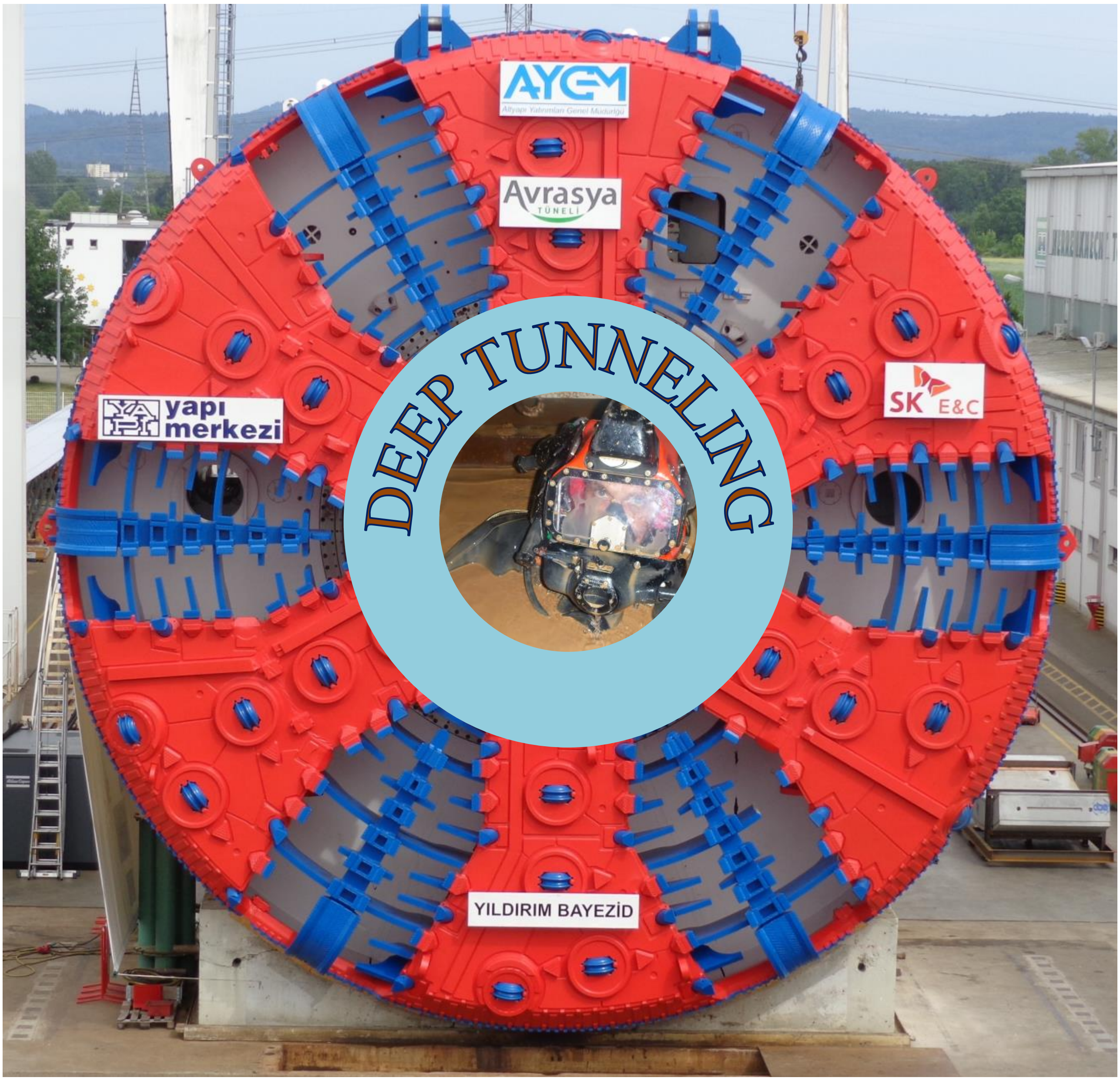
NORDSEETAUCHER GmbH

(N-Sea-Divers)

Hyperbaric Tunnel Construction and Diving®

and



Part I   Projects

Work under Hyperbaric Conditions

Diving and Compressed Air Work

on

Tunnel-Boring-Machines

TBM's

www.nordseetaucher.eu

With the current edition

„Hyperbaric Tunnel Construction and Diving®“

the NORDSEETAUCHER GmbH (N-SEA-DIVER) would like to thank our client, customers and suppliers for the shown confidence quite cordially.

For a pleasant, interesting and successful cooperation we are available also in the future.

And of course we assure you a professional and qualified execution of our work furthermore, too.

Hamburg / Ammersbek in August 2015

The NST Team

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
E-mail: info@nordseetaucher.de; Internet: www.nordseetaucher.de

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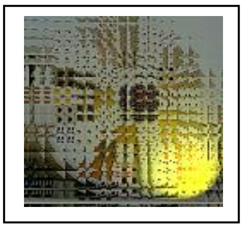
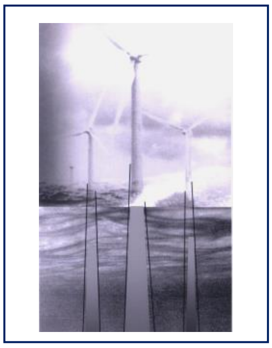


Int. Diving Contractor

OffshoreWind Inwater Service®

Hyperbaric Tunnel Construction and Diving®



Bramkampweg 9
22949 Ammersbek
Germany

Tel.: +49 4102 23180
Fax: + 49 4102 231820
Mobile: +49 172 4300598

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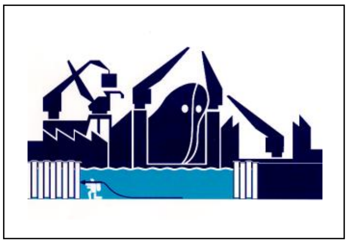
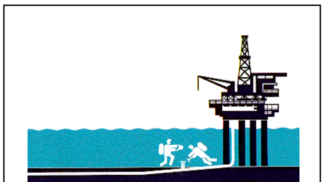
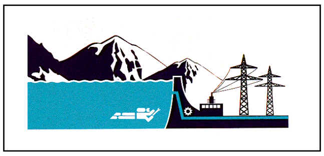


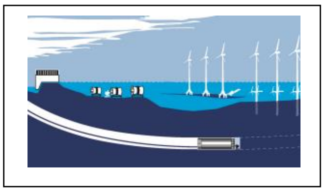
Inshore / Inland



Offshore Oil and Gas



Water Power Plants and Reservoirs



Renewable Energies
Hyperbaric Tunnel Constructions

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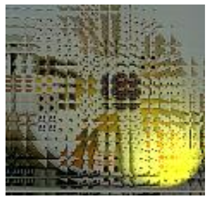

Arbeiten in Überdruck
Taucher- und Druckluftarbeiten im maschinellen Tunnelvortrieb

Ab einer Tiefe von 40 Metern (4,0bar Überdruck) kommt der Druckluftarbeiter in Bereiche wo es von der Zeit her nicht mehr interessant ist Druckluftarbeiten auf herkömmliche Art auszuführen. Da aber die nächste Generation von Tunnelprojekten immer länger und immer tiefer gebaut wird war es nur eine Frage der Zeit und Gelegenheit den Einsatz von Tauchern für die Arbeiten in Überdruck mit einzubeziehen.

Work under Hyperbaric Conditions
Diving and Compressed Air Work in Tunnel-Boring-Machines

Below a depth of 40 metres (which equals 4.0bar over pressure) workers enter a zone where it is no longer effective to carry out compressed air work under conventional conditions. However, because the next generation of tunnels will be longer and deeper than anything we have at present, it can only be a matter of time and opportunity before divers start playing a key role in hyperbaric work.

Trabajos en ambientes hiperbáricos
Trabajos de buceo bajo aire comprimido para la construcción mecánica de túneles

Por debajo de una profundidad de 40 metros (equivalente a una sobrepresión de 4,0 bar) los buzos entran en una zona donde ya no resulta efectivo llevar a cabo trabajos en ambientes hiperbáricos bajo las condiciones tradicionales. Dado que la próxima generación de túneles se proyectarán cada vez más largos y a mayor profundidad, era sólo cuestión de tiempo y ocasión el destinar buceadores a los trabajos hiperbáricos.

高压氧环境下作业
在隧道掘进机内进行潜水和压气作业

在 40 米水深下（相当于 4bar 的超压），按照常规进行压气作业已不再有效。但是今后的隧道的发展趋势是更深，更长，那么潜水员在压气作业中开始扮演重要角色就只是时间和机会的问题了。

Работы на глубине под давлением

Проведение строительных работ по прокладке тоннелей начиная с глубины 40 метров и при давлении 4,0 бар становится сложным. Это та граница, когда вести строительство тоннеля традиционным способом становится трудно. Однако, как показывает жизнь, большинство новых тоннелей будет прокладываться на все большей глубине и они будут еще длиннее. Это только дело времени, когда к этим работам будут привлекаться специалисты - водолазы.

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
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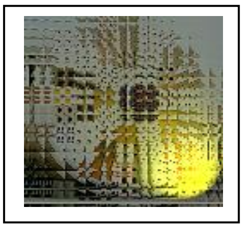
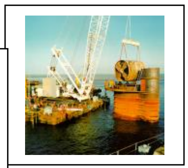
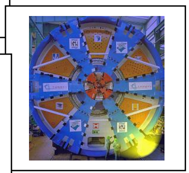
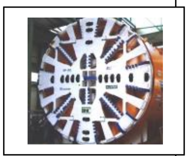
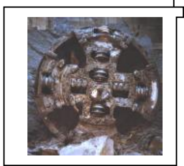


Reference List for Hyperbaric Work
Diving, Compressed Air, Mixed-Gas Maintenance and Repair Work on Tunnel-Boring-Machines (TBM's)



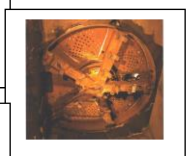
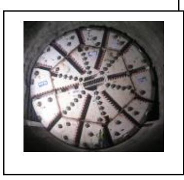










1994

	Europipe I and II, North Sea-Germany

1997

	Bewagtunnel, Berlin-Germany

1997 - 2000

S-108	**4th tube River Elbe Crossing, Hamburg-Germany**

1998 - 2002

S-137/38 Westerschelde Tunnel, Zeeland-The Netherlands

1999

M-498	**Mompas, San Sebastian-Spain**

2000

S-127	**Socatop, Paris-France**
M-532	**Crosswaytunnel-4th tube of River Elbe, Hamburg-Germany**
S-110	**Fernbahntunnel, Berlin-Germany**

2000 - 2001

S-152	**Wesertunnel, Nordenham-Germany**
S-149	**Airporttunnel, Zürich-Switzerland**
S-140	**Bahn 2000-Thalwil, Zürich-Switzerland**

2001

M-611	**Neva-Crossing, St. Petersburg-Russia**

2001 - 2002

S-164	**Lefortovo Tunnel, Moscow-Russia**
S-150	**Sophiaspoortunnel, Rotterdam-The Netherlands**
S-168	**Pannerdenschkanaal, Arnhem-The Netherlands**

2002

S-205	**Peristeri Metro, Athens-Greece**
M-518	**TENP Los 4/5, Lörrach-Germany**
S-170	**Deep Sewerage, Singapore**

2002 - 2003

S-192	**CTRL-Thames Tunnel, London-England**
S-175	**Oenzbergtunnel, Switzerland**
S-200	**Herrentunnel, Lübeck-Germany**

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
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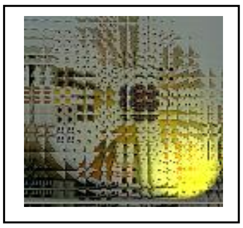

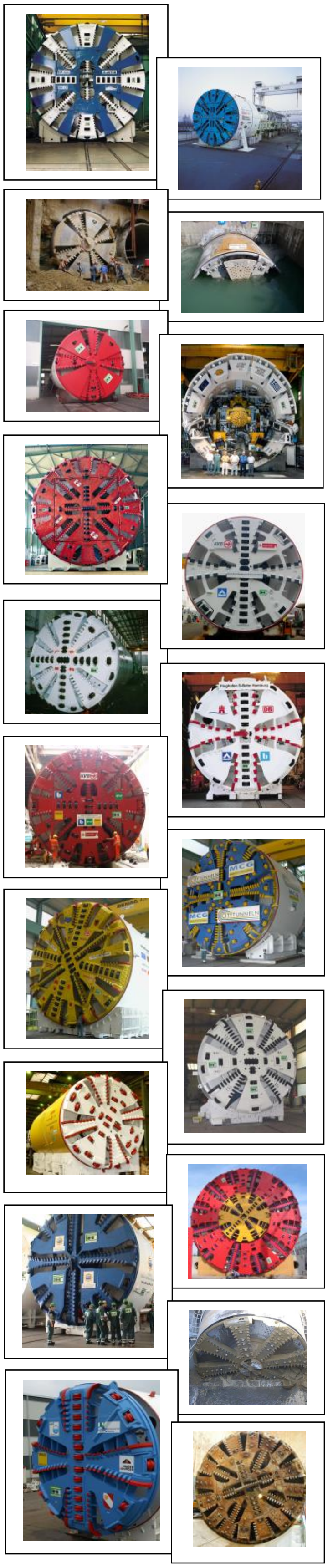

2003

S-209	**Aanlegspoortunnel, Antwerpen-Belgium**
S-185	**Heathrow Airport Tunnel, London-England**
S-187	**Metrotunnel, Caracas-Venezuela**

2003 - 2007

S-250	**Silberwald, Moscow-Russia**
S-290	**Silberwald, Moscow-Russia**

2004

S-127	**Socatop, Paris-France**
S-242	**Metro Line 3, Guangzhou-China**

2004 - 2005

S-252/53	**Smart Tunnel, Kuala Lumpur-Malaysia**
S-238	**Metro Line 1, Napoli-Italy**
M-929	**Kura West River Crossing, Azerbaijan**

2004 - 2006

S-255	**Metrotren, Gijon-Spain**

2004 - 2007

S-221	**Metro Line 9, Barcelona-Spain**

2005

M-000	**Medientunnel Leipzig-Germany**

2005 - 2006

S-258	**Flughafen S-Bahn Hamburg-Germany**
S-302	**Metro de Madrid-Spain**

2006

M-675	**La Malata, A Coruña-Spain**
S-327	**Harbour Tunnel, Durban-South Africa**
S-320	**Almatymetrohurylys, Alma Ata-Kasachstan**
M-614	**Chateau d'Olonne, France**
S-324	**Metrotunnel, Ankara-Turkey**
S-325	**Metrotunnel, Istanbul-Turkey**

2006 – 2007

S-331	**Fernwärmetunnel, Copenhagen-Denmark**
S-314	**Stadtbahn Köln Los Nord, Cologne-Germany**
S-321/22	**Stadtbahn Köln Los Süd, Cologne- Germany**
S-127	**Socatop, Paris-France**
S-328	**Metro Strogino, Moskau**

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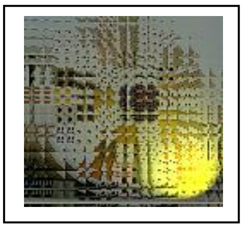


2006 -2008

- **S-260** Metrobus, Brescia-Italy
- **S-326** City Tunnel Leipzig-Germany
- **S-340/41** Citytunnel, Malmö-Sweden

2007

- **S-317/18** Traffic Tunnel Shanghai-China
- **M-971** Wuhan, China
- **M-1016** Santander, Spain
- **S-264/65** Katzenbergtunnel, Germany

2007 -2008

- **S-334** U-Bahn Linie 3, Munich-Germany
- **S-389** Thun, Switzerland
- **S-227/28** Metro Esfahan-Iran

2007-2009

- **S-352** H3-4 Münster / Wiesing-Austria
- **S-381** H8 Jenbach-Austria

2008

- **M-1198** Doha-Qatar, Persian Gulf
- **S-407** Water Tunnel Shanghai-China
- **M-518M** Pescanova Fishfarm, Mira-Portugal
- **S-358** Yellow River Tunnel, China

2008-2009

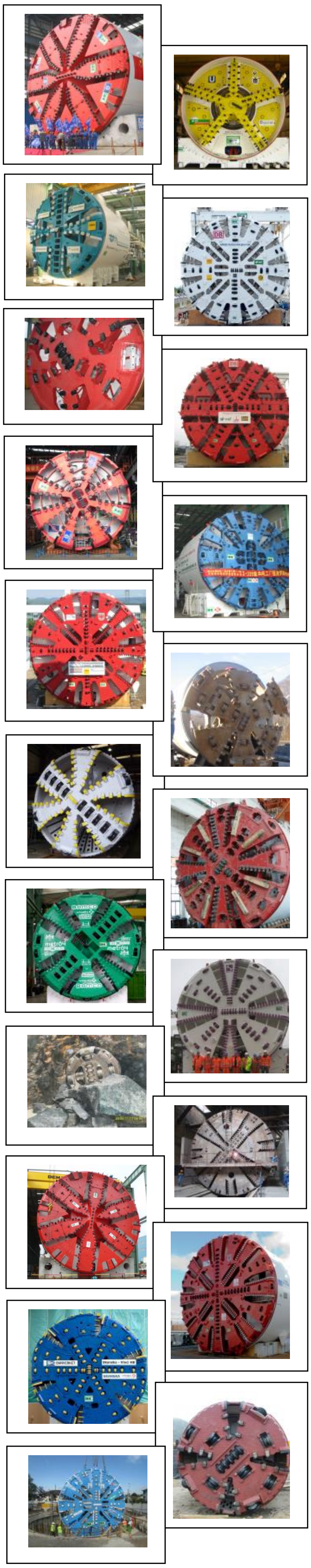
- **S-349/50** Nanjing Yangtze River Crossing-China
- **M-1193** RS1 H8 Jenbach-Austria
  RS2 H8 Jenbach-Austria
- **S-419/20** Finnetunnel, Erfurt-Germany
- **M-254M** Sammler Ost, Hamburg-Germany

2008-2010

- **S-440** U4 HafenCity, Hamburg-Germany

2009

- **S-307/08** Metro Tunnel Singapore
- **S-408** Water Tunnel Shanghai-China
  Emstunnel, Emden-Germany
- **NFM** Railway Tunnel Schlüchtern-Germany
  RS3 H8 Jenbach-Austria; RS4 H8 Jenbach-Austria
  RS5 H8 Jenbach-Austria; RS6 H8 Jenbach-Austria
  RS16 H8 Jenbach-Austria; RS18 H8 Jenbach-Austria
- **S-477** CREC Tunnel Foshan-China
- **S-464** Diabolo Tunnel Brussels-Belgium
- **S-354** Metro Line 4 Budapest-Hungary



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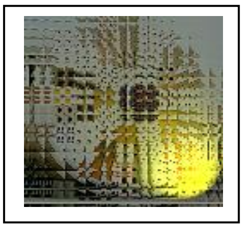


2009-2010

S-423 **Metro Line 3, Cairo-Egypt**
M-1061 **Sea Outfall, Salvador de Bahia-Brasil**
M-907M **Großrohrschirm Zürich-Schweiz**
S-221 **Ute Gorg, Barcelona-Spain**
S-444 **Ute Trinidad, Barcelona-Spain**

2009-2011

S-227 **Metro Esfahan-Iran**
S-228 **Metro Esfahan-Iran**

2010

S-246 **Hallandsås, Förslöv-Sweden**
S-532 **LocoBouw, Antwerpen-Belgium**
M-1317 **Sammlers Ost 2.BA, Hamburg-Germany**
M-0000 **Düker Brunsbüttel-Germany**
M-518M **Großrohrschirm Zürich-Switzerland**
S-362 **Ute Ave Girona, Girona-Spain**
M-1419 **Opal Peene Querung Anklam-Germany**
M-0000 **Maindüker Schweinfurt-Germany**
S-509 **Metro Tunnel Wuhan-China**
S-525 **Metro Tunnel Sofia-Bulgaria**

2010-2011

S-491 **Wehrhahn-Linie, Düsseldorf-Germany**
S-451 **Tunnel Weinberg, Zürich-Schweiz**
S-547 **Kaiser-Wilhelm-Tunnel, Cochem-Germany**
M-1186 **Sanitary Drainage Networks, Jeddah-Saudi Arabia**
S-452 **ATUBO Biel-Schweiz**
S-551 **Nuclear Tunnel Project Taishan-China**

2010-2012

S-544/45 **XFEL Tunnel, Hamburg-Germany**
NFM **Railway Tunnel, Beijing-China**

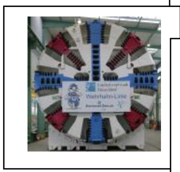
2011

S-546 **Metro B Lyon-France**
M-1455 **CFPP Kraftwerkstunnel W.-haven-Germany**
S-642 **Wisla River Crossing, Warsaw-Poland**
S-550 **Railway Tunnel Shenzhen-China**
S-554 **Metro B Rom-Italy**
M1096 **Zürich-Oerlikon-Schweiz**
S-618 **West Island Tunnel-Hong Kong**
S-502 **Lake Mead, Las Vegas-USA**

2011-2012

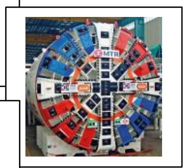
S-597/98 **Metro Hangzhou-China**



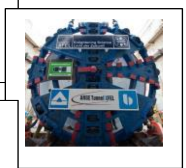




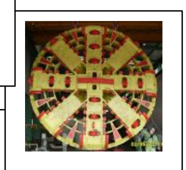








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2011-2014

S-630/31 Mei Lai Road to Hoi Ting Road Tunnel-Hong Kong

2011-2015

S-550 Railway Tunnel Shenzhen-China
CCCC Nanjing Weisan Tunnel-China

2012

S-644 Metro Warsaw-Poland
S-636 Metro Hangzhou-China

2012

S-668 Road Tunnel Nanjing-China
S-324 Metrotunnel, Ankara-Turkey
S-666 Traffic Tunnel Shanghai
M-663M Drainage Tunnel Catania-Sicilia

2012-2014

S-731 Crossrail Tunnel London-UK
S-683 Railway Tunnel Nanjing-China

2012-2015

S-623/24 Railway Tunnel Shenzhen-Hong Kong

2013

S-605 Metro Singapore
S-569 Changjiang Xi Road Tunnel Shanghai

2013-2014

M-1553 Corrib Pipeline Tunnel Ireland
Emscher Tunnel Germany
M-1186 Sanitary Drainage Networks, Jeddah-Saudi Arabia

2013-2015

S-762 Eurasia Tunnel Istanbul-Turkei
S-788 Metro Tunnel U5 Berlin-Germany

2014-2015

M-1439 Elbedüker Hetlingen-Germany
S-869 Metro Tunnel Karlsruhe-Germany
S-838 Hin Keng to Diamond Hill Tunnel-Hong Kong
S-865/68 Metro Red Line North Doha-Qatar

2015

M-1575 RheindükerCologne-Germany
M-907M Düker Kiesen-Schweiz
S-844/49 Green Line Underground Doha-Qatar













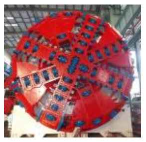

Breakthrough Bosporus Tunnel
S-762

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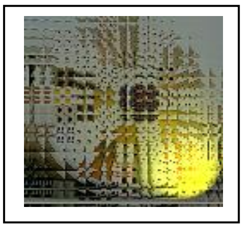
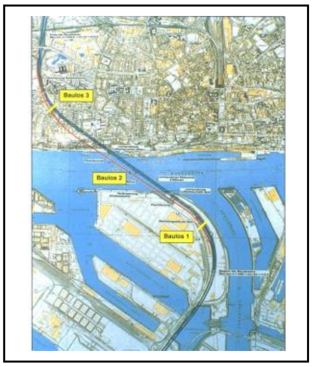


Work under Hyperbaric Conditions
Diving and Compressed Air Work in Tunnel-Boring-Machines

Below a depth of 40 metres (which equals 4.0bar over pressure) compressed air technicians enter a zone where it is no longer effective to carry out compressed air work under conventional conditions. However, because the next generation of tunnels will be longer and deeper than anything we have at present, it can only be a matter of time and opportunity before divers and compressed air technicians start playing a key role in hyperbaric work.

High groundwater head is a major challenge for tunneling in soft ground and weak rock. It has a strong impact on design and operation of Tunnel Boring Machines (TBMs) in order to prevent excessive groundwater inflow, to ensure face stability and to enable access to the cutterhead for maintenance, which can lead to an increase of the required construction period and budget. Designers should keep this in their mind when planning a tunnel alignment.

The 4th River Elbe Tunnel was a milestone in Slurry-TBM tunneling due to the large TBM diameter of 14.2 m, low cover of as small as 7 m and high groundwater pressure of up to 4.5bar.



The southern section of the 2.561 km long tunnel was excavated in glacial deposits consisting of sand, marl and boulders, while more cohesive ground such as marl and clay with sand lenses and boulders was present on the northern tunnel section.

Frequent interventions for cutterhead maintenance were necessary due to presence of abrasive soils. Severe wear was observed on excavation tools and on the backside of the cutterhead which had to plough through accumulated spoil at the bottom of the excavation chamber. Thus intensive and time consuming repair works (6 weeks) were required under compressed air.

At the deepest point of the river crossing, the crew had to enter the excavation chamber and work under compressed air up to 4.5bar.

In total 10,920 work hours were spent under regular compressed air at pressures up to 4.5bar by the engineers, diver and technicians during the 4th River Elbe Construction In total 2,738 man interventions were performed, 237 of them at pressures >3.6bar.

In total 21 cases of decompression illness were reported, all of them occurred at pressures < 3.6bar.

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
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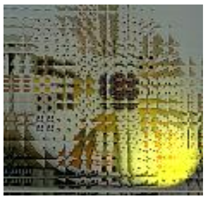
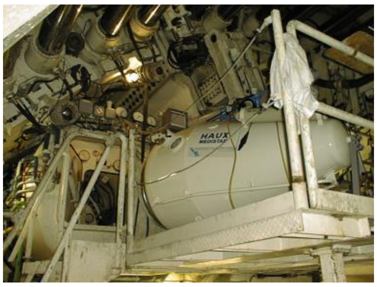
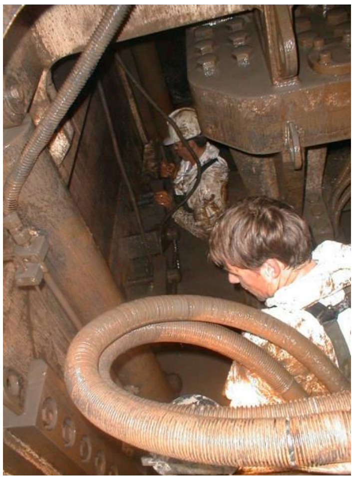




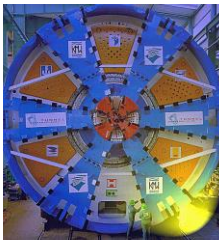
The 4th River Elbe tunnel was the first project where a rescue could be completed by connecting a NATO flange to the compressed air lock on the TBM to enable transport of injured personnel under compressed air pressure to a shuttle for pressurized transport the surface. Fortunately it was not necessary to use it.

The 1.640 km long twin tube **Wesertunnel** crosses the river Weser north of Bremen, Germany. A Slurry-TBM (∅ 11.71 m) was used to excavate the tunnel in glacial deposits. The glacial soil consists of poorly graded and partly very loose cohesion, less sand with hard granite boulders, and very soft to soft clay and peat in shallow areas. Below the river, plastic clays were found to have mainly stiff to hard consistency reaching shear strength values of weak rock.



The tunnel invert's deepest point was 40 m below sea level. Due to tidal influence of the North Sea the water level of the river was typically between +/-2 m above/below sea level and reached in maximum +5.2 m above sea level. Along the tunnel route, groundwater head encountered at tunnel invert was typically in a range of 2.5 to 4.0 bar and reached a maximum of 4.5 bar at storm tide.

Maintenance under compressed air was performed at up to 4.5 bar air pressure for works at the cutterhead and up to 5 bar for works at the stone crusher. Additionally divers were used to work within the bentonite slurry under pressure of up to 5 bar. Regular compressed air (no mixed gases) and oxygen decompression were successfully used. In total 5.000 h of compressed air works and a total of 1.400 man interventions were performed while 600 of them were under pressures exceeding 3.6 bar. Only 15 minor cases of decompression illness were reported, all of them under pressures less than 3.6bar.

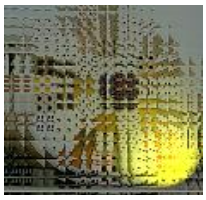


The 6.6 km long **Westerschelde Tunnel** is the first tunnel project where saturation diving technique was used for excavation chamber interventions. The twin tube tunnel was excavated by two Slurry-TBMs (Ø 11.33 m). Ground conditions consist of medium to fine quaternary sands within shallow sections and a massive formation of tertiary stiff clay on a length of approx. 2 km. Dense tertiary sands are found below the clay within the deepest tunnel section.

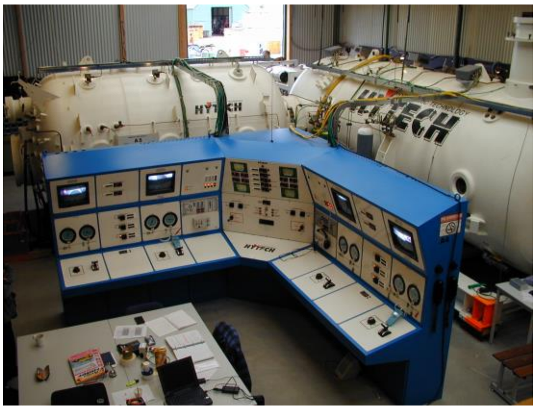
At the deepest point the tunnel invert is at a depth of 60 m below sea level. The water level was typically within a range of +/- 2.5 m above/below sea level and reached about +4.0 m in maximum. The tunnel cover was in a range of 28 m to 40 m.

NORDSEETAUCHER GmbH

Hyperbaric Tunnel Construction and Diving®



When Nordseetaucher GmbH was asked to cooperate on this project to build two tunnels under the Westerschelde in the Netherlands, we didn't hesitate a moment, knowing that it would be an ideal opportunity to put to use the skills and expertise we had gained during our 4th Tube of the River Elbe Crossing and the Wesertunnel, Germany contracts.



However, the problems we could expect to face were on a slightly different scale. In the 4th Tube of the River Elbe Tunnel we were working under pressures of up to 4.5 bar, while work in the Wesertunnel was carried out at 5.0 bar. The brief for the two tunnels of the Westerschelde Tunnel Project called for us to work at pressures of up to 8.5bar.

It is impossible to work at 8.5bar pressure with compressed air, because the nitrogen contained in breath causes narcosis. Accordingly, from the very start we planned to work using mixed gases.

For several decades, a number of methods and procedures have been tested and applied in international commercial offshore diving which can also be used in machine-driven tunnel construction projects carried out in hyperbaric pressure in excess of 5.0bar.

For instance, the use of mixed gas. These gases are a mixture of oxygen and various inert gases, blended according to the specific pressure spectrum to allow the divers to work for days and weeks under pressurised conditions (saturation method). At hyperbaric pressures of between 3.0 and 6.0 bar compressed air can be used as working gas with the saturation method, and may indeed be the method of preference in future. In order to use mixed gases safely and successfully, meticulous preparations to the tunnel boring machine and logistical processes are necessary.

Due to the relatively thin clearance above the tunnel it would have been dangerous to lower the bentonite level in the cutterhead chamber, the excavation chamber. Accordingly, specially trained diving personnel were on hand to carry out inspections and tool changes in the event of repair and maintenance work becoming necessary.

In total, 6 excursions in saturation were performed with a total saturation time of 40 days. The decompression time was 4 days each time. 10 inspection excursions with mixed gas were performed, in addition to 1.652 hours with compressed air involving 546 man interventions. 5 cases of decompression sickness occurred, all of which were successfully treated in the onsite treatment chamber.

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
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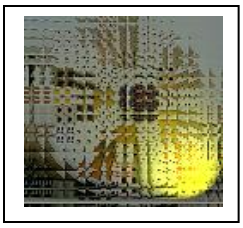


Diving in Bentonite

Preparation

To allow manned interventions to be carried out in the bentonite, special flanged connections were installed in the pressure walls of the tunnel boring machines. These lines supplied the divers with breathing air, reserve air, communication lines, lighting, video and data transmission, and water to flush the breathing regulators in the diving helmets. Those flange connections are also perfect for the new overpressure work helmet.

The Diving Helmet

Diving helmets normally used for offshore diving were specially modified to allow them to be used for diving in bentonite. To make it easier for the divers to breathe in the bentonite, which is a clay suspension, and to reduce breathing resistance, the helmets were fitted with a water flushing system for the air regulator. The constant supply of fresh water also prevents the breathing membranes from sticking together.

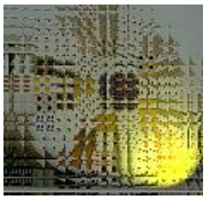
The Umbilical

As the name indicates, the umbilical is the diver’s lifeline. The umbilical consists of a variety of differently coloured tubes and cables, which pipe in air, reserve air and fresh water, and also contain communication lines, light, video and data transmission lines.

Diving and Compressed Air Work in Saturation Conditions

The Living Chamber

Saturation diving means living and working under hyperbaric conditions for long periods of time, i.e. anything up to 28 days, although the limits have never been fully tested. To enable divers and engineers to survive and work under these conditions requires a pressurised living chamber consisting of a number of rooms outside of the tunnel zone. Up to 9 divers and engineers can live in this system, and it contains all the necessary facilities, from berths to showers and toilets.



The Transport Shuttle

Due to technical and hygienic reasons, it is not as a rule feasible to locate the saturation habitat in the tunnel zone and link it to the tunnel machine. This makes it necessary to use a mobile transportation system – a shuttle. The shuttle collects the divers from the habitat outside the tunnel zone and takes them to the tunnel, where they dock on to the tunnel machine. Each pressurised shuttle can take up to 4 divers, technicians and engineers. Once it docks on to the tunnel machine, the passengers disembark and go to their stations in the control room and the excavation chamber to carry out all necessary inspection, maintenance and repair work to the cutterhead.

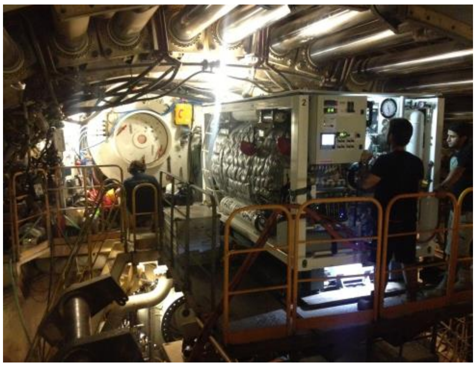
The NEW Technology 2012/2013

Lake Mead (USA) and

Nanjing Weisan Tunnel Project (China)

The new Mixed-Gas-Saturation Generation is designed and manufactured by IHC Hytech from the Netherlands in co-operation with Nordseetaucher GmbH. Those mobile Systems are for overpressure up to 20bar. The containerised System can be installed on the TBM in the shaft and/or on the surface.

The diver/technicians will be transported from the Living Chamber into the tunnel and on the TBM with a special designed Shuttle and Lifting System.



Since September 2013 the designed new Mixed-Gas-Saturation System is busy in Nanjing-China on the TBM of CCCC-China Communication Construction Company.

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
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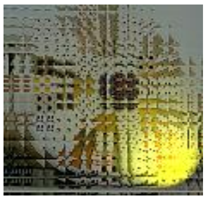


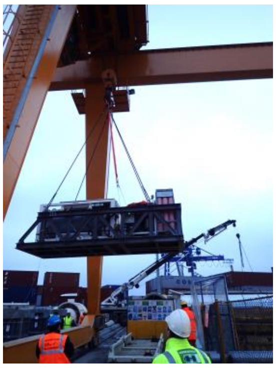
The NEW Technology 2015 **10.8bar Overpressure**

at

Eurasia Tunnel – Bosporus Crossing - Istanbul
Strait Road Tube Crossing Project

The intended purpose of this project is to provide a bi-directional, safe, robust, reliable, comfortable, durable and uninterrupted transportation of light vehicles under the Istanbul Strait for a design life of 100 years.
The length under the Bosporus will be 3.340meter and the Diameter of the TBM is 13,67meter.

The new Mixed-Gas-Saturation Generation has reached Europe. The mobile System is designed for overpressure up to 20bar. The containerised System is located on the surface. The maximum pressure on the project was 10.8bar.
The diver/technicians will be transported from the Living Chamber into the tunnel and on the TBM with a special designed Shuttle and Lifting System.



Hyperbaric Work at 10.8bar

Hyperbaric Welding at 10.8bar

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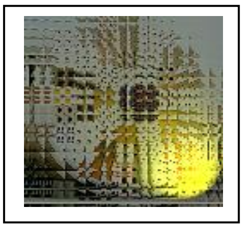


The Hyperbaric Helmet

Unlike in the 4th Tube of the River Elbe Tunnel and Wesertunnel projects, where the pressure was in excess of 4.5 and 5.0bar, we were unable to work with compressed air under the Westerschelde. Instead, we used mixed gases, consisting of helium, nitrogen and oxygen. The equipment used by the divers was identical to that used in the other tunnel projects. Partially submerged work under the Westerschelde was carried out with the aid of a new, lightweight type of helmet used in the chemical industry.

These helmets, which are not available on the free market, were specially refitted and adapted for the task. All tests and trial runs prior to the start of the project were carried out at the Belgian Navy's Hyperbaric Centre in Zeebrugge. This special helmet has two breathing regulators and a controllable cooling system, the latter being essential, as temperatures in front of the tunnel face can reach up to 50° Celsius.

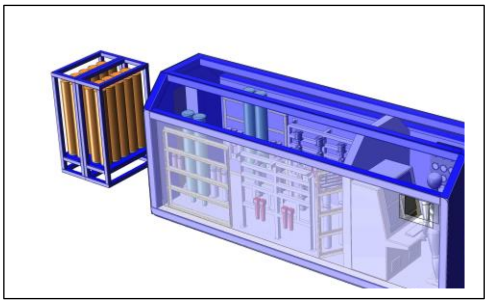
The NEW Technology 2012/2013

This new helmet design of Composite Beat Engel, Switzerland is the construction of an overpressure helmet. It has been realized in close co-operation with Nordseetaucher GmbH. This type of helmet - that with an additional kit can be transformed within one hour into a breathing controlled helmet - is now operational in extreme hazardous environment like tunnel machines and gives full satisfaction to the user.

Every helmet is provided with connections for surface air/gas supply, an independent emergency air/gas connection and communications equipment.

The NEW Technology 2014/2015

Up from December 2014 we are able to reclaim 80% of the breathing gas by a special designed Reclaim System designed by IHC Merwede Hytech. The new Free Flow Helmets are designed by Composite Beat Engel.



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NORDSEETAUCHER GmbH

Hyperbaric Tunnel Construction and Diving®

The **Nanjing Yangtze River Crossing Tunnel** is a 2.990 km long twin tube crosses the river Yangtze in Nanjing, China. Two Slurry-TBMs (∅ 14.96 m) are in use to excavate the tunnel in soft alluvium strata. The strata are mainly silt and fine sand.

The tunnel invert's deepest point is 65 m below sea level. Due to tidal influence the water level of the river is typically between +/-1.5 m above/below sea level.

On this project, welding in compressed air was the major task to carry out. From our experience and research of welding in compressed air and under water we knew that it is not a real problem. But this time it was very extreme. The buckets of 6 arms of the TBM had to be renewed. Therefore we welded new supports on the side arms of the cutterhead. The total time of this work took more than 12 weeks, day and night. The pressure was up to 5.4 bar overpressure in air. To keep the support pressure stable we used bentonite with a special mixture of high density and viscosity.

Maintenance and repair under compressed air was performed at up to 5.4 bar air pressure for works at the cutterhead and up to 6.5 bar for works at the stone crusher. Regular compressed air (no mixed gases) and oxygen decompression is successfully in use. In total more than 4.000 h of compressed air works and more than 945 total man interventions are performed. Only 3 minor cases of decompression illness are reported.

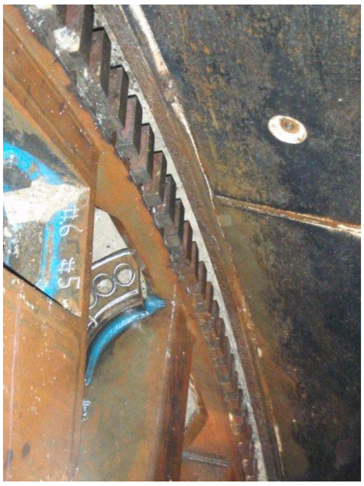
For the welding operation we used the first time a new special designed compressed air helmet with triple air supply, two regulators and one free flow, communication and an integrated welding shield with sensors.

NORDSEETAUCHER GmbH

Hyperbaric Tunnel Construction and Diving®

The **Esfahan Metro Tunnel** is a 4.550 km long twin tube between Shohada Aquare and Azadi Aquare. The west and the east tunnel crosses the river Zayandehrood in the south of Esfahan, Iran. The two EPB TBM's (∅ 6.96 m) are in use to excavate the tunnel in soft alluvium strata. The strata are mainly silt, fine sand and gravel.
The tunnel invert's deepest point is 20 m below street level and river.

Welding in compressed air is the major task to carry out. But this time the job is more extreme. The 8 cutterhead arms of the TBM had to be renewed more or less completely from the front side and the cutterhead edge of both machines from the back side. Therefore we welded new vertical side plates and new cover plates on the arms of the cutterhead and new hardox plates on the cutterhead edge. The total time of this work will take more than 6 month, day and night. The pressure is up to 2.0 bar overpressure in air. To keep the support pressure stable we used bentonite with a special mixture of high density and viscosity.



Maintenance and repair under compressed air is performed at up to 2.0 bar air pressure for works at the cutterhead. Regular compressed air and oxygen decompression is successfully in use. In total more than 2.000 h of compressed air works and more than 375 man interventions until 31.03.2010 are performed. No minor case of decompression illness is reported.

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
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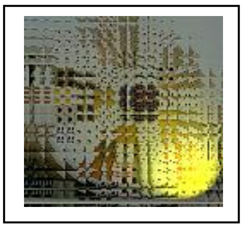


Beijing Railway Tunnel ZJX – 2 Project

NORDSEETAUCHER GMBH

Hyperbaric Tunnel Construction and Diving®

WELDING PROCEDURE SPECIFICATION

WPS No. 004/2011 **Beijing Railway Tunnel ZJX – 2 Project** Job No.: 1-1410

Joint Description: Qualified Professional Hyperbaric Cutterhead Welding accor. EN ISO 15618-1 / EN 287-1 /AWS 3.6D

111/ Rev.: Shielded Metal Arc-Welding Joint No.: 01/Fillet Weld a 25mm

02/2011 Retzlaff Rev.: PA, PB, PC, PD, PE, PF

W01

2.8 bar

30-40° C Compressed Air

	approved by:	date:
Project Mgr.	Claus Mayer (NST)	2011.04.08
QC Supv.	Martin Wenning (GL)	2009.11.06
Client*	CRTG China Railway Tunnel Group	
ANI*		

*if required

amrau date of birth: 1969.02.09

Frank Jans date of birth: 1959.10.14

Specification of Base Material : S355J2+N

Welding Method : Compressed Air -Shielded Metal Arc-Welding (SMAW)

Form of Welded Joint : multi –run fillet weld

: DIN EN 287-1 / PD, PB, PF

: DIN EN ISO 5817:C

ion : Fillet Joint

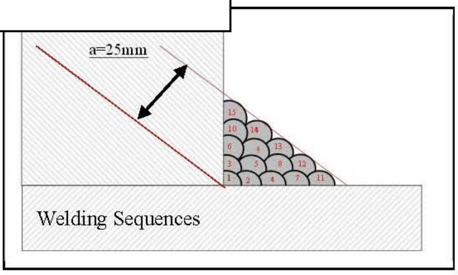
) : 1) t1=60mm / =30mm

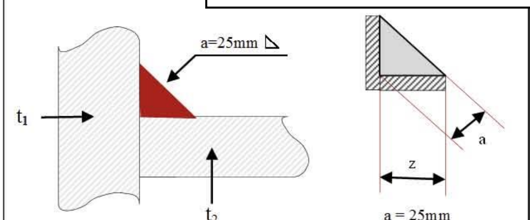
2) t2=60mm / =35mm / =50mm

: NFM / Nordseetaucher GmbH

: CREC

tificate : GL DIN 18800-7, Class C/D





Joint Design: 01

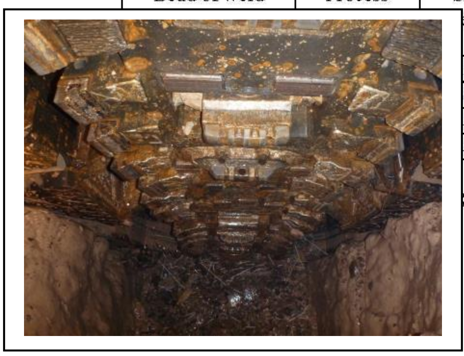
Name of Filler Material: ESAB OK 53.16 special

Filler Metal: E 38 2 B 3 2 H10 (EN ISO 2560-A)

Details for Welding

Preheating Temperature: 50 – 80°C

Interpass Temperature: max. 200°C



Bead of weld	Process	Size of …er metal	Current Intens. A	Voltage V	Kind of polarity	Wire Feed	Travelspeed cm / min
		.50 Ø	ca.80		= -	/	/
		.25 Ø	ca.130		= +	/	/
		.00 Ø	ca.180		= +	/	/
		.00 Ø	ca.180		= +	/	/

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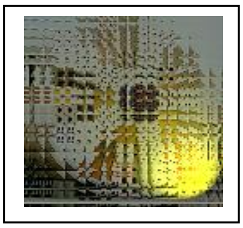
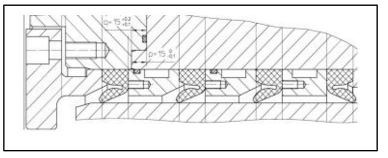


Project: S-636 Metro Hangzhou

Change of the Main Drive Sealing System at 2.1bar overpressure.



All 4 seals of the Main Drive Sealing System of a TBM were worldwide changed in overpressure in June 2012 for the first time. The unusual feature of this repair primarily consisted that the seals had to be changed, not like in the manufactory in a horizontal layer, in a vertical layer.

To make the dismantling and assembly work easier some grits were mounted in the excavation chamber, so that each place of the Main Drive Sealing System was attainable without problems. The dismantling of the faulty seals and the Chamber Rings was carried out by means of pulling-off devices made especially for it.

Before the opening of the Main Drive Sealing System it was needed to clean the cutterhead and excavation chamber and suck out all material to make sure that no pollutions be able to hinder the seal replacement.
All chamber rings and the seal housing were cleaned from any dirt and grease with high pressure water and cold-cleaner.

The new seals were volcanized with a special bonding device of Nordseetaucher. To ensure a one hundred per cent connection, the device has been heated up to approximately 70 - 80 ° degrees Celsius for three hours.

The correct situation of the single seals and chamber rings were measured before and after the mounting. The measurements record was made according the design plans, delivered by Herrenknecht AG.

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
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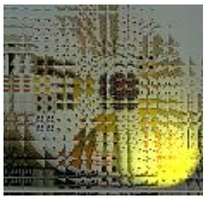

The Guangzhou-**Shenzhen-Hong Kong** Express Rail Link is a committed cross boundary transport infrastructure project, which will provide high speed rail services between Guangzhou and Hong Kong, and a connection to the national high-speed passenger rail network serving major mainland cities outside of Guangdong province. This network, which will comprise some 16.000km, is under construction since 2012.

The CRCC, measuring about 2x3.253km length from Shenzhen to the Boundary, will use a dedicated corridor to ensure that the required capacity of trains running at 200 kilometer per hours can be achieved, whilst ensuring operational compatibility with the Mainland of Hong Kong. The tunnel straddles 2 territories with 1.763m in China and 1.490m in Hong Kong.

Compressed Air Work is the major task to carry out. The maximum overpressure was 4.6bar. But this time the job was more extreme. The 4 stators and the flushing nozzle had to be renewed completely from the back side of the cutterhead (Ø9.18m). The total time of this work was more than 4 weeks, day and night. The pressure was up to 3.8 bar overpressure in air.

Maintenance and Repair under compressed air is performed at up to 4.6 bar air pressure for works at the cutterhead. Regular compressed air and oxygen decompression is successfully in use. In total more than 30,000h of compressed air works and more than 5.800 man interventions until 31.01.2015 are performed. No minor cases of decompression illness are reported.

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
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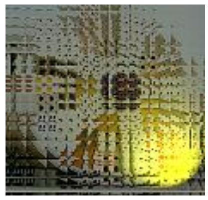


Summary

High groundwater pressure (above 4 bar) makes tunneling much more difficult and requires special knowledge of cutting edge technologies during design and construction. TBM, tunnel equipment and tunneling procedures should be designed to enable reliable application of adequate support pressures at all times during excavation and hyperbaric interventions to counterbalance the acting groundwater head.

If adequate primary components and backup systems are not installed on the TBM, major problems including cost overruns and time delays can occur.

Tunnel excavation in strong, fine grained cohesive soils and rock under high groundwater pressure is generally not problematic for Slurry- and EPB-TBMs, as typically the face is stable and the amount of inflowing water is low due to low permeability of the ground. In coarse-grained soil or unstable rock, tunnel excavation requires a reliable active face support to provide face stability and prevent excessive lost ground during tunneling and interventions. Suitable active face support is easier to achieve with Slurry-TBMs.

Depending on the level of the groundwater pressure, abrasiveness of the ground and the length of the corresponding tunnel sections, the TBM should include provisions for hyperbaric interventions using regular compressed air, mixed gases or saturation diving, depending on pressure level and duration of intervention time expected.

Only in very strong, low permeability soils or in competent rock are risks of attempting cutterhead interventions under free air reasonable (if not otherwise restricted), but there should always be provisions available to apply adequate compressed air support or ground treatment if needed.

The experience gained in the projects proves that the saturation method is a very successful approach to hyperbaric tunnel constructions. It also shows us that work in compressed air is possible up to 6.5 bar overpressure, but not very efficient.

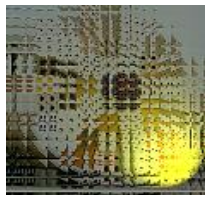
The cooperation between the tunnel construction companies, the manufacturer of the TBM's, the Herrenknecht AG, the Hyperbaric Medic Dr. Niecke, the Hyperbaric Training Center, Germany, the Classification Company Germanischer Lloyd, the Design and Manufacture Company Composite Beat Engel and the NORDSEETAUCHER GmbH is very rewarding and productive, and we hope that it can be intensified in future co-operations. The excellent training of the diving personnel, engineers and hyperbaric construction technicians involved in this ground-breaking-projects, the continual training and the adaptation of the tunnelling machines to the existing conditions open up a highly promising perspective on the future of tunnel construction:

deeper, larger and longer.

Requirements for Work in Compressed Air and Mixed Gas

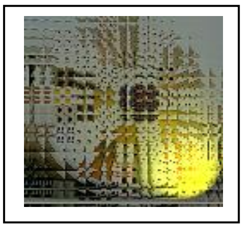
Operation Pressure 0.7 – 3.0 bar

Intervention Method	Required Equipment on the TBM	Required Equipment for Hyperbaric Works	Required Personal	Requirement at the Excavation Chamber
Breathing Gas: Compressed Air **Work Method:** Technician in Compressed Air Divers in Bentonite	**Minimum** 1 Air Lock equipped according to Compressed Air Regulation device with O_2 Decompression Excavation Chamber with double compressed air supply lines for safety reasons Compressed Air Breathing System for welding and cutting DN 300 mm Penetration Flanges for diver/technician breathing gas, monitoring, HP-Water and Hydraulic supply	**On the TBM:** Front Gate & independent regulation tank to regulate the excavation chamber pressure during compressed air work Video Monitoring System **At the Surface:** Compressed Air Station inclusive air cooler and air filter	**Compressed Air Supervisor** **Compressed Air Team:** 1 Shift Supervisor 2 trained Technicians changing the tools 1 trained Technician in charge of material handling and service **Surface Team:** 1 Lock Attendant (chamber operator) 2 Service Technicians Max. working time in compressed air 0,7 bar = > 4:00 hrs to 3,0 bar = 2:45 hrs ________ **Hyperbaric Doctor** **Medical Advisor**	Necessary to lower the level of Bentonite under the location of the tools to be changed, to have free access to the excavation chamber



Operation Pressure 3.1 – 5.0 bar

Intervention Method	Required Equipment on the TBM	Required Equipment for Hyperbaric Works	Required Personal	Requirement at the Excavation Chamber
Breathing Gas: Compressed Air or Mixed Gas **Work Method:** Technician in Compressed Air Divers in Bentonite	**Minimum** 2 Air Locks equipped according to Compressed Air and Mixed Gas Regulations with O_2 Decompression Excavation Chamber with double compressed air supply lines for safety reasons Compressed Air / Mixed Gas Breathing System for welding and cutting DN 300 mm Penetration Flanges for diver/technician breathing gas, monitoring, HP-Water and Hydraulic Supply	**On the TBM:** Front Gate & independent regulation tank to regulate the excavation chamber pressure during compressed air work Gas bottles for Mixed Gases Operations, specific Hyperbaric Helmets for the workers (see Nordseetaucher document) Video Monitoring System **At the Surface:** Compressed Air station inclusive air cooler and air filter	**Compressed Air Mixed Gas Supervisor** **Compressed Air Team:** minimum 2 shifts 1 Shift Supervisor 2 trained Technicians changing the tools 1 trained Technician in charge of material handling and service **Surface Team:** 2 Lock Attendant (chamber operator) 2 Service Technicians Max. working time in Compressed Air 3,1 bar = >2:50 hrs to 5,0 bar = 1:00 hrs Mixed Gas 5,0 bar = 2:15 ________ **Hyperbaric Doctor** **Medical Advisor**	Necessary to lower the level of Bentonite under the location of the tools to be changed, to have free access to the excavation chamber For diving in Bentonite extra entrance door below the centre in the lower area. Not necessary to lower the level of Bentonite



Operation Pressure > 5.0 bar

Intervention Method	Required Equipment on the TBM	Required Equipment for Hyperbaric Works	Required Personal	Requirement at the Excavation Chamber
Breathing Gas: Mixed Gas **Work Method:** Technician and Divers in Mixed Gas Divers in Bentonite Entering in Semi-Sat and Saturation Method	**Minimum** 2 Personnel Locks equipped according to Sat-Diving Regulations Excavation Chamber with double compressed air supply lines for safety reasons Due to the long decompression time, specific equipment at the surface (see Nordseetaucher report) are necessary Mixed Gas Breathing System for welding and cutting DN 300 mm Penetration Flanges for diver/technician breathing gas, monitoring, HP-Water and Hydraulic Supply	**On the TBM:** Front Gate & independent regulation tank to regulate the excavation chamber pressure during compressed air work Gas bottles for Mixed Gases operations, specific Hyperbaric Helmets for the workers (see Nordseetaucher report) Video Monitoring System **At the Surface:** Compressed Air station inclusive air cooler and air filter Saturation Living System 2x Transport Shuttle (see Nordseetaucher report)	**Saturation Mixed Gas Supervisor** **Team:** minimum 2 shifts 1 Shift Supervisor 2 trained Technicians changing the tools 1 trained Technician in charge of material handling and service **Surface Team TBM:** 2 Lock Attendant (chamber operator) 2 Service Technicians Sat.-System Team 24 h Service on request Max. working time in Semi-Sat or Saturation: on request ________ **Hyperbaric Doctor** **Medical Advisor**	Necessary to lower the level of Bentonite under the location of the tools to be changed, to have free access to the excavation chamber For diving in Bentonite extra entrance door below the centre in the lower area. Not necessary to lower the level of Bentonite

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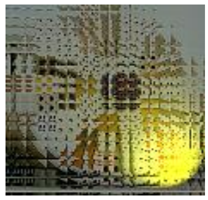

Hyperbaric Work (Diving and Compressed Air)

Reference List for Work in Compressed Air deeper 3.6bar and the use of the Tables

NST – AIR/OXY/12M – NST
NST – Canadian Forces – NST
NST – DruckLV – NST

01st August 2015

Year	Project Name	Overpressure	Man Interventions	Total Time	DCS I	DCS II
1997-2000	4th River Elbe Crossing	3.6 - 4.5 bar	223	839 h	00	0
1998-2002	Westerschelde Project	3.6 - 4.4 bar	546	1.947 h	01	0
2000-2001	Wesertunnel	3.6 - 4.7 bar	559	1.639 h	00	0
2008-2009	Nanjing Yangtze River	4.8 - 6.5 bar	945	3.948 h	04	0
2008-2010	U4 HafenCity Hamburg	3.6 - 4.2 bar	149	522 h	00	0
2011-2014	Hong Kong, XRL820/821	3.6 - 3.9 bar	197	611 h	00	0
2011-2015	Guangshengang-Shenzhen	3.6 - 4.6 bar	6.612	34.027 h	06	0
2011-2015	Nanjing Weisan Road Tunnel	5.2 - 6.5 bar	4.125	17.793 h	07	0
2012	Metro Line 3 Nanjing	4.8 - 5.6 bar	619	2.877 h	01	0
2013-2015	Eurasia Tunnel Istanbul	4.1 - 6.5 bar	176	1.007 h	00	0
			14.151	**65.210 h**	**19**	**0**

NST-DruckLV-NST
Decompression with Oxygen under normal conditions
Work pressure between 0.7 and 1.5bar (officially 3.6bar)
Experience: More than 235.000

NST-AIR/OXY/12M-NST
Decompression with Oxygen without compromises
Work pressure between1.5 and 6.0bar
Experience: More than 74.237 hrs.

NST-Canadian Forces-NST
Decompression with Oxygen without compromises
Work pressure between 4.5 and 7.2bar
Experience: More than 7.176 hrs.

Ammersbek, 2015-08-01

Nordseetaucher GmbH
Claus Mayer

Superintendent
Specialist Hyperbaric Competence

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
E-mail: info@nordseetaucher.de; Internet: www.nordseetaucher.de

NORDSEETAUCHER GmbH

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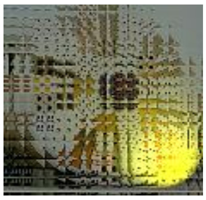

Mixed-Gas-Saturation Interventions
in
Deep Tunneling

1999 - 2002 Westerschelde Tunnel Zeeland-The Netherlands

Max. Overpressure 7.9bar

Team Interventions in Total 6 =18 Man Interventions
Working Days 40

2012 - 2015 Nanjing Weisan Road River-Crossing Project Nanjing-China

Max. Overpressure 6.5bar

Team Interventions S+N-Line in Total 36 = 108 Man Interventions
Working Days 649
Time under Pressure 52.552:20
Work Time under Pressure 8.606:00

2014 - 2015 Eurasia Tunnel Istanbul-Turkey

Max. Overpressure calculated 11bar

Team Interventions in Total 07 = 22 Man Interventions
Working Days 39
Time under Pressure 4.759:05
Work Time under Pressure 740:00

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Decompression Treatments (Bends) 00

Ammersbek, 2015-08-01

Nordseetaucher GmbH
Claus Mayer

Superintendent
Specialist Hyperbaric Competence

Nordseetaucher GmbH, Bramkampweg 9, D-22949 Ammersbek, Germany; Tel. +49 4102 23180, Fax +49 4102 231820, Mobile +49 172 4300598
E-mail: info@nordseetaucher.de; Internet: www.nordseetaucher.de