts through three of the city's five boroughs, ending in Queens. When completed it will be a new water supply facility of 24–20-ft (7.3–6.1-m) dia. pipe extending approximately 13.7 miles (22 km). principally through the Bronx and Manhattan. (City Tunnel Number Two was completed in 1936, is approximately 20 miles (32 km) in length, and supplies approximately 800 mgd of water through 17-ft (5-m) dia. pipe.) It is designed to supply adequate water for population increases into the next century as well as to allow the present level of water supply to continue while maintenance is performed on existing tunnels. The new tunnel is located at depths of between 400 and 800 ft (122 and 244 m). Included in the tunnel are three major valve chambers with manifolds, laterals and a great deal of underground mechanical work. Three major construction entrance points (see Fig. 1) allow access. In addition, 17 riser shafts extend from the tunnel grade to the surface. Each of these riser shafts includes valve chambers near the surface.

The New York City Board of Water Supply submitted its *Report of the Board of Water Supply* describing the proposed City Water Tunnel Number Three Project to the Board of Estimate in July 1966. The proposal, in its final form, described the largest non-defense construction contract to be awarded to that date on the American continent, a bid package which came in at over $222 million. The contract was bid December 18, 1969, and the NTP was given on February 6, 1970. After default of the original joint venture, Water Tunnel Contractors, in December 1974 — due principally to the inflexible nature of the contract in allowing accommodation of the work to changing conditions — the work was re-bid under essentially the original contract. Water Tunnel Number Three, originally scheduled for completion in 1975, is now not expected to be completed until about 1990.

New York City is acknowledged to be one of the most difficult urban construction climates in the United States, if not the world. It enlarges and intensifies the usual problems of urban construction. In 1970, when construction of Water Tunnel Number Three began, nearly 8 million people were crowded into the city's 320 square miles (830 km^2), making it one of the densest housed populations in the world. This figure does not include over three million transients who commute from the suburbs each day to work and shop.

This concentration of people is possible because the city's stable rock foundation allowed almost unlimited vertical construction. This occurred during a period when new engineering achievements — the elevator, structural steel, sophisticated electrical and mechanical systems, etc. — made high-rise buildings possible and when the city was affluent enough to afford them. Parallel to the increase in commercial and residential density came the need for the infrastructure — the transportation, water, sewer, power, communication and other systems — to support them. As Lewis Mumford observed in an article in the *New Yorker* magazine entitled, "Is New York Expendable?": "The frantic effort to crowd the central district of Manhattan with enough tall office buildings to make traffic a permanent tangle is rapidly approaching complete success. Already, after ten in the morning, a reasonably healthy pedestrian can get across town faster than the most skillful taxi-driver. Underground, the situation is similarly congested. It is said that a cross-section through a typical city street in Manhattan Island contains a greater complexity, diversity and quantity of systems — the city's nerves and arteries — than any other urban area in the world.

This mechanical complexity, which contractors are used to dealing with, is equaled if not surpassed by the city's cultural, geographical and political complexity. New York's five boroughs occupy portions of three large as well as a number of smaller islands. As the accompanying map shows, Water Tunnel Number Three passes under three of these boroughs — Queens, Manhattan and the Bronx. Added to these large political units, the tunnel passes under numerous other jurisdictions, such as a number of city parks, each requiring permits, consultation and other coordination activities.

Other, often more difficult, complexities — the kind contractors traditionally shun — occur in crossing people-related boundaries such as those of ethnic, racial and religious groups, of labor unions, and those caused by the alternation between areas of affluence and relative poverty. Contrary to popular belief — although it was the gateway through which immigrants, of more extremely divergent ethnic, racial and religious backgrounds than any other of the world's principal cities, entered the United States — New York City was and is not a great "melting pot" in which people are merged to become simply "Americans" or "New Yorkers". As Glazer and Moynihan observed in their study, *Beyond the Melting Pot*, the ethnic and other group identities immigrants brought with them to the city were apparently intensified and solidified rather than dissipated. In their words, "We should not confuse the heterogeneity of most of the great cities of the world with that of New York." For the contractor building a major project which cuts through a number of these boundaries, the interface problems — those affecting hours of work, union rules, environmental issues and other people-related realities — are multiplied as for no other great city in the world.

City Water Tunnel Number Three construction cut through all of this complexity, and each area that it cut through evoked a different response. It passed under slums and very expensive neighborhoods, under parks and public lands, under Black, Jewish, Puerto Rican, Italian, Irish and other racial, ethnic and religious enclaves, and under other geographic and political domains, each presenting a unique challenge in response to the work being accomplished. Although there was one government jurisdiction, that of the City of New York, the response of each area and neighborhood, although channeled through government agencies, came in a much different form, each demanding different treatment in order to allow the work to go forward. Certain areas of the city demanded a good deal more attention than others, commanding calls from mayors, U.S. Senators, and other high government officials, while other neighborhoods received attention from local policemen or ward politicians. Although each answered to the city government, no two had the same interest. For example, although the city's need for water was well established and well known, there was little regard on the part of the Parks Department concerning access to work sites or of the Traffic Department concerning transportation of material in and out of the work complex. It took thousands of man-hours to coordinate and work with the various city agencies in order to bring together and focus their various interests on the project so that work could progress in an orderly manner.

An examination of specific problems encountered and of the responses to these problems will illustrate the nature of the impact of the urban environment on Water Tunnel Number Three. Although these problems can be roughly classified as people-related, construction-related or management-related, they all overlap in their impact on the progress of the work.

Community response as work progressed through various neighborhoods created problems not encountered in the usual urban, suburban or rural worksites. For example, multiple shift operations became a major concern, something unexpected in what was generally believed to be a city that operated "around the clock". Although the required permits for multiple shift operations were secured by the contractor, the actual ability to work those shifts was controlled by the population living in the various areas involved. On numerous occasions the contractor's representative, with permit in hand, was forced to stand by while demonstrations by neighborhood groups, with the tacit support of local police, stopped shift work because it was felt that the peace and tranquility of the area were being disrupted. Certainly these groups often were correct; in many instances there was substantial disruption. However, this fact did not mitigate the unexpected negative impact on the work caused by these demonstrations, particularly after the contractor had obtained the proper documents required for the work to continue. As a result, multiple shift operations were generally discontinued at all work sites, except for construction entrance points and the tunnel itself.

A related community response which affected the project was the impact on the local community with regard to access, particularly as it affected small businesses. Such disruptions were usually confined to work sites where riser shafts intersected the surface. Although a good deal of consideration was given to minimizing the impact of these operations through the careful planning of work site layouts, there were many instances where physical access to neighborhood businesses was blocked or where disruptions to power, water, communications and other services occurred.

In both of these situations — problems related to multiple-shift operations and to access to local businesses — several actions were taken to mitigate disruptions to the progress of the work. A coordinated communications program to anticipate problems in affected neighborhoods helped to reduce tensions by planning around specific situations. The contractor, on his own initiative, assigned public relations personnel to interface with neighborhood groups and business owners to explain construction requirements and resolve issues. The establishment of a physical plant designed to minimize the noise, air pollution and other discomforts associated with work operations also reduced friction between the work environment and the neighborhood. Although these and other planning techniques were often employed in the construction of Water Tunnel Number Three, they were not always successful and the work was often frustrated as a result of community response to these work-related activities.

Another people-related area that affected the progress of the work was the use of union labor. At the period of peak employment, about 2000 miners, operators, electricians and mechanical tradespeople were employed. Union activities in New York are particularly difficult because of long-standing agreements between the various unions themselves and other local entities. Under these circumstances, union work rules and regulations had a substantial negative impact on the project, leading to conflicts between various trades, hiring of redundant personnel, work stoppages due to changes in jurisdiction, and other similar situations. Not all of these situations could be anticipated, and, as a result, union problems added to the cost of the work and negatively affected work schedules, although the quality of the work produced was quite good.

Related to, and overlapping with, these people-related problems were more purely construction-related problems, some expected and planned for and others unexpected, that were a product of the urban environment. For example, primary work sites required special design consideration to minimize the dust and noise related to material handling and the tunnel ventilating systems. To minimize the sound produced by material transfer, such items as muck hoppers were insulated and enclosed. Small equipment such as jack hammers and compressors was also muffled, and times of hauling were strictly controlled. Many such environmentally sensitive problems could be anticipated and planned for, but others had to be taken care of as they occurred, often affecting the schedule and requiring redesign. Perhaps experience in working in the local environment coupled with a contract flexible enough to accommodate such changes is the only method of handling these unanticipated problems.

In a congested urban environment, the use of explosives generates an entire set of unique problems. In developing and mining the tunnel, shafts and chambers, drill and blast operations were employed. In New York City, the transportation of explosives within the city, as well as storage and handling, is very tightly controlled. The City of New York has tasked the Fire Department with responsibility for controlling and monitoring all blasting operations and the general use of explosives within the city limits. This is accomplished under unique regulations that are stricter than those of other urban areas. For example, explosives and primers must be delivered in separate trucks, and the trucks themselves must be bulletproof and operated by a two-man crew. Department rules require that each individual stick of dynamite be numbered, and the use of prills or other bulk explosives is not permitted.

On delivery, each box is opened and each stick is counted. To ensure a secure operation as well as to provide an accurate audit of explosives used and on hand, a special team was established, answering to the project manager, to inventory and monitor the consumption of all explosives at each of the tunnel entrance points as well as at each individual work site. This minimized theft, and there were no unplanned explosions during operations.

The disposal of excavated material is another major consideration. In New York City this was a particularly difficult problem because of the congested, densely populated areas surrounding the work sites, the lack of vacant land, and the resulting delicacy of the ecological balance which must be preserved. Each of the three primary work sites posed a unique problem for the disposal of shot rock, requiring careful coordination with local groups as well as city officials. In one location a barge disposal option was chosen, with the excavated shot rock being loaded into bottom dump barges and hauled to sea where it was deposited under an ocean dumping permit. For the two other sites, the excess material was transported by trucks to designated areas within or near the city. Considerations regarding disposal of material in this manner included not only the transportation of the material but also finding economical, environmentally viable locations in which to dump the material. In New York, sites designated for land fill or the reclamation of swamp land provided the best opportunities for this type of disposal. The transportation of material by truck required careful planning because of restrictions on truck traffic requiring use of designated routes, often zoned as to time of day, and of environmental issues such as noise and dust pollution relating to the necessary high volume of heavy traffic movement.

Management-related problems, like those related to people and construction, were also strongly impacted by the urban environment. City traffic, for example, caused significant changes in the usual structure of project supervision and management. Although movement to and from the various work sites on any linear project causes problems for management, to some extent these problems were intensified by congested New York traffic. Logistically it was nearly impossible for management to monitor the 13.7 miles (22 km) of tunnel on a continuous basis. To compensate for this, the project organization was structured to minimize the requirement for travel over the entire project by confining it to small segments. Although several members of top management had overall responsibility for seeing that the use of men and equipment was maximized, the three primary work sites were each run by separate project managers who confined their activities to their sites and adjacent work areas. Not only were they better able to control the actual work involved, it was easier for them to become acquainted with the representatives of the communities surrounding the project and work with their needs and requirements.

This decentralization of management responsibilities on a daily basis was at first aided by the organization of city's Board of Water Supply, the client. By structuring its project organization in parallel with that of the contractor, good interface and working relationships were maintained. Unfortunately, because of the bureaucratic, compartmentalized nature of New York City government — particularly at the local level — this productive, efficient working relationship frequently did not extend to other agencies and gradually deteriorated. The resultant lack of communication, particularly with agencies such as the Parks Department and Traffic Department, often caused delays and misunderstandings that were counterproductive to the work in progress.

Efficient, cost-effective management of the project was also frustrated by the contract document itself, with the result that significant contract and technical problems were not always resolved in the best professional manner. For various reasons, the final contract documents, produced over more than a three-year period, were not the result of a central philosophy established by the owner in which risks were to be identified and shared and the contractor allowed the flexibility to use his experience as a professional. Instead, the contract grew to be a defensive collection of sometimes conflicting instructions built upon the strategy — ultimately bureaucratic in origin — of transmitting all risk to the contractor. It was a document through which the ultimate, comprehensive goal of the project — the timely, cost-effective construction of Water Tunnel Number Three — became lost in the administration of the details of a contract designed, at all cost, to hold the level of expenditure at that established three years earlier — before inflation, lack of credit, and other problems had taken their toll on the city's finances.

The resolution of many of these contract-related problems had to be achieved in court after lengthly litigation. This was not a circumstance that proved cost-effective or worthwhile for either the City of New York or the contractors involved with the work. Unfortunately, the ground conditions were much worse than anticipated and the cost of the project was very high relative to original expectation. Without the benefit of a contract document in which both risk and responsibility could be shared, the contractor was stymied in adjusting the original document to fit actual conditions. Both contractor and owner suffered inordinate financial loss as a result of these disputes.

In conclusion, major projects in urban environments generate major problems. Although each metropolitan area has its own variety of these problems, New York City, as perhaps the most diverse and technologically complex of the world's great cities, epitomizes and intensifies them. City Water Tunnel Number Three, in cutting through various political, ethnic, racial, religious and other city boundaries related to human beings, provides a cross-section, not only of the unique construction problems encountered on a major project, but of the unique people-related problems that can often have as great an impact on construction progress as problems relating to the actual engineering and construction work itself. Although careful planning and monitoring of the work can mitigate the impact of these social, cultural and environmental factors, perhaps the best preparation for major construction in an urban environment is detailed knowledge of the specific city itself and a solidly written contract document that allows the construction professionals involved in the work to share the project's risks and responsibilities in order to accomplish the work in the most cost-effective, timely manner possible to achieve a quality product.

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Topic

UNDERGROUND AND ENVIRONMENT / TUNNELLING METHODS

Title

Construction of an Underground Railway in Warsaw - Man Environment Protection

Author

T. Romanowski

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Construction of an Underground Railway in Warsaw — Man Environment Protection

T. Romanowski

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An underground line, as a group of underground facilities, exerts a considerable impact on the environment and the conditions of living of the city inhabitants.

Its favourable effect is indisputable, nevertheless, an adverse impact should not be ignored.

Whether a negative impact can be eliminated or reduced, and whether it is long-term or just transient, depends on such factors as: cost, local conditions, soil conditions, technical and technological resources, and, to a great extent, also determination and forecasting ability on the part of those who participate in its construction and their appreciation of the significance of environment protection. It is also necessary to distinguish between the environmental impacts of underground line operation and the consequences resulting from the underground line construction.

The first underground line, 23 km long, will run from the South to the North of Warsaw, at the left side of the river. Its purpose is to provide rapid transit for approx. 700 000 of residents in this zone, where about 50% of employment places are located.

Moreover, the underground line will integrate three railway stations, an air terminal and four bus interchange facilities with the City.

The line will have 23 stations. The whole line is designed as a shallow underground, hence the hollow from the rail head to the ground surface will range from 9 to 15 m.

All the stations will be constructed in lined trenches. The tunnel segments between the stations in the southern and northern part of the line will be constructed also using the cut-and-cover method. The tunnels between the stations in the city centre, approximately 6 km long, will be constructed using the shield-driving method. For the underground facilities adjacent to the existing buildings, moulded walls or concrete sheet pilings will be applied. This method will be also used in cases where groundwater level decrease can be avoided.

The complete, 23-km long line will be put into operation in eleven years. For this purpose, the following investment organization was adopted.

The tasks of the investor, coordinator and organizer of the line operation were assigned to Dyrekcja Budowy, Metra — DBM (Underground Construction Management) in Warsaw, subordinated to the President of the City of Warsaw. DBM, as the Principal Contractor of the Investment Project, exercises control over the funds assigned to the Project from the State budget and subcommissions design projects and agreements to contractors and furnishers.

The Chief Designer is the "Metroprojekt Design Office" which, following an agreement made with the Chief Contractor, prepares technical documentation (certain specialized tasks will be entrusted to other design offices).

Technical working plans, after having been consulted and approved by the appropriate authorities and institutions safeguarding the interests of the City, its inhabitants, the environment, and the Underground prospective operator, will be sent by the Chief Contractor to the contractors of the individual project sections. Supervision by the Chief Contractor and designer's supervision permit coordination and inspection and ensure that the conditions of construction work and the completed objects will meet the requirements of the technical working plans, hence they will comply with the regulations of environment protection.

Hazards for soil and water environment may be created by permanent or temporary decrease of the ground water level, damming up of ground water or changes of flow direction, and pollution of deep waters with subsurface water.

The consequences of the above phenomena are self-evident and need no comment. However, attention should be drawn to their countermeasures. Moulded concrete walls, soil injection and proper each work drainage will reduce harmful decrease of ground water level below the basements of the existing buildings.

The hazards of water damming up

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will be eliminated completely by using the equivalent filtration layers under the tunnel bottom, as well as at the appropriate height of the tunnel walls. This will permit the ground water flow transverse to the barrier, i.e. the tunnel.

Wherever a temporary decrease of ground water level creates the risk of surface soil drainage and destruction of green areas, the greens will be hydrated throughout the whole period of drainage work. Along the whole route of the First Underground Line piezometers will be installed to control the effects of construction on ground water behaviour and to undertake the proper counter-measures.

To prevent a steady decrease of ground water level, caused by the tunnel structure, permanent drainage will not be used in the underground facilities as the means of preventing water infiltration inside the structures, since they will be constructed of watertight concrete and protected by water proof-insulation.

Deep water pollution with sub-surface water will be reduced by filling of all the prospective bores, as well as depression wells after they have been used. To realize to what extent this problem has been ignored, it is enough to remember that some specialists have suggested drainage by drilling large-bore wells which would drain-off subsurface water into deep waters. Such a solution was supposed to lower the cost of excavations drainage.

Noise, vibrations, air pollution, traffic diversions, demolitions and disturbances in functioning of public utilities occur to a greater or lesser degree, depending on the counter-measures applied.

However, complete elimination of these problems during construction of the First Underground Line in Warsaw will be impossible. Control and prevention of the factors affecting the environment begin as early as during planning, design and inspection of the project by appropriate authorities and institutions safeguarding the standards and regulations of environment protection.

Contractors (building contractors and specialized branch offices) must also comply with the regulations on work execution, besides the general rule of complying with the design principles.

The following solutions are suggested:

- to avoid noise and vibrations, instead of driving steel piles of the Berlin type lining of the trenches at high depths, the piles will be placed in drilled holes; piles at the depth of 2–3 m will be driven using vibro-hammers;
- operations causing excessive noise and vibrations will be carried out only during the day shift;
- shield tunneling in the city centre will permit 24-hr operations with no harmful effects on the environment, reduce traffic inconveniences (less diversions) and the amount of each work, and thus transport requirements;
- properly arranged traffic diversions and pre-assigned routes will reduce the problems of by-passes;
- the wheels of vehicles leaving the construction site will be cleaned to prevent pavement soiling and air dustiness;
- disturbances of urban underground installations cannot be avoided. Special structures are designed for underslinging all kinds of underground installations, in order to minimize reconstruction of the facilities;
- out of the existing buildings, only a few small houses will be demolished. In this respect the construction of the First Underground Line in Warsaw outruns all competition, especially in view of the fact that it is a shallow underground. This is possible thanks to farsighted assignment of space for the future underground in town planning;
- work under compressed air has been abandoned, in view of health hazards for people working in such environment;
- noise and vibrations transmitted out of the Underground tunnels during the Line operation will be reduced through utilization of flexible truck ties, special screens in the soil and solid bottom plates and tunnel walls. Furthermore, rigorous service conditions for the underground rolling stock and railway subgrade should ensure fulfilment of standards applying to the noise and vibration sources, as well as suppression devices;
- noise, vibrations, drafts inside the underground facilities and rail cars are the problems which have not been solved yet. Nevertheless, mufflers in ventilation ducts and closed ventilation systems in cars, proper arrangement of entrances and exits, as well as ventilation systems of the tunnels between stations and station tunnels provide better comfort for passengers and staff.

The Underground Line will markedly reduce vehicular traffic in the area, which will improve the conditions of living for the residents and conditions of work at places of employment located in that area.

Air pollution will be reduced to a great extent, since the liquid fuel consumption will decrease by about 60 000 tons per yr, hence there will be lower content of harmful compounds in the atmosphere, such as carbon dioxide and oxide, methane and other hazardous agents.

Translocation of urban transportation into the underground level and elimination of pedestrian traffic from the road level will bring significant improvements of vehicular traffic, reduce traffic congestions and air pollution with exhaust gases.

In all the cities which operate an underground the number of road accidents has been reduced. Trams and buses, which at present carry 10 passengers per m^2, will be relieved from overcrowding. Consequently, transmission of infectious disease will be diminished.

Speed and regular service of the underground railway will permit time savings of about 17 million hr per yr, which may be devoted to sport, recreation and family life, etc.

High comfort of travel by an underground railway favourably affects the general sense of well-being and reduces stresses.

Integration of distant suburbs with the city centre has also a considerable cultural impact.

The above-mentioned, short-term environmental hazards resulting from the underground construction, in view of the possibilities of their minimization, are far outweighted by the actual long-term advantages of the underground railway for both man and his environment.

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Topic

UNDERGROUND AND ENVIRONMENT / TUNNELLING METHODS

Title

Problèmes de reprise en sous-oeuvre lors de travaux souterrains à Bruxelles

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Résumé:

Remarks:

Problèmes de reprise en sous-œuvre lors de travaux souterrains à Bruxelles

J. Vander Linden

Abstract — Highly specialized techniques must be used when subsurface structures are constructed at shallow depth against or under existing foundations. The author describes three cases making use of three different techniques: pinning of the foundation slab, underpinning by means of Miga-piles and ground freezing.

L'environnement que l'homme est appelé à protéger lors de travaux dans les villes consiste le plus souvent en des édifices importants ou des monuments de valeur artistique ou historique dont ses prédécesseurs ont enrichi le patrimoine commun.

Construits au fil des siècles, sans coordination dans le temps ni dans l'espace, ces ouvrages se trouvent souvent bien mal placés lorsqu'on implante de nouvelles infrastructures telles que voies de communications routières ou ferroviaires.

Les réseaux sont élaborés en fonction de la demande en déplacements et les impératifs des tracés, rayons de courbure et autres, empêchent de contourner l'obstacle.

On arrive ainsi à devoir faire passer des ouvrages souterrains au pied ou même *sous* des constructions qu'il faut préserver.

Sauf dans le cas de tunnels profondément enterrés, exécutés au bouclier, l'ouvrage futur passera donc contre ou *sous* des fondations existantes.

Cela demande beaucoup d'imagination de la part des auteurs de projet et beaucoup de savoir-faire de la part des exécutants, et surtout une parfaite synergie entre eux. Il faut faire appel à des techniques hautement spécialisées et faire un choix entre celles-ci pour chaque cas particulier, en fonction de la nature de la construction à reprendre en sous-œuvre et surtout de l'état géologique du sol, qui reste l'élément déterminant.

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Des inconnues apparaissent en cours de travaux qui demandent des réorientations de l'étude et de l'exécution, et donc beaucoup de souplesse dans l'interaction maître d'ouvrage, auteur de projet, entrepreneur.

En Belgique, où les villes ont un tissu très serré on s'est trouvé à maintes reprises dans l'obligation de faire passer des tunnels métro ou routiers, à faible profondeur, sous des constructions existantes, aussi bien à Anvers qu'à Bruxelles.

Il ne peut être question, dans le cadre réduit d'un "case history" de faire la liste exhaustive des méthodes employées, et nous préférons citer trois cas faisant appel à trois techniques différentes:

(1) La ligne est–ouest du métro à Bruxelles a dû passer *sous* l'arc de triomphe du Cinquantenaire, monument classé. Le tunnel passe sous les deux piliers centraux, d'un poids de 22 000 tonnes.
Ces derniers avaient une fondation hétérogène, de ballast, briquaillons et débris de pierre sur 6 m d'épaisseur, s'appuyant sur un sable tertiaire homogène, le Bruxellien.

La nappe phréatique se trouvant à profondeur suffisante sous le futur pertuis métro, il fut décidé d'opérer comme suit:

(a) Epinglage de la semelle de fondation par 500 forages verticaux et inclinés avec scellement de barres à béton du type crénelé de 32 mm de diamètre à l'aide de coulis de ciment injecté sous pression. On a pu ainsi réaliser un massif cohérent.

(b) Construction d'une galerie blindée au départ de puits d'accès extérieurs et construction en fouille blindée du mur médian du tunnel.

(c) Reprise de la charge de l'arche centrale par la mise en œuvre de 12 vérins de 520 tonnes prenant appui sur le mur médian.

(d) Construction analogue des 2 parois latérales et calage de 2 fois 14 vérins de 520 tonnes sur celles-ci.

(e) Construction par tronçons de la dalle de plafond et ensuite des dalles des différents niveaux souterrains.

Pendant toute la construction, il a été possible, en jouant sur les vérins, de réaliser l'équilibre entre les tassements dûs aux terrassements et le risque — encore plus grand — de soulever les arcades par l'action des vérins.

Les mouvements dans les deux sens n'ont pas dépassé quelques millimètres.

Inutile de dire que la hardiesse du projet demandait de la part de l'entrepreneur compétence et rapidité d'intervention et une parfaite coordination avec l'ingénieur-conseil.

(2) Toujours à Bruxelles, la ligne de ceinture du métro devait passer *sous* le tunnel de chemin de fer assurant la jonction entre les deux gares principales.

Ce tunnel à 6 voies est une construction massive, d'une largeur de 50 m, constituée de 68

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sections d'une longueur d'environ 25 m. Le tunnel métro devait passer en oblique sous 2 de ces sections.

La solution initiale était de reprendre le poids de ces 2 sections du tunnel-jonction sur des pieux forés de grand diamètre. Ces pieux devaient être forés à partir de la dalle supérieure de cet ouvrage et le traverser de part en part.

Une fois les travaux commencés, l'entrepreneur constata que la nappe aquifère sous le radier existant se trouvait deux mètres plus bas que prévu. Il proposa donc de profiter de cette tranche de terrain sec pour mettre en œuvre une solution moins coûteuse et surtout moins contraignante pour le trafic ferroviaire très intense.

On décida donc de reprendre les 2 sections du tunnel en sous-œuvre par des pieux Méga, foncés au vérin hydraulique par éléments successifs, soudés les uns aux autres. Par l'exécution d'un réseau dense de pieux de faible charge unitaire (50 tonnes) la charge du radier fut reportée uniformément en profondeur.

En travaillant en éventail au départ d'une galerie-pilote creusée sous le tunnel-jonction, tous les pieux Méga purent être foncés sans aucune répercussion sur le trafic. Sur base des essais de pénétration et des premiers fonçages de pieux, le diamètre de ceux-ci put être déterminé de façon à leur donner la longueur minimum compatible avec la charge à reprendre et la nécessité de les dénuder ultérieurement pour le passage du tunnel métro.

Les terrassements pour ce dernier furent donc exécutés entre une forêt de pieux métalliques supportant l'ouvrage existant. Après bétonnage du pertuis métro, les pieux traversant celui-ci furent recépés.

A un autre endroit de cette même ligne de métro, la technique des pieux Méga permit également de passer sous un hôtel sans perturber aucunement son fonctionnement.

(3) Enfin à deux endroits à Bruxelles et deux à Anvers, c'est la méthode de la congélation du sol qui a permis de faire passer le métro sous des immeubles importants. Par l'utilisation, à l'avancement, de tubes-congélateurs horizontaux, il a été possible de créer des massifs de sol congelé formant radier provisoire et permettant de creuser les galeries nécessaires à l'exécution du toit du métro.

De même, lorsqu'un tunnel doit passer non plus sous une fondation fortement chargée mais juste au pied de celle-ci, la création d'un mur de glace vertical peut être la meilleure solution.

Cela aussi a été appliqué à Bruxelles.

Cette technique de congélation exige de la part de l'entrepreneur beaucoup de know-how et d'expérience.