

# Industry Leaders'

## Round Table

Where the global industry discusses the key issues and concerns in today's tunnelling sector



*Left to right: Bill Hansmire, Gerhard Robeller, Olivier Vion, Gunnar Nord, Martin Knights, Brian Fulcher, Pekka Nieminen, Lok Home, David Caiden, Daniel Ruckstuhl*

## Discuss, debate, deliberate...♦

**W**ELCOME to the second *World Tunnelling* roundtable. We invited some of the top minds in international tunnelling from engineering consultancy, contractors and equipment manufacturers to meet last year in Hamburg on November 30 – the eve of STUVA – to discuss some of the most talked about issues in tunnelling. Heading up our A-list of candidates was ITA President Martin Knights, who chaired what was to become an enthralling, engaging and memorable discussion.

The roundtable is just one of the conference formats organised by Aspermont UK across its publications and it has proved a useful way of generating meaningful debate. In inviting some of the finest minds in the industry to discuss a broad range of tunnelling topics, the idea is to generate ideas, forge new relationships and, hopefully, provide solutions to some of the vexing questions of the day. Just as importantly, it also provides

you, the reader, with a concise and current snapshot of where we are on some of the important issues affecting the industry.

**“The idea is to generate ideas, forge new relationships and, hopefully, provide solutions”**

At the meeting we raised the topic of the global financial crisis and its effects on tunnelling. Where were people expecting to find future opportunities? We discussed how to make tunnelling more attractive to prospective candidates, and how we can improve contract documentation to avoid delays and

disputes on tunnelling projects. How effective are geotechnical baseline reports as risk-management tools? Will we see a greater convergence between tunnelling and mining technologies and methodologies? And, we covered other questions too, which you can read in the following pages and online at [www.world-tunnelling.com](http://www.world-tunnelling.com).

The end of the discussion focussed on the importance of ITA and how the tunnelling industry can better support it. This is not included here as it forms a substantial chunk of information, which, due to space limitations, will be featured in the March issue of *WT*.

For the time being, I hope you will study the following pages and deliberate the responses of our esteemed panel. They brought to the table a wide range of valuable industry experience, which I am sure you will find rewarding.

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### PARTICIPANTS

#### Martin Knights (chairman), president, ITA

An operations director and board member with Jacobs, Martin is an engineer with 37 years' post-graduate experience in global civil infrastructure, gained mainly on tunnelling and underground space projects. Elected ITA president in 2007, he has been a tireless promoter of tunnelling.

#### David Caiden, principal, Arup New York

David's international engineering career has focused on major infrastructure tunnel projects, including road, rail and utilities. He worked in Europe, Asia and Australia before joining Arup as a principal in New York eight years ago. He is director of construction for the DHA Joint Venture designers working on the Second Avenue Subway, Manhattan.

#### Brian Fulcher, project director, J F Shea Construction

With an engineering background in bridges, tunnelling, hydroelectric and transit systems in the US, Canada, Puerto Rico and Taiwan, Brian has worked on complex tunnels, large caverns and underground power houses. He now focuses on water, sewer, transit and transport tunnels and shafts.

#### Dr Bill Hansmire, senior VP, Parsons Brinckerhoff

For the past 30 years, US-based Bill has carried out project management, tunnel design, geotechnical and construction management roles. He is working on the Alaskan Way tunnel in Seattle, US, is a member of the Moles and has been elected to the prestigious National Academy of Engineering.

#### Dr Martin Herrenknecht, chairman, Herrenknecht (not at meeting, responded in writing)

An engineering graduate, Martin started as a design engineer for road-construction machinery and vibration drums, followed by project-management roles. In 1977, he founded Herrenknecht GmbH, of which he is now chairman. He has received numerous awards, including Germany's Order of Merit, the US Moles' Award and an honorary doctorate.

#### Lok Home, president, The Robbins Company

Lok graduated in mining technology and was project manager in Canadian mine development from 1965-68. In 1985, he started TBM and equipment supplier Boretac, which acquired Robbins in 1998. The two companies were consolidated.

#### Pekka Nieminen, global manager for tunnelling and underground civil engineering, Sandvik

Graduating from Helsinki University, Pekka joined Outokumpou as a mining engineer. He later joined Tampella Tamrock, now part of Sandvik Mining and Construction.

#### Gunnar Nord, adviser, Atlas Copco

Originally trained as a geologist, Gunnar is an advisor with Atlas Copco's Underground Rock Excavation division in Sweden. He has been with the company since 1983, prior to which he worked at Skanska for 25 years as an engineering geology consultant and in other roles.

#### Gerhard Robeller, area manager, tunnelling, Züblin

Stuttgart-based Gerhard has over 25 years' underground construction experience, gained in Germany and abroad. Following tunnelling work at Bilfinger Berger, he became responsible for tunnelling at major contractors and is now responsible for all of Züblin's export tunnelling activities.

#### Daniel Ruckstuhl, director, Meyco

Daniel graduated in civil engineering and has held numerous construction chemical-marketing roles in positions, including vice-president and senior vice-president (marketing). He has worked for Holcim, skw-mbt and Degussa, which was later acquired by BASF.

#### Olivier Vion, executive director, ITA

With ITA since 1995, Olivier is a civil engineer with a specialism in communications. He has worked on cement applications in tunnelling on the Channel Tunnel and also on other projects globally. He runs his own tunnelling consultancy, specialising in marketing for tunnels and underground construction.

## Speaker key

MK Martin Knights  
 DC David Caiden  
 BF Brian Fulcher  
 BH William (Bill) Hansmire  
 LH Lok Home

MH Martin Herrenknecht  
 (written responses, did not attend)  
 PN Pekka Nieminen  
 GN Gunnar Nord  
 GR Gerhard Robeller  
 DR Daniel Ruckstuhl  
 OV Olivier Vion

During the three-hour round table discussion, the following questions were discussed, all of which had been circulated to the participants prior to the meeting

**Q1** What is your view of the global financial crisis as far as tunnelling is concerned? Are you optimistic for the future?

**GN** I am definitely optimistic. I think this financial crisis is only a blip in an overall upward trend. I see no reason to be pessimistic. It's only a matter of time before we start to recover.

**DC** I'm also optimistic and I think you've only got to look at the attendance at these sorts of [tunnelling] conferences around the world to see that most people are optimistic. One thing on the positive side is [that] I think issues like climate change and environmental factors are starting to come down in favour of tunnel jobs because people now have to consider sustainability and environmental issues.

**PN** My question is: have any of you actually seen any downturn in tunnelling? For me, businesses associated with tunnelling have suffered, but tunnelling itself has remained quite strong. I believe we will see further growth in the future. There are many projects in the pipeline, and now that governments are injecting money into the system these tunnels will get built as well.

**MK** On our agenda at ITA is the Copenhagen Summit and climate change, and what I would call the sustainability issue. I agree with David. Things like extreme weather, flooding, the need to build larger-diameter tunnels – whether for storage or drainage projects – will all, I think, start to impact more on the tunnelling industry. Whereas before, people had a benign view about it, I think now they're going to be forced into looking more into the underground option.

**LH** To be a bit negative, I'm still optimistic about our industry, but, certainly, we would have been a lot better off without the crisis. For these large projects we need good, stable, long-term money. What's happened is we don't have that stable, long-term money now. It's in a state of flux. I agree with the overall long-term trend and, while I think there's not going to be a recession, I think we'll suffer in the short term. It will be difficult to finance big projects and I think we'll see repercussions.

**MK** That's a very good point. In the UK, we suffer particularly more than many other countries. There is no PFI funding unless it's got guaranteed government backing. The problem is that a lot of people are just putting savings in banks and that is doing nothing. That's why a British politician I recently spoke to has proposed a kind of infrastructure bank in which people might have more interest and confidence in investing, which could be converted into infrastructure investment; something like the World Bank or European Development Bank model?

**OV** As an example, in Spain, where the property market is so depressed, the Spanish government has decided to invest heavily in infrastructure to increase public works and create more employment. In this way, they are compensating for the crisis in the building industry.

**DR** But, on the other hand, we've not really seen a lot of stimulus money flowing into this type of [infrastructure] project. But we have seen project delays and doubts over new projects. And I'm sure we have not yet seen the end of the



financial crisis or its impact on the tunnelling industry. However, I still believe we can be cautiously optimistic about the future.

**MK** From a European perspective, I envy economies like China, Singapore and Hong Kong, which have governments able to order the supply chain to comply with national initiatives to prevent unemployment and bring forward future investment plans: they can get a better market price now because companies are looking for work. To some extent, I think President Obama is trying to do that in the US through a stimulus plan. Basically, we have to look for construction projects that can be implemented now. Unfortunately, countries like the UK leave it to the market, which, I think, shows a lack of leadership. Tunnelling is highly mobile and well paid, and labour will go where the work is.

**BH** Tunnelling work has slowed disproportionately less compared to other segments of heavy construction, but I don't think it is long term and certainly not permanent. What we defer today, we will be doing tomorrow. It may take a few years, or many years, but I think that work will be there eventually.

**GR** There is a huge requirement for tunnel projects overall. If the projects I am aware of go ahead they will carry the industry over for the next 10-15 years. But, I am very anxious that the financial crisis will stop many of these projects in their tracks. Politicians can very easily put a stop to infrastructure projects. Transport projects are driving us, but this is a very sensitive market.

**MH** Since tunnelling projects are both planned and contracted out on a long-term basis, worldwide tunnel construction will not be influenced too much by the financial crisis. Projects are supported by the infrastructure measures planned and carried out by states, meaning we can look to the future with optimism.

**Q2** Where in the world are you expecting good project opportunities in the future?

**LH** I'm hoping my new markets come from such countries such as Germany, Austria, France and Italy. I'm already well-established in China and India.

**GN** It depends on who you are and where you are looking. If you are Chinese being paid low wages, you can find good markets all over the world. And if you are a highly-paid European or American worker, it is bad wherever you are looking. But, if you are well educated, there are good opportunities wherever you search. We see China as being a bright hope for the future.

**DR** There is tremendous opportunity in the very near future, but on different levels around the world. We still see very good potential in infrastructure projects, particularly in high-speed railways, such as in Spain with its highly ambitious plans. We see hydroelectric power projects continuing on a large scale in India, large metro projects in Asia – particularly in China, but also in Singapore and Hong Kong – and a variety of different projects coming on-stream. There is also some infrastructure development in the US.

**DR** Just coming back to Olivier's comments on Asia, I think it's easy to see where the potential is. Look at every major city today in Asia that is larger than two million people. They will, sooner or later, need a metro system. So, these are our potential markets. And that's just Asia, which offers more than enough opportunities.

**MH** We are expecting good project opportunities worldwide.

**Q3** Should owners be forced by new planning laws to at least consider the underground option for some developments in urban areas, taking into account energy use, sustainable long-term benefits and rational use of scarce surface space? And should there be more statutory pressure to ensure a finished tunnel should be multi-use rather than just road or rail? Should tunnel designs include adequate provision for future services, irrespective of their immediate use?

**MK** Should we actually be forging planning law to force developers, either public or private, to look at the underground option, at least in evaluating whether a scheme in the city area should actually be put above ground or whether an underground solution would be better? Should we be actually providing a stimulus to force people to at least evaluate the underground option?

**PN** Statutory pressure will help, but it would be more important to have an overall masterplan, formulated by planning officers, where different tunnels are designated for different depths and locations around the city to act as a guide for designers.

**GN** In Helsinki, they are well advanced on this use of underground space. They have even classified various areas as suitable for underground work to house the various utilities. That will really help in planning multiple-use, underground space.

**DC** New planning laws are one issue, but in some countries we have more basic issues to address. In tunnelling, you're not constrained by city maps and you can go in any direction. Unfortunately, in the US, this isn't the case because land ownership laws dictate that when somebody owns a piece of land they own it to the centre of the Earth. And, unless you can fix archaic laws like that, none of this stuff really stands a chance.

**BH** I want to respond to the concept of requiring multi-use for tunnels. In typical US public works for water and sewer, great effort is needed on the part of utility owners to get a major new tunnel project built for just one purpose. Where the tunnel is paid for by rate payers there has to be someone else to pay for the added cost of multi-use. Multi-use is not in the culture of private and public utilities, and is not easily changed. In dense urban areas, I think requiring some form of multi-use is possible, but in smaller cities and one-off rural projects it will rarely make sense.

**BF** In the US, and perhaps other countries, some utility companies are private whereas an underground facility may well be a public infrastructure project. So, compelling people to plan becomes a matter of conflict between private and public interest. We know of a tunnel in Russia with multiple traffic – road and rail – and I'm sure there are also utilities in there. But, it's the ultimate public/private partnership that would bring this together, and some of the statutes restricting that have to be overcome by allowing public entities to engage with private entities for multiple use.



**MK** An area we tend to forget is the Gulf. Dubai may be in difficulty, but other nations around the Gulf are thinking responsibly about their future infrastructure; looking at utilities in a more sustainable way, putting them underground in what I would call 'utilidors' that allow access without having to dig up streets. That way they use the surface more responsibly. I see a trend happening there in terms of civil infrastructure and metro systems. I think there are aspirations in the Gulf to plan cities in a more responsible way. We might look to some really good models there.

**BH** In the US, in the long term, we will continue to build the smaller-diameter CSO tunnels as part of the continued water-pollution clean-up mandated by the US Clean Water Act of many years ago. Secondly, I see a resurgence of transit tunnel construction. Los Angeles has more tunnel projects planned and New York also has such projects. Some tunnels will be required for high-speed rail in California. It has taken decades to get the NY projects going, and other major cities will have major infrastructure projects with tunnels.

**DC** Like everybody else we are seeing continuing confidence in China, Hong Kong, Singapore, India and even Australia. But, one area nobody has mentioned where we're actually investing now is South America.

**BF** One of the interesting details about high-speed rail in California is that it was a bond issue – a local vote dedicating several billion dollars to high-speed rail and all the associated infrastructure. Some of us are still a little dubious as to whether it's a good investment, but at least, by democratic standards, it's now been voted in and earmarked.

**GR** Going underground is the only solution to improve infrastructure in most cases, especially in dense urban areas. As Martin Knights said before, we have to bring utilities underground, which is a challenge. Sewerage and water supply is also a big issue for the future. But, the question is: where are the next main areas for tunnelling?

**OV** I recently toured Southeast Asia for ITA. Indonesia and Vietnam have metro projects and are planning how best to use the underground for their infrastructure. In Jakarta, putting the metro above ground is no longer a consideration and they are also looking at putting utilities underground. It's the same in Vietnam and also in Laos, which is a poor country building hydroelectric projects as a necessity and selling the electricity.

**GN** I support Gerhard's statement that going underground is the only viable solution as cities grow bigger and land prices shoot up. In Stockholm it has proved profitable to run electrical high-tension lines in new tunnels, releasing land for development.

**MK** In London, over the past 19 years, utilities have actually given up transmitting high-voltage lines into the city centre, or digging up streets and putting them in trenches. They now have a planned programme to put the primary distribution and primary transmission in cable tunnels underground, as has happened in the preparations for the 2012 Olympics. This has proved a very sustainable solution.

**MK** Because of the narrow streets in Prague, they can't dig trenches so they have to have shallow tunnels running beneath the main streets, distributing power and sewerage water. The way they overcome the ownership on a project like this and the interfaces between the various utilities is that they are owned by the municipality, which in effect becomes the temporary custodian and main point of responsibility. I tried, with my company, to interest the transmission, water and telecoms companies to all share the same space for a cable tunnel that we're going to build, but they were worried about what happens if water spills and who's going to pay for the indirect and consequential losses? But, perhaps in a community where you have public ownership of everything, it becomes a little bit easier.

**GR** Underground space is not unlimited. This is nothing new for us specialists, but most people do not recognise the fact. It is up to us, the specialists, to make sure the relevant people and politicians in each country, at each level, are educated.

**OV** One of the main tasks of ITA is to communicate these concepts to decision makers to allow them to consider the underground option, but it's quite difficult as things are different in each country. In France, the new Paris masterplan stipulates – thanks to the French Tunnelling and Underground Space Association – that an underground solution has to be considered for any project.

**MH** The owner should also consider the social aspects associated with inner-city development schemes.

**Q4** How do we make tunnelling more attractive to prospective candidates at every level of the industry? The money won't attract them, so what will?

**MK** We do have an issue here, as in some countries – the average age of the tunnelling industry is going up by one year every year. So, how do we reflect society in the people we employ? I think we have to work hard at packaging ourselves in a more attractive way to reflect society, so that we might bring in people who might not have otherwise thought of being in our profession.

**LH** Our industry suffers a lot from claims, so that's the first thing we ought to clear up. Many projects are over-budget; nearly half of them in fact, and it gives our industry a black mark. We've really got to focus on this claim issue, and do what we say we're going to do and do it on budget, and not go around, especially us TBM manufacturers, claiming our machines can do everything. That's a big mistake. The consultants claim they can design when they can't. There are a lot of errors made in our industry and we should start to clean up our act.

**DR** I think this goes back to being part of the construction sector generally, which, for many people, is no longer an attractive option as a profession. You can make better and easier money in other industries. So, why would somebody choose a job that involves a lot of hard work and responsibility with relatively low reward? On top of that, you have to look to see where tunnelling ranks in the construction sector – that is the fundamental problem and, to be quite honest, I personally can't see how it can be made more attractive.

**BF** We have the same dilemma in the US: not enough of the right people with the education and experience. There is very little formal education in the US tunnel engineering business – we basically learn on the job. The real problem is getting people into the door with enticements, such as good pay, company car, rewards and recognition. But, we don't do that because we're old-school, and we expect people to work 12 hours a day and be ready to go from job to job. In some respects we do a lot to make the job unattractive. We have to change that because, as Martin Knights said, the age demographic of the whole industry is increasing. We need to better educate and better train our people on the job and make it attractive at the same time.

**GR** Our problem in the West is that fewer and fewer people are studying engineering at university. While it may look attractive, it is not easy to get an engineering degree. We all know this. I think this represents a cultural shift and if we don't improve the situation I'm convinced other people will step in. Maybe this type of work is shifting from the Western hemisphere to the Third World, where people are hungry and keen to do the job. There's a huge requirement for underground construction, especially in Asia.

**MK** I think you may have a point. The centre of gravity of public infrastructure is moving to the East. What ITA can provide is the legacy of knowledge from all the public infrastructure that was built during the 1950s, 1960s and 1970s, and pass that on and build on it with new technology. Over the last four or five years, the ITA has had much demand for training and education, coming mainly from China, India and other parts. I find that people like to see ITA as an independent umbrella organisation to impart this knowledge because it's not seen as partisan or belonging to a particular nation. We also have UN status, which is regarded as another independent badge.

**DC** There are some good training courses around, such as the BTS course in the UK and the Colorado School of Mines course in the US. Attendance at these courses is growing, which is a positive sign. In my own tunnelling group, at Arup in New York, we have quite a few keen young people and thus a low average age. So, I don't think it's all doom and gloom, but we certainly need more of these courses. They should also be made more affordable – at the moment, attendees are reliant on companies paying for them. More company sponsorship might increase attendance.

**BH** I want to support David's view that things are not that bad. Parsons Brinckerhoff people involved in tunnelling have education in civil, geological, geotechnical and mining engineering, but not necessarily formal education in tunnelling. Often, the lack of opportunities to work meaningfully in tunnel construction keeps some people from getting into the business. We recognise the essential need to get our younger staff on to full-time tunnel-construction projects to provide essential, practical experience. But, we cannot expect that more university education on its own will produce the people needed; we must 'grow' them in the business.

**MK** One of the initiatives that ITA has been asked to take up through the British Tunnelling Society is to form a working group to share lessons learnt, and provide a forum so that good and bad practice is documented in a relevant way – whether to do with safety, procurement, design or contract procedure – and do that in a way that can benefit the industry. Certainly, the insurers are increasingly playing a more prominent role in contracts and the procurement of projects. They're encouraging us to do that so we can accumulate a source of information and be able to share it with clients, particularly those who have big projects infrequently.

**MH** More comprehensive, practice-oriented courses of study, specialising in tunnelling, like the courses sometimes offered by the ITA, would be desirable.



Pekka Nieminen  
(right)

**Q5** Vague, confusing and ambiguous contract documentation plays a major role in causing disputes on tunnelling projects. How can the situation be improved and who is best placed to ensure that contract documentation is as clear as possible for a given job?

**BH** I feel that having clear contract documents is very much the responsibility of engineers working with their clients. I have found that, for a variety of reasons, owners are often the ones most responsible for some of the biggest problems. They typically don't understand tunnelling and don't understand risk sharing. There may have been some disasters in the past where, with the help of lawyers, the city or agencies, laws and regulations are promulgated to create terms and conditions

of contract appropriate for some previous problem project, but which are ridiculously inappropriate for a tunnel project. As professional engineers, clear contract documentation should be our responsibility.

**MK** Certainly, procurement and the procurement strategy aren't thought about early enough in the evolution of a project. I think engineers have a duty to talk to clients about the way a contract is going to be procured. The contracts that back that up truly reflect the ability of the parties who will be part of that procurement to take and manage the risk. I think we're seeing a move toward more responsible risk allocation and risk management.



Lok Home

**DR** As a supplier, we recognise this and have started to focus more on working hand-in-hand with designers and engineers, and partially with owners to make them aware of technologies.

**BF** As a contractor, we look at these contracts on a couple of different levels, certainly on the technical side, such as concrete and steel. More and more, we are compelled, if not obligated, by our senior management to really know, understand and interpret the actual contract itself for changes, differing site conditions, delays, extra time and things that matter to us because it matters to our pocket-book. Generally, we will try and clarify, through questions and answers, anything that looks vague, confusing or ambiguous prior to an acceptable level, we will stand down from the contract or put so much contingency in that we're not likely to be competitive. And that is counter-productive to the owner's interests. Hence the clarity and lack of ambiguity in contract language, as Bill said, largely written, or at least advised by an engineer, is fundamentally important to achieve an economical solution to a contract.

**GR** Speaking as a contractor, we have to do two things: identify a project and get listed, and then compete against the other contractors and win the tender. As long as owners find contractors who are willing to enter into such risk then they are happy.

**MK** Are you advocating then, in order to get a job you've got to bid the lowest price? That's going to result in, probably or potentially, major costs and schedule overruns. It's going to cause an adversarial relationship and probably eventually end up with costly litigation. So, what, in your experience, is the optimal form of contractual procedure to try and avoid that? Or are you saying it just depends from one country to another?

**BH** In the 1970s, when there was a great deal of difficulty and cost overrun with a water tunnel in New York and other tunnels in the US, the National Research Council publication *Better Contracting for Underground Construction* was a landmark achievement toward improving the situation. Geotechnical baselines and current practices to manage and appropriately assign risk eventually evolved from the recommendations in that document. The recent update, *Recommended Contract Practices for Underground Construction* 35 years later, is a reaffirmation of the principles and an update on several contract issues. These documents are the manifestations of the very substantial efforts in the US to improve contracting practices. The principles have been established, but implementation for the myriad owners and projects remains. If we'd had widespread implementation of these recommendations quickly, we would be better off. But in the real world such major changes take time.

**DC** As far as I can see, it was a repeat of the earlier document because the recommendations haven't been adopted. It's very true that every country has its own practices, but within English-speaking countries at least, I think it would be

very helpful if the form of the new engineering contract, the NEC Contract, promulgated by the Institution of Civil Engineers, could be adopted because that simplifies things so much. One of my favourite forms of the contract is the Target Cost Basis contract, which is a much fairer way of doing things with pain/gain scenarios. One of the best things about the New Engineering Contract is the fact that it's written in modern English that ordinary people can understand, whereas the traditional forms of contract, particularly in the US, are written in an archaic form of English that most people really don't understand.

**MH** In response to this question and the following (Q6), I would say it is of major importance that sufficient and comprehensive geological and hydrological investigative work is carried out before a bid for a project is placed. The construction company should be able to choose the construction methods.

**Q6** How effective is the geotechnical baseline report (GBR) as a risk management tool? Should the GBR specify or preclude means and methods of construction? What has been your experience?

**DC** This is a sore point with me as I've been involved in many contracts, normally from a dispute position or an expert witness position where, in fact, the GBR has been a total disaster. On the international stage we mustn't get confused with the original American-style GBR, which was written specifically to deal with differing site conditions clauses, which are contained in what we generally term the 'Federal Terms and Conditions' – the federal conditions of contract that end up being used in all [US] states. So, it might be helpful if, from an international basis, we didn't use the term GBR, but used 'Geotechnical Reference Conditions' or something similar, as is used by the ITG in its recommendations. Over the years there has been a lot of confusion and it seems to be getting worse. As originally intended, the GBR was supposed to be a purely contractual document defining who pays for what. So it was a risk allocation document. But, it seems to have been adopted and adapted, and melded into other things. My personal view is that it's fine to have a document such as that if what it's defining are parameters; things that can be easily measured, geotechnical parameters, known things that we all understand. But, the contract needs to define how those parameters are measured. So many of the jobs I've come across have a GBR, but they don't stipulate how you measure the parameter, so you can manipulate the situation to get the answer you want. And, if you can do that, it's an absolute waste of time. So, a GBR – or the contract itself – has to specify how parameters will be measured within the contract to be tested, to decide which side of the line a claim falls.

**BF** In the US, the GBR has been, for several years, a document of great significance within the contract. A lot of the jobs we look at have a GBR, and to a great extent we will not bid for a job that does not have a GBR. But, not all GBRs are the same. They do not always look at ground behaviour, but tend to dwell on ground properties. And they don't always dwell on the expected construction method, e.g., a TBM versus a roadheader in certain conditions. It's still murky. All too often, the GBR is the document that is under great scrutiny and under attack from both sides. So, it's not always a 'decisive' document.

**GR** The GBR exists in only a small part of the world. In most other parts, nobody knows about it. They don't use it. And it's also a theoretical question. It depends on the type of contract you have to enter into.

**BH** I've worked with GBRs and seen them go astray. They're too long and too complicated. They stray from their purpose, which would be, as David says, to identify what was a 'differing site condition'. One of the greatest problems is having incomplete or conflicting technical requirements (specifications, drawings), geotechnical baselines, and terms and conditions of the contract. For instance, a GBR should never specify anything. I want to comment on the issue of should we specify or preclude means and methods of construction? In terms of the context of how a baseline is established, obviously the baseline will, or should, be different if a roadheader, TBM, or drill and blast is being used for tunnelling. What has been difficult in the profession is to write a GBR that is relevant to the construction context, yet distinguish it from specifying the construction method. We should not write GBRs that stipulate how you build the tunnel, but it is essential that baselines are relevant to the construction method. I'm a fan of GBRs despite all the things I've said here.

**Q7** We are approaching TBM diameters of over 16m. Can this figure increase any further and will we see more circular-shaped TBMs as per the Japanese model? What is the next major development in the evolution of TBMs?

**MK** Every time I read the global tunnelling press, it doesn't surprise me to see that TBM diameters have increased yet again. They're approaching nearly 16m now. Do you think there's any limit to the diameter?

**LH** I don't think there is a particular limit in size directly related to the mechanical structure or operation of the TBM. We could make one 25m in diameter, so I don't think the limit is there – it's just not a mechanical problem. But, I don't think jumping to a 19m tunnel would be a reasonable step either. We go from 13m to 14m, to 15m to 16m, and gain our experience like that, which is logical and practical. So, I think evolution will take its course. Segments will get bigger and the mucking systems will catch up, but to take a big leap is a mistake.

**GN** I agree. Certainly, it can't be a mechanical problem, but more of an economic one. When will I have a use for the space created by a 19m machine? If you need it for road tunnels and so on, then it's probably much easier to opt for, say, two 10m machines. So, I think the issue of whether 19m, 20m or 25m is largely irrelevant.

**OV** The only purpose of a 19m or 20m-diameter tunnel is as a double-deck truck tunnel. For the moment, all the double-deck tunnels that are planned are only for cars. It would be 18m or 19m in diameter if, say, we wanted a double-deck tunnel for trucks, in place of two tubes.

**BH** Seattle and Washington State are planning to replace a seismically-vulnerable, elevated highway structure with a double-deck tunnel, with full-length emergency egress and all associated ancillaries. This could easily require a TBM of 18m diameter or more, but for cost and risk reasons the project is likely to end up with a 16-17m diameter TBM, selected by the tunnelling contractor.



**GR** If the need is there and it makes sense, bigger diameters will come in. I'm convinced of this. And it's not a technical question – the capabilities are there, but is it economical? The future will give us the answer.

**DC** The most exciting thing I've seen recently is the idea developed between Bouygues and Herrenknecht called TIMBY for river crossings, which is a cross between an immersed tube and a segmental tunnel. I think it opens up possible solutions for a number of projects that wouldn't have been possible with conventional means.

**BF** I'm not sure that the circular tunnel getting bigger is always the right solution, as opposed to some other shape. Certainly, double-dot and triple-dot configurations are more amenable to, say, transit or road tunnels. So, looking at those configurations, as opposed to just getting bigger single bores, needs to be studied. What Gerhard said – that bigger is technologically possible – as a contractor, I would say no problem. But, the collateral effects, such as lifting segments, track and pumping, is all the stuff that makes this big machine work – they too must be resized to manage the bigger,

larger operation. With that size increase comes people training and other things that aren't necessarily appreciated as consequences of larger diameters.

**LH** Round is a nice design, but sometimes other sectional tunnels are a good idea. For non-circular tunnels it would be wise to use technology that has already been developed in Japan. They have worked out the problems and that's what we should be doing – using what's been built already, instead of going off into dreamland and saying we're going to design something completely new. There's a reason why the joint-venture machine that has been proposed and mentioned isn't out in practice – there's too much risk associated with it.

**GR** My ideal development in a TBM would be to be able to adjust to different ground conditions quickly, to be able to change between EPB, slurry and hard rock! Well, that's my dream. The big task for TBM suppliers is to at least proceed in this direction.

**LH** To respond to that question, what has happened is that nobody wants to take the risk or properly share the risk. If we were to propose such a machine and something doesn't work, we're going to get claimed, and historically we have. That's what happens. We're willing to design new products that can undergo quick changes, but there's risk involved. Who's going to share that risk? Otherwise we know we're going to get a claim. We get a claim even if we do it right. That is the reality because a lot of contractors issue claims against both owner and supplier. That is the reality of our business, so I agree these things need development. I agree that we can develop them, but we've got to make a profit too.

**MH** Circular-shaped TBMs will prevail in machines with diameters greater than 14m. There will definitely be new developments with respect to cutting wheels, cutting tools and tunnel linings, as well as developments in the logistics sector.

**Q8** TBMs are not considered economical below 3km lengths. Can this figure ever be reduced by improved TBM technology?

**MK** I've heard it said that TBMs aren't economical below a distance of less than 3km. Do you think this figure can be reduced?

**LH** Yes, I think it can. The specification comes out, it says it has to be so many horsepower, and have so much thrust, and go this fast and so on. Not necessary. You can drive a 16km tunnel with 500hp. We can design these; we might go slow, we might take a long time, but we can do it. We are just really going headlong into these high-spec machines, and we should back down our specs and go for shorter tunnels and less powerful machines. With less powerful machines we can build shorter tunnels safely.

**MK** Do you think there's too much over-specification going on for TBMs, which cuts out the innovation that you might be able to provide?

**LH** I would not agree with around two-thirds of specs that come out for TBMs. But, it's in the spec and they come to us and say, hey, let's try to compromise on this, and we do. Our customer is the contractor and we work something out with him, but I don't necessarily agree with all the specs. I think Martin Herrenknecht would agree with that.

**BF** This whole idea of a line in the sand that says a tunnel has to be over a certain length to be economical is all relative. If you own the equipment or have the advantage you will find the best answer with or without a TBM. The second part of the question was specification of the equipment. We, as a contractor, like to see little specification. Leave that decision, the operation and the risk of the operation up to the contractor. That's why you hire us. With two specific exceptions, we have yet to come across a designer or owner that actually bought the TBM for a tunnelling contractor to use. But then that carries certain risks, so when that machine doesn't exactly perform according to the ground conditions you go back to the owner of the machine. My point is really that contractors pride themselves in knowing from experience how best to buy a machine, working very closely with the manufacturers and developing the best technical solution to specific ground conditions – not ignoring the contract, but working in complement to the contract.

**BH** Who says a 3km length is not economical? Length is clearly relative to many conditions. Many other projects have required TBMs, although drill and blast would be technically acceptable, but unacceptable to the public. I want to respond specifically to Lok on why we specify so much? I think it comes down to the fact that we want a machine that will do the job. My experience over the years has been that as tunnelling technologies have been maturing for EPB or slurry TBMs, it was at one time essential to specify the equipment capabilities (TBM specs) in order that all contractors had the additional cost in their bids. As tunnelling and equipment continues to improve, specifying the equipment should decrease as the industry demonstrates a good record of using the right equipment as an essential part of a successful project.

**DR** I just returned from Singapore where there are many very short drives. A lot of TBMs are in the ground and many more will come. They speak of something like 50 TBMs over the course of the next couple of years. And you will see them utilising very short sections; obviously very economically, otherwise they wouldn't have been considered.

**GN** As a representative of the conventional drilling sector, I think it's time to kill this 3km statement. Many tunnels are much more feasible and economical to drive in the conventional way, instead of using TBMs, even when they are considerably longer than 3km. Every tunnel project has unique conditions.

**DC** Don't forget the Port of Miami Tunnel. I think that's just over 1km long, including the cut-and-cover bits. And that's just been signed up.

**MH** The use of a TBM depends on the diameter, geology and hydrology. With diameters less than 6m, it may be interesting to use machines for lengths upwards of 1km.

**PN** I agree that geology plays a bigger role when selecting the method. In hard rock, drill and blast may be the most economical method while roadheaders may be the optimum solution in soft rock. In clay or sand, below water level, TBMs can be the best alternative, despite the length of the tunnel.

**Q9** Progress has been made in increasing safety on tunnel projects, but who is best placed to ensure safety awareness is taken to a higher level?

**MK** Let's talk about safety. There has been a lot of effort made by the industry to raise the profile of safety, and not just make it a process but to actually make it a culture and a behaviour, and place responsibility on management and drive it through into the workplace. But, what observations have people got about safety in their own companies? What kind of initiatives are you taking? And who do you think is best placed to ensure that safety awareness is taken to a higher level?

**GN** The first issue must be to raise safety to similar levels all over the world, but there's a huge difference depending on where you are. Australia, Canada and Sweden are very strict on safety, so instead why not try to spread safety awareness to other parts of the world?

**BF** Tunnel contractors have a little way to go on their safety culture. In the US, we are moving in the direction of becoming self-insured. The culture is changing in the direction that is driven by economics so, by default, we are more inclined to train, equip, educate and frankly enforce our training programmes, but we still have a way to go. Attention to safety on the job site is generally a way of life for us, but at the same time there are still some who just don't have the training.

**PN** Safety has been the focus for a couple of years now at Sandvik. We have put a lot of effort into it and we have achieved phenomenal results. I don't agree that we should only promote safety in certain countries. There is room to improve everywhere. When safety improves, workers are happier and more productive.

**DR** At BASF, safety is paramount and it clearly starts with the company culture. If the company adopts a culture of safety, it will drive safety, and it has to be everybody's daily responsibility to live up to that. It has helped us to achieve very good records and it will continue to improve.

**LH** I take the issue that Gunnar takes. In developing countries we see that their tunnels aren't safe. We have a responsibility to set a world standard in safety. It isn't there and I think it should be. I also think ITA should do it and we should fund ITA to do it. I try to encourage everybody to contribute to ITA because I think it needs funding and help. The rich machine manufacturers, contractors and consulting firms should step up.

**OV** Funding is not the main problem at ITA. We have to get all the right people working together; most people working for ITA do so on a voluntary basis. Of course we need money, but we also need you contractors, consultants and manufacturers to send people to work with ITA to achieve this.

**GR** In the application of chemicals today there is too much safety bureaucracy in the EU. The user doesn't really understand what's in the chemical, but the chemical industry should give safety advice on its products. How much will it all cost is always asked, and for me the best way to minimise such costs and increase safety levels sustainably is to have skilled people.

**MK** Just adding to what Gerhard has said, it is a question of competence; not only technical, but also awareness on site. One of the initiatives that the British Tunnelling Society (BTS) has taken is to help set up a group called Tunnel Skills, where contractors, clients or consultants will have to ensure that no employee goes on site unless they have a competency or safety awareness passport. That way, you don't get itinerant labour who have never been on a site before.



Brian Fulcher (left)

**BF** Safety culture is very important. It's developed within and around the job site, and other places. But, it has to be a top-down thing – the management and owners of the company must buy into the programme and be willing to fund it, be that through training, facilities or education, or, in some way, apprentice people who don't have the skills. Secondly, safety needs to be designed into the work that designers are doing as part of their constructability analyses and other phases of their services to a client.

**DR** I feel obliged to answer on behalf of BASF regarding the chemical aspects. We have a tradition where we drive innovation to achieve better performance and safety. We've been instrumental in bringing forward alkali-free accelerators to the market and do not offer phenolic-based injection materials, having fully embraced the commercial consequences of doing so. But, we have also invested heavily in robotic spraying for better quality and operator safety; something that has not yet been taken up to the extent we would like to have seen. On the other hand, I also see contractors following a downward slope in terms of price pressure on the material side, which makes it very hard to promote better and safer technology.

**OV** This means clients are not doing their job because they are still allowing this commodity product to be used. We know they are not good in terms of safety or sustainability, but it's the client's job to take care of this.

**MH** Safety awareness can be driven to higher levels by Health and Safety, or the professional Accident Prevention and Insurance Associations as control bodies.

**Q10** Has the introduction of drill-rig software allowed owners and contractors to gain the sort of efficiencies in excavation that one normally associates with TBMs?

**MK** What do we think will be the next major development in the evolution of drill rigs?

**GN** We see a lot of progress being made. Drill-rig production rates are drastically improved, so is the quality of the drilling. We are also seeing radical improvements on the overbreak. Drill rig software allows better analysis of the tunnel face or the rock ahead. We can also provide new rock-support systems, including mesh and ductile bolts, to be erected for better safety, but also for better absorbing large deformations in the rock. We are also seeing real improvements in blasting technology, especially with electronic detonators.

**PN** There would be no real competition between TBMs and drill-and-blast on long, straight, fixed-diameter or round tunnels. But, with variations in diameter, section and plan, drill and blast becomes very effective, especially with new software that allows you to design and optimise the drilling pattern according to the available space, and simultaneously save on detonators, explosives, the amount of drilling and time. Such new developments improve the competitiveness of drill and blast.

**LH** As a tunnel-equipment manufacturer, we really appreciate the developments in drill and blast. In fact, we try to adopt them. With our probe drills we want to probe out 60m in advance. We want to record the rock, which we can with these new developments. We also try to use your rock-support systems and your safety systems and adapt them, so I don't see drill-and-blast as competition. In some ways, I think it is an adjunct to simply better tunnelling.

**DC** I really appreciate the advances that are being made. Unfortunately, in some places the level of operator skill isn't keeping up with the equipment capabilities. I'm not sure what we can do about that other than more training. But, in territories where we have issues with unions and demarcation it sometimes gets difficult to get the full benefit of drill and blast that we otherwise could do.

**GN** Yes, I fully agree. It's more of a problem with drill and blast because it requires greater skill, so we have to keep an eye on training. Also, I agree with Lok as I do not regard it as competition because all the efforts and all the good things that the TBM industry has made, especially in soft ground under cities, has really made people think of TBM tunnelling as the viable alternative. And that has also boosted conventional drill-and-blast tunnelling.

**BF** Recent jobs we've been involved with had two TBMs going through very altered ground and I would say that, without question, the success of the excavation was in large measure due to the fact that we had an instrumented drill doing probes which triggered water, which triggered grouting, which triggered certain appreciation of the immediate ground behaviour in front of the machine. So we would drill two, four, six holes in an instrumented manner, record that data and decide how we're going to mine the tunnel with the TBM. Take away the drills, the probing and the data that came from it, and we would still be mired in a problem. It was a very successful complement to the machine, even though it was not a TBM device – it was a drilling device.

**Q11** As resources dwindle, and longer tunnels are needed to reach orebodies in mines, will we see greater overlap between mining and tunnelling sectors?

**MK** Are the mining and tunnelling industries converging in terms of technology use?

**BH** Using a TBM in mining is not new and for some time it has been advocated by the civil tunnelling business. I think it is going to be essential to use them for economical development of deep mines with declines or long haulage drifts. However, the underground miners' mindset is that they regularly, day-in and day-out, use drill and blast for excavation, not TBM. Even miners using roadheaders will probably not automatically favour a TBM over drill and blast, say, for a long decline to an orebody. I don't know how the acquisition by Caterpillar of Lovar relates to more TBMs in mining, but maybe it's part of its strategy.



Gunnar Nord (left) and Gerbard Robeller

**LH** I think we'll see Caterpillar get out of the TBM business because it's probably too difficult for them. We have seen a lot of people over the years – Dresser, Ingersoll Rand, Atlas Copco. They all got in and got out. So, my projection is that Caterpillar will get out. I might be wrong, but I don't see there's a correlation between them entering this business and tunnelling and mines.

**BF** If you are really driving it from the outside, we've got access for 61m, 91m or 122m trailing gear; you have a pretty good chance of having the opportunity for a TBM, again, geology being what it is. But, if the shafts are going to 2,400m deep in Arizona and other places, there's considerable potential for some level of technology that we have already applied to a vertical TBM. That's another thing to keep an eye on.

**DR** Referring more to product technology than TBMs, I'd say we have an equal share in tunnelling and mining. Our experience shows that the technologies have come together. The quality of sprayed concrete, membranes, injection material and so on is of equal quality. In fact, I'd say that, particularly for robotic sprayers, the mining environment will probably have a faster take-up than tunnelling because mining is a process. They have a longer-term perspective and can train their people differently. So, I would not be surprised to see the mining industry overtake tunnelling in terms of uptake of new technology.

**GN** When it comes to the technology of excavating tunnels, the mining sector can learn from conventional drill-and-blast techniques in civil construction; maybe also from TBM methods. I can see that some mines have adopted civil tunnelling techniques and they have also achieved improved results on drifting speed.

**DC** Arup has certainly seen an overlap of the two industries because in the last few years we have been getting an increasing number of enquiries from mine operators and contractors bidding for work in mines. The other overlap we're seeing is the reuse of abandoned mines for other facilities; for instance, the Dusel underground facilities project. As more exhausted mines become available, I see that as a growth area as well.



Martin Knights



**Q12** Is the use of shotcrete as a primary support becoming more accepted in place of rockbolts?

**MK** There has been a lot of development in robotic spray-concrete linings and, certainly, I've seen some really good applications in the UK recently. I've also seen good examples of sprayed-on waterproof membranes as well, which offer a good substitute to sheet membranes.

**BF** I have a question for chemical suppliers: is there a successful sprayed-on waterproof membrane for a drill-and-blast tunnel? Shotcrete isn't waterproof. Is there a product that our experienced designers would say 'works' and an owner would say 'that's what I want'?

**DC** I actually believe there is because we've used them. We've done one in Hong Kong and one in Australia, and the people involved said it was very successful. Personally, I'd rather see more use of waterproof concrete. There's been a lot of that going on in Germany and Austria because if you can make the concrete waterproof, why do you need the spray-on membrane?

**DR** Spray-on membranes are very useful for cross-passages, difficult geometries, different sections and so forth, when compared to conventional waterproofing membranes. If you have a straight section then, clearly, sheet membranes will always be more economical. But, then you have to take it further and you consider composite linings in single-shell tunnel design and that's where spray-on waterproofing becomes attractive as a total tunnel-design concept. We have had tremendous success with spray-on membranes in the rehabilitation of tunnels and it's a growing market.

**LH** I'm no expert in sprayed concrete, but it seems to me that there are no adequate regulations on how to use it. When it is used there have been some tremendous accidents. It gives you a false sense of security. You put up the sprayed concrete and then you have a disaster. We have it on TBMs; we just had a collapse on a section they shotcreted. There should be some kind of standardisation on shotcrete – how to use it, what's safe – but there doesn't seem to be.



**BH** I feel there is definitely a willingness to use more robotically-applied shotcrete and, where possible, less rockbolting. However, from an engineering geology perspective, there will be a reason why there is a need for rock reinforcement. Some rock conditions are just going to be too blocky to be supported by shotcrete alone in the normal mining cycle, and it will not be possible to replace the role of rockbolting with shotcrete. Also, it used to be that you never used shotcrete in soil, but that has changed over the past decade or two. You can do things in soil today that you would never have done some years before.

**GN** Can you rephrase the question to differentiate between primary and secondary lining? In the primary you have regular bolts and shotcrete, and in the secondary lining there is an option for replacing the in-situ concrete lining with shotcrete.

**GR** Of course, using shotcrete for the second lining is only for special sections. Normally, using sprayed concrete for the second lining is too expensive.

**DR** In the Hindhead tunnel it has been proven that composite lining concrete was the most economic option. This has to be a consideration for all projects.

**MK** The Hindhead tunnel in the UK is a great example of proving that you can have a finished shotcrete lining that is economic, and it can look good too. There are some really good examples in South America, such as on the metros of Santiago and Rio de Janeiro, and I'm sure they saved an absolute fortune on the secondary lining, compared to having used in-situ concrete, and it's a beautiful lining as well. So, I think the evidence is there for people to see.

**OV** One thing we have to take into account is the fire protection of concrete: you can do more things with shotcrete than with in-situ concrete.

**DR** What I sense in this part of the discussion is an industry that, by and large, is still very conservative. We are part of this conservatism and I think sometimes we would all be better off by having a more open mind, and getting out and seeing these projects, and actually proposing it for one of our new developments.

**MK** Are we really a conservative industry? What makes us conservative? Is it the people? Is it the regulations? The insurance that drives us in that direction? If you hadn't been to a tunnel site in the last ten years, would you go on a site and say 'not a lot has changed'?

**GN** I go back to what Lok said earlier: it's about the risk of being sued if something goes wrong – that's why we are taking it in small steps.



**BH** Precast today almost always looks perfect as a final lining. However, there was a time in the US when precast was an emerging, developing application for a final tunnel lining. Shotcrete robots have been around longer than ten years, but I see increasing use and a better quality product. So, I think that, just as we can specify and reliably get a good precast concrete tunnel lining with a TBM, we are also moving towards being able to specify a final lining of shotcrete for the right situations – and get a good product.

**DC** I just want to say there was nothing wrong with precast when I was involved in building in the 1960s.

**BF** I think we are clearly conservative as an industry. Some of our equipment and methods date back to the 19th century. We are often slow on the uptake [for new technology] because we're a little averse to change and the risk of performance. At the same time, as contractors, we're dealing with projects that compel us to take on more risk. And yet we're still using 100-year-old equipment designs that work well and applying these to new risks. So, we have this contrast or constant conflict.

## Q&A

**MK** Lok, I'm sure you want to comment on TBM technology, which, in the last 15 years, has really come on by leaps and bounds.

**LH** You say so, but I don't think so. EPBs have been here since the 1970s; they've just moved into the American market. By 1985, the Japanese had produced over 1,000 EPB machines. It's a problem of disbursement of information in our industry, but ITA is doing a lot to help with that. Most of our developments are incremental. Most of the TBM developments are incremental and I think they will continue to be so. I don't see any big breakthroughs, but I'm comfortable with 'incremental'.

**Q13** Too often, consultants, contractors and TBM suppliers do not want their problems or solutions highlighted, resulting in costly, repeated mistakes on subsequent projects. What then is the best way to disseminate knowledge regarding problematic projects and their technical solutions?



Olivier  
Vian

**GN** The problem is to make people pick up information and learn what has happened. The facts are there; slightly distorted maybe, but there. So, the problem is knowledge transfer, not knowledge creation.

**MK** Do you think that's a role that ITA or national tunnelling organisations should be taking on – being that bridge?

**DC** I don't think it's often that consultants, contractors and suppliers don't want their problems highlighted. In my experience it's more often the owners and the end-clients that prevent it. I can

remember writing papers many times and having them blocked because the owner didn't want dissemination at a tunnelling conference; it's never been ourselves as consultants that haven't wanted publication. And I don't recall ever having that problem with contractors or TBM suppliers. But, the solution is obviously total openness and honesty. That's the only way. Put it out there, put it in papers and get it published.

**MK** Certainly, RETC conferences are a great forum for airing problems where there's an honest endeavour by all practitioners in the industry to talk about things, but I very seldom see clients at these events.

**BF** I have to disagree a little bit with Gunnar on one thing. We have been involved with several jobs that have not gone so well. Typically, what happens is that the contractor and owner are embroiled in an issue that could go to litigation. As soon as lawyers are involved, they have a duty to review everything in print, so all the hard-fought, expensive, aggravating lessons from a tough job are rarely recorded. So, we have to go by word of mouth, but it's not a recorded piece of data. A very significant job in the US was a great tunnelling job, but it became mired in lawsuits. As a result, there was next to nothing about it published and yet it achieved great strides in our tunnelling industry. But litigation prevailed.

**GR** The process is very difficult. Everybody involved in the process can talk, but, for example, from a contractor's point of view, you can't go to a publisher and say you have problems and have made big losses on a project. When the stock market finds out, you could be in trouble.

**MH** Any experiences, whether positive or negative, can only be made transparent by the clients themselves.

**MK** I would like to end with one point. A few weeks ago, I was reading through a paper written by a city engineer who said wouldn't it be a good idea, with all the works that are going on in the city, that somehow we use the underground space in a more planned, sustainable way and considered it at the beginning of projects? Do you know when that paper was written? It was written by the city engineer of New York in 1923.

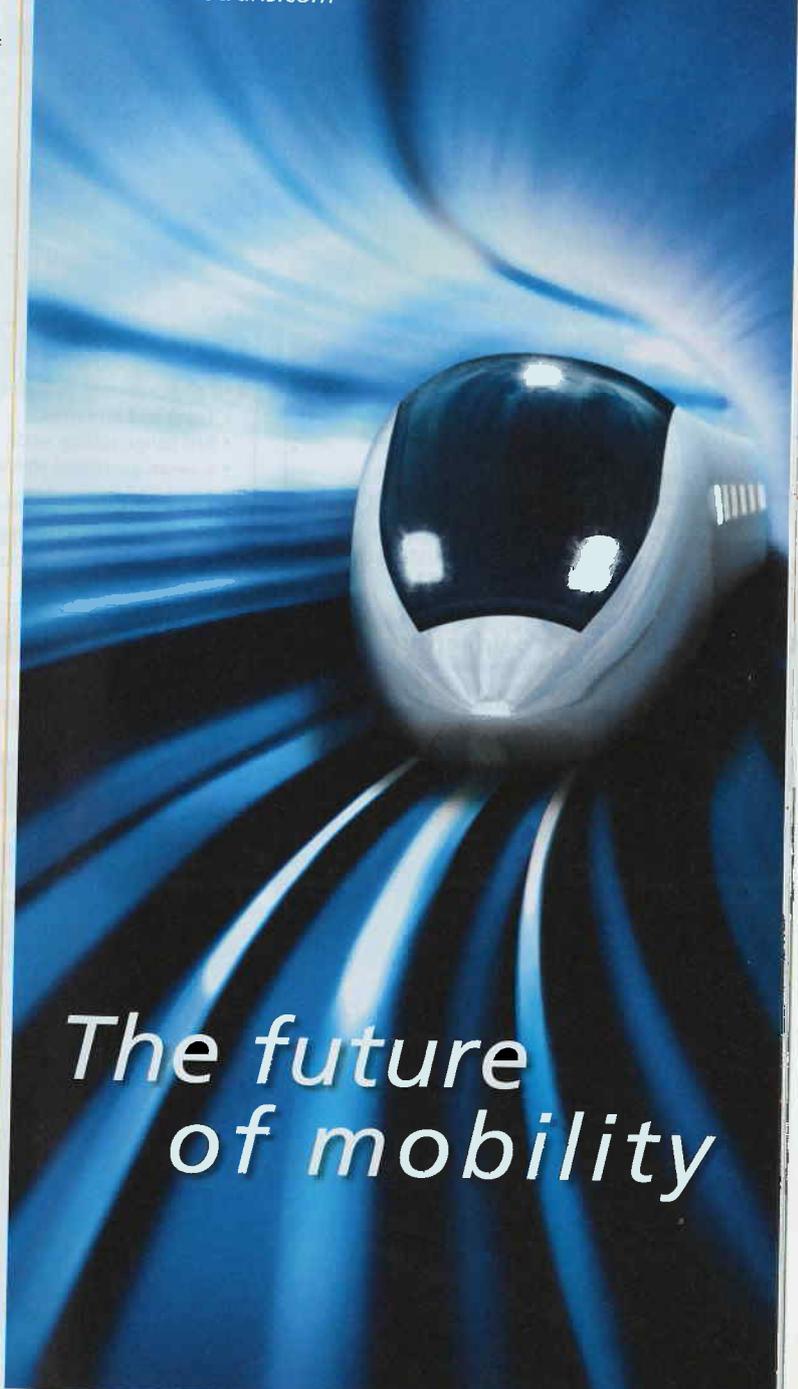


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