The Dutch Approach looking for a new tunnel concept; the “Totally Other Tunnel (TOT)”.  

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ABSTRACT: The Netherlands is a small country with limited space for further urban development. Further the number of inhabitants is still growing which means a further need for houses, roads and additional workspace. The combination of the above means a densification in the build up areas. Conventional solutions may take too much space; new alternatives including Underground Construction are necessary. Conventional Underground Construction is an option but expensive. Therefore innovation is sought, for new construction methods, cost reduction and reduction of risks. One of the challenges TOT is the quest for a shallow tunnel in the Holocene soil layers. Whether this is feasible will be the result of the project. The methodology applied is the organisation of Creative Workshops. A positive setting is created where one is asked not to criticize ideas, but to come up with solutions that would make unconventional ideas work. In this way creativity is triggered in its utmost way. Characteristic patterns are broken through, leading to out-of the box solutions. Based on the results conceptual ideas research are formulated. The First round of TOT will be finished halfway 2008. Planning is going on to organize a second round.  

1 INTRODUCTION  

Due to the increasing pressure on the available space in the Dutch Delta, the use of the underground for underground facilities both for utilitarian purposes as well as for line infrastructure, i.e. (rail)-roads is more and more taken in consideration. Underground Construction is an attractive solution for spacing problems that may solve problems related to air-pollution and noise. Since a number of decades the application of immersed tunnels, excavations build in situ and since last decade bored tunnelling techniques have been applied for the Construction of underground facilities and tunnels in the Netherlands. Related to the latter, with support of the Dutch Government in 1996 the Centre for Underground Construction, COB, was established. The research and development related to the projects initiated by the COB has helped to establish a forward position with respect to the knowledge on underground construction in soft ground.  

The experiences gained in the application of the different types of Underground Construction techniques have produced the situation that these techniques are becoming more and more standard. The reverse side of this is that innovation is slowing down. The investments related to the “conventional” types of solutions are still high, and these costs need to compete with other societal spending. This situation might even slow down on decision making for new infrastructure. Densification of the urban areas however does not halt, and construction time may be long, therefore new techniques and construction methods are sought to offer solutions situation.  

With the introduction of “Totally other Tunnels”, abbreviated as TOT, it is meant to create a breakthrough in this position triggering the articulation of new feasible Underground Structures and the necessary new Underground Construction techniques. The method applied for this is the application of Creative Workshops, where engineers from the field of Underground construction are brought together with People engaged in the use of these facilities and are challenged to come up with new creative ideas on Underground facilities. By creating a situation free of obligation and responsibilities, the participants are invited to come up with their ideas on underground construction, in a positive setting. The participants are asked to respond on the ideas of others in a positive sense: “What would be necessary to make this idea work”, what techniques would be needed to construct the structures that are proposed. By organizing workshops in this way creativity is triggered in its utmost way. Characteristic patterns in design processes are broken through, which leads to lateral thinking, leading to out-of the box solutions. Based on the conceptual ideas from the workshops research topics are formulated.
The First round of TOT tunnels will be finished halfway 2008. Considering the enthusiastic way that people participated in the process, it is likely that a second round of TOT workshops will be organised. Up to now TOT has given us:

- Revolving ideas for the continuation of TOT
- 12 conceptual ideas for other Underground Construction methods or use
- 5 directions for further research that may support other Tunnel design initiatives and Other Tunnel construction methods
- A network of colleagues in underground Construction that is interested in the quest for other tunnelling solutions.

2 DEVELOPMENT TECHNIQUES

In order to create some distance to the ‘normal’ process that is undertaken for an infrastructure project, some attention will be given to the methodology that is normally applied to come up with a feasible solution for an infrastructure initiative. To process normally is started by whomever states that there is a problem that needs to be solved and asks for a solution. After that the initiative is taken and taken over by a party with authority, solutions are sought for feasible solutions. Solutions that are subsequently evaluated and optimised. In the process decisions are taken on alternative steps in the further development and optimisation of the design of the object, and on the continuation of the process.

The innovation that we are looking for Underground construction may also be seen in the light of such a process. Only the question that is posed and the solutions that are sought are not aimed for a specific solution for a certain location, but the undertaking is aimed to find new solutions in general, that would fit for a certain class of problems.

In analogy to a design process, the development of innovative ideas may have the following steps:

- a process (developing in time)
- requiring skill (for the creation of alternatives)
- optimisation (of a future object)

In the next paragraphs the aspects recognised above will be discussed in more detail

2.1 Innovation as a process

It is customary for modern time design processes to follow a number of logical steps that finally after passing a number of evaluations come up with a feasible solution for the problem that was stated. It is not unlikely that the manager for such a process has taken Iso 9001 as a process. The only thing that must be realized is that it’s not a sequential process but quite often a circular process. Sometimes apparently coming back to a former position, but in reality making progress in minimizing the uncertainties with respect to the feasible solution, see Fig. 1.

2.2 Designing as a skill

The development of creativity, i.e. the ability to produce alternatives that meet requirements, is one of the main objectives of a civil engineering education. The skill to find alternatives that fulfil and satisfy the required functions, based on analysis of the structure’s functions and knowledge of subsystems and components.
The actions that might be recognised as being executed in this process, in a successive way are:

* The collection of information
* Analysis of the structures functions
* distinguishing subsystems in the structural functioning
* database solutions of subsystems of structural functions
* brainstorming (optional)
* deductive power,
* composing of alternatives
* checking the integrity of an alternative
* ranking alternatives
* choosing the favourable alternative

2.3 Development of alternatives

After alternative solutions have been put to the tests the alternatives are classified with respect to their fitness for purpose and cost and a choice is made; for a certain level of abstraction. After that, quite often the process is repeated, and boundary conditions and details of the proposed solution are worked out in more detail. Sometimes a hindrance is found and a step back needs to be taken, a feasible solution seems not to be possible in hindsight, and the process continues again with a reduced set of alternatives.

2.4 Designing as an optimisation exercise

The last aspect of the design process is the development of knowledge; i.e. relevant information. Among others, De Ridder, (1994) makes a reference to the fact that there is a parallel between the development of a design, and the methodology of scientific development. With respect to this he quotes Popper (1959), who states that:

Tentative Solutions; TS, are being generated based on available knowledge. Depending on the friction between the ability to full-fill the demands on the tentative solution, TS will be taken in consideration or rejected (in terms of Popper falsified).

In case of the design for a civil engineering object, it is common practice to express the relevant issues in financial terms to obtain an objective measure for the effort of creating the object and of the value being created by it.

For a new challenge, e.g. the first immersed tunnel to be constructed, the first bored tunnel in soft ground; for conditions were there is insufficient experience the development of feasible solutions can be an effort in itself. geometric solutions need to be developed that satisfy the functional and structural criteria. All kinds of foreseen or unforeseen boundary conditions need to be evaluated. Model tests may be necessary and numerical and other types of analysis will be used to check the solution in order to be sure that no critical situation is overlooked.

For situations where there is experience quite often a short-cut will be made to choose for a solution that has been constructed before, that has proven its applicability; solutions from the book. Only if these do not work or if during execution, the construction comes to a halt due to unforeseen conditions, one gets to get together and tries to find a new solution that may help taking away the
barrier for further construction. Creativity is often triggered by necessity. In this way on the longer run new solutions are coming forward. This way of development is a relatively slow path that can be followed, avoiding unnecessary risk to innovate engineering practice.

From past experience in other fields however, there is a notion that there must be other solutions to solve engineering solutions in practice; Experience learns that over time innovation progresses on a moderate speed. The question is what we can do to speed up the innovation process. Not having to wait for decades before new innovations are found on the slow path that was described here. One of the solutions sometimes used is to give special attention to creative workshops in the process.

3 CREATIVE WORKSHOPS; THE DEVELOPMENT OF CONCEPTUAL IDEAS

By creating a situation free of obligation and responsibilities participants are invited to come up with unconventional ideas. Others may only respond in a positive setting, e.g. asking, “What would make this idea work”. In this way creativity is triggered in its utmost way. Characteristic patterns are broken, leading to out-of the box solutions.

As one of the steps in the TOT project, mid 2007, a number of these creative workshops where undertaken, where COB participants where invited to attend a meeting. As a first catalyst the problem of construction of shallow tunnels in the soft Holocene upper layers of the Netherland was put forward. Participants where asked to come up freely with ideas for the construction of tunnel or underground space, for different use and different combination that might solve existing construction problems or that might solve existing societal problems.

Based on these workshops, various ideas have been selected and combined, in order to come up with conceptual ideas on a higher level of abstraction. In total about 11 conceptual ideas have been found, that will be discussed in the next section.

3.1 Conceptual Ideas

Combi-tunnel
A hybrid system of directional drilling and micro tunnelling. First a pilot tunnel is constructed with conventional directional drilling techniques. After that a larger tunnel is constructed using a micro tunnel that is pulled by the tube that was put in by directional drilling techniques. The spoil of the tunnel excavation is transported through the pulling tube. Behind the micro tunnel the tunnel is stabilized by the construction of a lining, possibly of a reinforced polymer type. For this type of structure it is necessary to develop the new in situ build lining structure. Further there is a necessity to look into the Ultimate limit states of a “polymer” tunnel, especially with respect to fire loading.

Tunnel around Tunnel
This idea is about a tunnel within another tunnel, where the inner tunnel contains the functions for traffic and transport and the space around this structure is for cables, discharges, ducts, electricity, gas etc. The conduits are underground in this concept, but not under “unfriendly” conditions. The systems are dry and inspection and maintenance is relatively straightforward. The advantage of this system is combination of functions, which gives a reduction in the space it would take for concurrent solutions. With respects to the conduits, cables and ducts the advantage is that the necessity to dig is only once, with installation.

Connected city
A network of multifunctional branched tunnels, mainly within the urbanized area. Including alternative routes to create a redundant system of tubes with various connections to other functional objects within the city. The system may include various functional systems, such as freight within the city, travel facilities for citizens, such as metro, tram and moving sidewalk. The system may be located between the piled foundations of buildings above it. The profits to the city of such a multifunctional system of connected tunnels overrides the investment costs even thought the investment might be considerable.

Eco-route tunnel
The tubing of this tunnel is located on a relatively high level. This may even imply that the tunnel is close to the soil surface or may even cut through the Greenfield surface. Due to the absence of a high overburden the structure is relatively light and the outer surface may include solar cells to produce electricity. There may be systems to capture Particulate matter PM$_{10}$ and Carbon Dioxide, CO$_2$. Heating from the system may be used to feed the heating systems for nearby houses. The roof of the tunnel will prevent that noise is transferred to the open air. A glass roof may reduce the psychological feeling of a barrier to the landscape.

An “Auger” shaped tunnel entrance
Within the “Connected city”, a method to create entrances to the underground city by vertical auger shaped entranced. Entrances to underground tunnels, utility spaces such as car parks and shopping malls, warehouses etc. The advantage of the auger is the relatively limited space that is needed for the entrance in top view. For different types of entrance one may vary with diameter and depth of the auger.

Tunnel “bolognaise”
The start for this tunnel to be is created by improving the existing soil with different soil improvement techniques such as, injection, freezing, smartsoils®. Within the contours of the tunnel to be, the improved soil is injected with a chemical paste that dissolves the soil and transforms the soil into a constituency that makes it easy to excavate and transport. The excavated material is further transported out of the system, and an architectural finishing of the surfaces may be put in place.

The advantages of the method would be various such as a reduction in spoil and the absence to open up the green field, at large.

Capsule city
Within this concept the travelling equipment for a person would be a capsule, for one or more people. The capsule is programmed and may hook itself onto a moving transport system, e.g. a cable. The capsules may be individualized, and may include audio and video, and may even include a workspace. The capsules may either be for traffic and or transport of small cargo. Besides the system for personalized travel the system may include tubes for transport of small packages. Conduits and cables are positioned within the tubes, and some of the tubes may be equipped to function as storage and transfer for water, for special occasions.

Baked tunnel
This tunnel is close to the soil surface. The soil is petrified using laser type devices. The petrified arch gives shape to a tunnel trench that can be covered with a plate

Polystyrene tunnel
At the position of the tunnel to be polystyrene is put into the soil. With the placing of the polystyrene water is repulsed from the area which creates a dry space to construct a tunnel.

Underground Street
By the Construction of underground streets barriers in urban areas can be removed. With this method space is created in the otherwise “expensive” inner cities.

Multistage Repulsion™
This construction method in soft soil repulses the soil. Due to the compression there is no need for further removal of otherwise excavated soil. Due the compaction there is a rather high densification of the soil. Research is needed to further look into the effects of the repulsion and compression in the area.

Free underground architecture
Imagine that the underground would include a similar underground street system as above ground, including crossings, rotundas, parking garages etc., creating a free underground architecture. By variation and coalescence of the above ground and the underground space a more human friendly living environment would develop. Glass arches above the underground rotundas would give entrance to natural light entrance. This concept would be powerful if it could make use of materials at hand at the location.

3.2 Evaluation of the conceptual ideas
Evaluated on individual basis, most of these ideas seem to be Science Fiction. Some of the conceptual ideas seen from a present day technological view seem impossible or seem to show too many flaws or white spots with respect to present day engineering possibilities, to even start a preliminary study for a pre-design. The apparent flaws, the white spots, will give rise to a high risk profile that will not leave much space to create a cost effective proposal that balances with the functions created. On a number of fields of technological research some major steps need to be made before one can decide to take the further step of starting a design process for one of these futuristic
structures. Evaluation of the characteristics however lead to the recognition of a number of interesting fields for further technological research that are presented here in a matrix that shows the relation with the conceptual ideas, see Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Conceptual Ideas</th>
<th>Freight/good</th>
<th>Tunnel around tunnel</th>
<th>Connected city</th>
<th>Auger Entrance</th>
<th>Tunnel Boring Machine</th>
<th>Capsulated city</th>
<th>Baked Soil Tunnel</th>
<th>Polyurethane tunnel</th>
<th>Underground structure</th>
<th>Multi-stage Repulsion</th>
<th>Favel Underground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Repulsion</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Soil Improvement</td>
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<td>X</td>
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<tr>
<td>Lining</td>
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<tr>
<td>(Multi)functionality</td>
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<tr>
<td>Sustainability/Durability</td>
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#### 3.3 Research topics

The items for further technology development are derived from the Conceptual ideas in a sort of heuristic process; there is no straight forward derivation of the technology topic. However, one can recognize that if some scientific progress is made on the technology topics, the conceptual ideas will become more feasible.

The topics are clustered on a quite abstract level according to:

- Soil repulsion
- Soil Improvement
- Lining
- Multi-functionality
- Sustainability; Durability

In the next section these fields for technologic research will be discussed in more details, and some explicit research items will be derived from that.

**Soil Repulsion**

The Netherlands underground can be characterized as a very soft ground, i.e. the top 16 meters of the underground is very soft and weak. The question arises if one can change the disadvantage that soft soil normally means into an advantage, e.g. would it be possible to create tunnels just by repulsion of the soil; pushing away the soil in front of the tunnel. One might look at this approach in a similar way that driven piles repulse the soil during installation. It is realized here that this method has limitations with respect to diameter, and depth. A too large diameter would give too much interference with the upper soils, possible lifting the cables and conduits that might be positioned in the layers above. A question related to repulsion is what would be the most favourable method to push the soil away?

To begin with one could make an inventory of the different geological strata that can be found in the Netherlands. The geologic mapping that is done by the government already might help in this respect. The differentiation of the characteristics possibly could give direction to further research.

Related to the repulsion, the surrounded soil is loaded and compressed. The amount of local compression and dewatering will determine the side-effects of repulsion to the surroundings, especially in urban areas.

If all the effects related to compression and dewatering are known, one can look for solution in order to control these effects.

**Soil improvement/Treatment**

For soft soil conditions, the low strength and weight of the soil is a hindrance to the construction of tunnels. To overcome this situation one may consider treating the soil, to improve the soil characteristics. Among other things the SmartSoils® project by Deltares is aiming at the development of techniques in this field, see Veenbergen (2005)
An inventory of the present techniques in this field, such as grouting, soil mixing and freezing, and a description of the state of the art of the application of these techniques may contribute to the further application of these techniques and the further development. Further one might look into the possibility to develop new techniques, e.g. applying bio-chemical substances, or polymers.

With respect to the present situation for the SmartSoils® project of Deltares, a further step to application might be taken. With respect to the need for techniques to block groundwater flow into excavations a further chance might be there for the application of bio-sealing techniques. The purpose for the ground improvement is to improve the conditions for excavations. The present techniques for tunnelling are to apply TBM's and lining, that stabilize the excavation and create a soil retaining structure and water sealing. If other methods can be found to create stiffness and strength and reduce the percolation of groundwater for the excavation, open excavation techniques from rock tunnelling might suffice to create the underground openings.

Behind the research for soil improvement, research into the reversibility of the processes applied would be needed. Like freezing techniques that create stiffness and strength, and thawing that reverses the process, more or less.

**Lining**

As mentioned before tunnel lining is meant to create a soil retaining and groundwater retaining function, further it creates the foundation for any road or railroad that is constructed in the tunnel. In general the tunnel lining, (for a TBM type constructed tunnel), is build of steel or reinforced concrete tunnel rings. Each ring being created by the assembly of a number of arched tunnel-lining segments that fit together with a key-stone. In this line of research the aim is to look for the application of other types of material or types of construction, e.g. the application of reinforced polymers? The application of different types of materials may also lead to different type's construction techniques.

A different issue to be solved for the lining is buoyancy. As the groundwater head is mainly hydrostatic, gradients in groundwater head are also determined by a static head, and consequently tunnels may be susceptible to buoyancy forces may cause the tunnel to float and move upwards in the soft soil deposits, up to the point that equilibrium is found with the overburden. If the tunnel is very shallow, in soft soil, shear forces may develop that may balance the buoyancy forces and create an equilibrium state of stress. The deformation that may be related to this process are considered the unfavourable, therefore the critical situation for the evaluation of acceptable depth of the tunnel mainly relies on the effective soil weight and not on shear forces. A topic for further research might be to look for other techniques to create the vertical equilibrium, e.g. putting in anchor or things like that.

**Multifunctionality**

In the discussion on Underground Space, Multifunctionality is an ever returning topic, e.g. the combination of different underground cables and tubes in “one” multifunctional tunnels is one of the solutions being discussed by the COB platform on Cables and Ducts. The expectation however is that there more that only this example, where the combination of functions will lead to profitable investment opportunities for the Underground. The discussion on climate change for instance and the increase in rainfall may lead to a demand for storage and/or transfer of water. Existing tunnels, if suitably equipped and build for this multifunctional use may be an option to use the tunnel temporary as an underground river in certain periods, such as for the Kanda river in Tokyo, see Hashimoto (1999).

Whatever combinations are evaluated, the risks that inevitably may be involved in combining functions need to be evaluated. Risks need to be controlled and minimised.

**Sustainability**

Sustainability is an issue that is high ranked on the political agenda. Underground construction may contribute to the development of a sustainable society. One of the potential ideas is to combine road infrastructure with horticulture in order to reduce the production of Carbon dioxide, and other nutrients. Another issue to look into in this respect is energy.

There may be several options to extract energy from a tunnel, e.g. by using the driving force created by temperature differences inside and outside a tunnel. Apart from the retrieval of energy from the higher temperatures that develop in road tunnels due to the traffic, the combination of geothermal energy with foundation elements such as tension piles or anchors may also be looked into. With respect to sustainability the research into the feasibility of covered roads and underground greenhouses needs to be mentioned.
Apart from these research topics one needs to look into sustainability as a process. What actions need to be undertaken in order that tunnels and other underground infrastructure are continually renewed on the longer term.

3.4 Network

Apart from the conceptual ideas and the research list, the project “Totally Other Tunnels”, has gained us a network of interested parties. For the main part these parties come from the participant network of the Centre for Underground Construction. The core of the network is formed by the participants of the September 2007 workshops and in the meantime is extended with some other interested people. The network has developed after successful presentations, e.g. on the “Day of Maarssen”; November 1, 2007 and the “Week of Underground Construction”; Amsterdam January 28, 2008.

Within the network a sounding board group is active in the further discussion how to proceed with TOT.

4 FURTHER ACTION WITH “TOT”

The continuation of TNO will both aim at solving some of the research question that have been distinguished and to mirror some of the conceptual ideas with practical applications, see Figure .... The combination of finding a practical situation with a problem owner is considered a requisite for the further development and application of the ideas of TOT. As with the process that was undertaken in the starting phase of TOT, one of the challenges for a step forward is to bring parties together.

With the organisation of a Community of Practice of all parties involved or interested, TOT will be given continuity. The organisation of this community of Practice may be lead by the former Delft Cluster Institutes, such as Deltares and TNO Build environment and Geosciences.

It is the expectation that as an off-spring of the COP, smaller groups will be formed that focus in on one or more of the topics that came forward of the first round of TOT. Besides the meetings of these groups the Sounding Board Group of TOT will meet on a regular base, two or three times a year.

4.1 Feasible topics for TOT from Engineering Practice

For the continuation of TOT we have looked for issues from Engineering Practice, that may be solved either by using one of the conceptual ideas that come forward in the first round of TOT, or in the situation that the methodology of TOT, i.e. creative workshops may be advantages to come up with out of the box solutions.

An inventory of potential issues to be research with TOT is:

- Underground railway crossings: In the near future a large number of railway crossings in the Netherlands, that at present are on level ground, needs to be reconstructed into underpass crossings. Preferably these new underpasses need to be cost effective and with minor hindrance to the rail schedule. The number of underpasses involved qualifies the project for further innovation.
- Underground parking in urban areas. Parking of cars is a hot topic in most of the inner cities in the Netherlands. The cars take space, and cars moving around looking for a parking space are a hindrance for other urban activities. Underground solutions for car parking are a challenge.
- Underground rail in urban areas: An increasing number of cities, mainly in the Randstad, the western part of the Netherlands are evaluating underground solutions for rail transport in there...
territory as a solution to reduce noise and pollution, and to remove the barrier that may nearly split a town in separate parts.

- Inspection, maintenance and reconstruction of tunnels; The increasing number of tunnels, especially bored tunnels lately, in combination with the development of modern types of monitoring techniques such as inspection robots, laser scanning etc. makes maintenance a challenge to look at with an unconventional eye.

ProRail, the Dutch agent for exploitation of the Dutch rail network has indicated to be interested in some of the ideas coming from TOT and also in the methodology that TOT may offer for the development of innovative solutions for the underpass of railroads. With respect to the other two issues that are related to underground solution in urban areas, we are discussing the possibility for projects with several Dutch communities. Further a workshop on innovative techniques for Inspection and Maintenance is foreseen in the autumn of 2008.

5 CONCLUDING REMARKS
The process used here to come to innovation creates a lot of energy and enthusiasm of the participants. Using this approach delivered several new perspectives for research and creates opportunities for the future to develop and implement new concepts for building tunnels.

Creativity is a tool to stimulate the participants to discover new opportunities by letting the existing go. The short time used for the first sessions is a first step to discover new methods and new ways of using tunnels.

One of the things learned from TOT is that if one postpones the time before fantasy and reality are confronted, and first asks, “What is necessary to make this idea work”, may lead to valuable insights and a perspective for further research.

For sure the process used for TOT is successful for questions that need a different solution than the existing ones. The deliverables of TOT are in a premium stage but will be used to find a solution for specific cases. U further step, to trigger innovation, will be to look for options to couple the ideas from TOT with the design process for practical problems. This means that probably parts of the ideas can be used for further development, or the new perspective in ideas will lead to new solutions.

6 REFERENCES
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Jan Jonker graduated in Civil Engineering from the Institute of Technology in Zwolle. After that he worked at the Engineering Department of the Dutch Railways in several functions related to the realisation of the Viaduct and tunnelling projects for the Railways. Since 1990 this section of Dutch Railways is privatised and continues to work as Movares, in the fields of mobility, infrastructure, spatial planning, transport systems and also water and energy. He worked as Strategic Consultant and is specialist in the field of underground constructions. He is Chairman of the Department Tunnelling Engineering and Subterranean Works of the Royal Institute of Engineers in the Netherlands.

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CERTIFICATE

The author(s) certify that the paper titled “The Dutch Approach looking for a new tunnel concept; the “Totally Other Tunnel (TOT)” and submitted for consideration for WTC 2008 on “The international Conference On Tunneling,” to be held from 22-24 September 2008 at Agra in India is original and has not been published or presented at any other forum.