Environmental and Sustainable Development Reasons for Going Underground

ITA –AITES Working Group 15
Underground works and the environment

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>> SUMMARY

The International Tunnelling and Underground Space Association Working Group 15 – Underground Works and the Environment has prepared this report to illustrate the many ways that tunnels and underground space have been used to reduce the effect on the environment, for sustainable development reasons, for the construction of important infrastructure.

The report illustrates over 100 tunnel and underground space projects on all five continents and covering a broad spectrum of the Association's Member Nations. The projects illustrate the opportunities and benefits of going underground to reduce the environmental impact on Society.

Highway projects cut a wide swathe through urban and rural areas and can be a scar on the horizon. By going underground major improvements can be achieved to minimise the effect on the environment. The highway projects represented 43% of the projects from 17 Member Nations and illustrate how bored, cut and cover, and immersed tunnels can be constructed to:

- Reduce noise, pollution, or congestion
- Preserve archaeological sites, historical cultural areas and historic towns and cities, or
- Preserve the environment.

The railway projects represented 17% of the projects and included:

- New railways in mountainous areas
- New railways in sensitive urban areas, and
- New high speed railways through sensitive areas.

The remaining 40% of the projects covered:

- Underground storage, emplacement and disposal
- Sewage treatment and water projects, and
- Underground facilities in urban and rural areas.

It is hoped that these examples will encourage clients to place more projects underground leading to more environmental and sustainable developments to the benefit of the public.

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>> Introduction

The International Tunnelling and Underground Space Association (ITA) Working Group 15 – Underground Works and the Environment, was officially launched at the ITA Washington meeting in April 1996. The initial studies carried out by the Working Group presented a review of the opportunities and constraints associated with the environment, which was backed up with an analysis of selected case studies demonstrating the environmental benefits that can be derived from the construction of underground works. The summary report was published in the ITA Newsletter Tribune in October 2002 and presented as a paper in the ITA Proceedings in Singapore in April 2004.

At the Working Group meeting in Durban in May 2000 it was decided to refocus the activities on the more practical aspects of underground works with the environment and sustainable development. The meeting prepared a questionnaire to be sent to Member Nations to collect data on projects which have been placed underground due to environmental and sustainable development reasons.

In 2002 the ITA published a booklet called «why go underground» (Plate 1). The booklet illustrated many reasons and features of the use of underground space. The main criteria for going underground were:

- Land use and location reasons
- Isolation considerations
- Environmental preservation
- Topographical reasons, and
- Social benefits

In practice most projects can be placed under several of these heading. The environmental preservation reasons for going underground were given under two main headings:
- Aesthetics, less visual impact, and
- Ecology, to help preserve the natural vegetation, and less damage to the local and global ecological cycle.

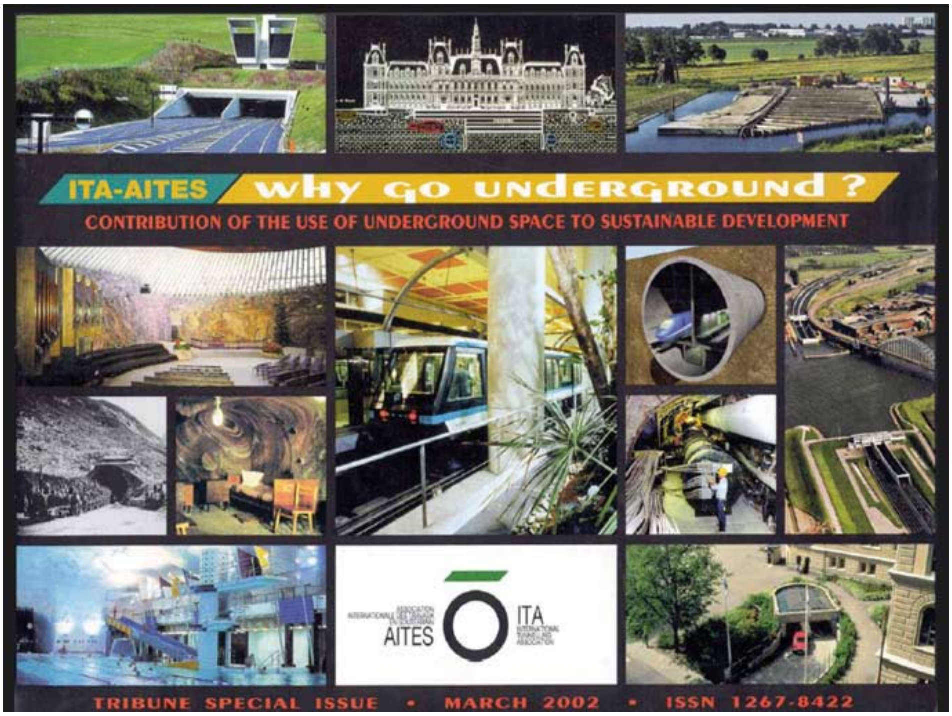

Plate 1 – ITA Report «why go underground»

This current report provides additional examples of underground projects highlighting environmental and sustainable development reasons for going underground.

Each Member Nation of the ITA may have its own reasons and rationales for going underground on account of the environment or sustainable development. In this context sustainable development has been defined as:

«development that meets the needs of the present without compromising the ability of future generations to meet their own needs».

A common theme is the preservation of the environment for other uses such as recreation, residential, aesthetic, to avoid congestion, more efficient and economical use of space and energy or for fortifications.

In most cases underground constructions are more expensive than the alternatives and therefore in some countries projects will be placed underground on account of environmental or sustainable development reasons and in others not. Politics, economy and other considerations will affect the decision.

The ground conditions will also have a major influence on this decision. In Scandinavia, for example, the typical hard rock enables large caverns to be excavated for underground space and the reuse of the excavated material for aggregates and road materials, while in a country with soft ground or poor quality rock the cost of an underground structure may be prohibitively expensive.

COLLECTION OF DATA

A short questionnaire was prepared and sent to the 32 members of the Working Group, representing 21 of the ITA Member Nations. Copies of the questionnaire were also sent to the other Member Nations not represented on the Working Group. The data received represents more than 100 projects from 21 Member Nations, covering the five continents and a broad spectrum of the Member Nations of the Association. Table 1 presents a summary of the number of projects by sector.

There was a large variation in the numbers of projects submitted from individual Member Nations. Seven Member Nations submitted one project each while one Member Nation submitted 30 projects. However, it should be appreciated that the topography, geology and GDP may be very different in the 21 Member Nations.

SECTOR	NUMBER OF PROJECTS	NUMBER OF DIFFERENT MEMBER NATIONS
Highway projects	46	17
Railway projects	18	9
Underground storage, emplacement or disposal	12	5
Sewage Treatment and Water Storage	13	6
Underground facilities in urban or rural areas	7	4
Subway projects	6	3
Services	2	2
Mining projects	4	2
Total No. of Projects	**108**	
Total No. of Member Nations Represented		**21**

Table 1 Projects by Sector

ACKNOWLEDGEMENTS

The ITA is very grateful to the 21 Member Nations who provided information and data for the report. The illustrations in the report were provided by the representatives of the Member Nations on the Working Party and the ITA acknowledges the copyright of these illustrations.

Australasian Tunnelling Society
Plates 9 and 20

Austrian National Committee of ITA
Plates 2 and 3

Brazilian Tunnelling Committee
Plate 24

Egyptian Tunnelling Society
Plate 21

Germany, STUVA
Plates 4, 15 and 16

Japan Tunnelling Association
Plates 11, 17 and 18

Norwegian Tunnelling Association
Plates 5, 6, 7, 8, 28, 29, 30, 33, 36 and 37

Public Works and Water Management , Rijkswaterstaat, HSL South
Plate 27

Russian Tunnelling Association
Plates 34 and 35

Swedish Rock Construction Committee
Plates 10, 26 and 31

Turkish Road Association
Plate 25

UK, Highways Agency
Plates 22 and 23

UK, Costain Ltd
Plate 19

USA, Underground Construction Association of SME
Plates 12, 13, 14 and 32

>> Highway projects

The highway sector is the largest sector affecting the environment. All the time new roads, expressways and motorways are being built and existing roads are being widened all over the world. The environment is affected by many of these projects. It was no surprise that the largest number of projects identified as being placed underground on account of environmental or sustainable development reasons were in this sector in both urban and rural areas. The 46 projects from 17 countries cover both bored and cut and cover tunnels.

The projects have been sub-divided into three groups:
- Projects where the reduction of noise, pollution and congestion were paramount – subdivided into bored tunnels, TBM or drill and blast tunnels, and cut and cover tunnels
- Projects in historical urban or rural areas
- Other projects in semi-urban and rural areas

REDUCTION OF NOISE, POLLUTION AND CONGESTION

Bored Tunnels

Many case histories were provided of projects being placed underground to reduce the impact of noise, pollution, congestion and traffic. Further reasons for underground structures were the improvement of the residents' living conditions, or the provision of open or recreation spaces, in cities, towns and villages.

In Austria five recent bypasses have been constructed with underground sections to improve the environment and reduce pollution, congestion and traffic including bypasses around Salzburg, Melk (Plate 2), Plabutsch, Graz and Zell am See (Plate 3).

Similar highway schemes with underground sections to improve the environment including Landshut (Plate 4), in Bavaria Germany, four schemes in Oslo, Norway, to reduce noise, pollution and congestion including the E6/E18 tunnel through the City and beneath the harbour, the Oslo Expressway 160 (Plate 5), the RV4 Highway tunnel (Plate 6), the Skaugum railway tunnel (Plate 8) and another at Nittedal, Norway, and major highways and expressways in Stockholm, Sweden.

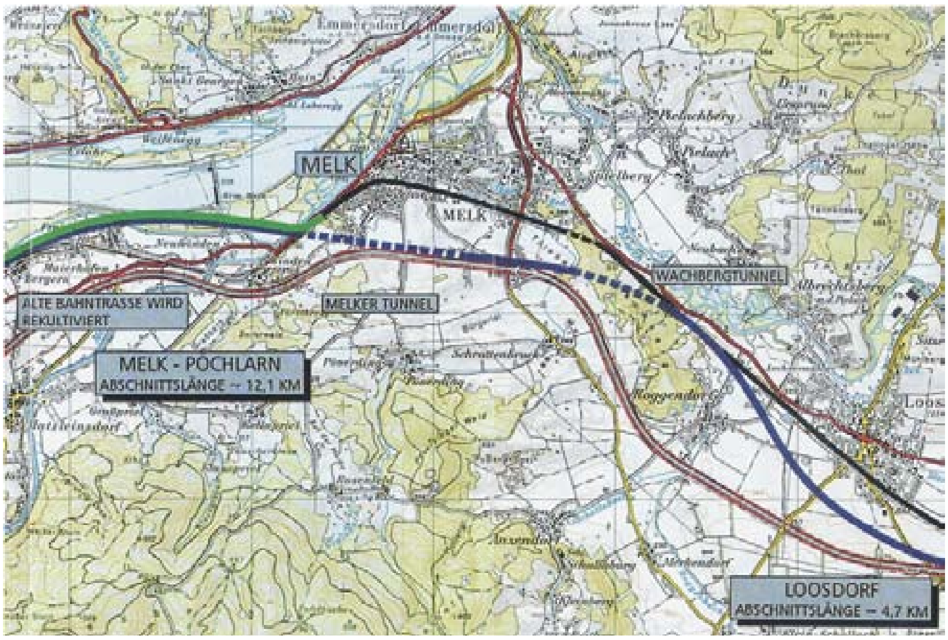

Plate 2 - Melk Bypass, Austria

Plate 3 - Zell am See Bypass, Austria

>> Highway projects

Plate 4 - Hofberg Tunnel Landshut, Bavaria, Germany

Plate 5 – Oslo Expressway 160 – Ullevaal – Taasen, Norway

Plate 6 - RV 4 Highway Tunnel, Norway

Plate 7 - Oslo E6/E18 Harbour Crossing

The E6/E18 (Plate 7) Oslo highway is currently under construction and has an immersed tunnel under the harbour connecting rock tunnels at either end. The project will improve the future traffic and the environment of the city centre and open up the harbour and adjacent land for recreation. Particular challenges include the avoidance of pollution in the harbour, the preservation of archaeological and historical sites, temporary traffic problems during construction and the movement of materials and plant.

Plate 8 - Skaugum Railway Tunnel, Norway

Plate 9 - Eastern Distributor, Sydney, Australia

Plate 10 - Southern Link Road Tunnel Stockholm, Sweden

The

Plate 11 - Tokyo Ring Road, Japan

The Sydney Eastern Distributor, Australia, (Plate 9) constructed as a part of the preparations for the 2000 Olympics, was placed underground in bored tunnel to preserve the existing buildings and urban profile.

Southern Link Road
Tunnel in Stockholm (Plate 10) is the most extensive underground road tunnel system in Sweden, comprising 16.4km of tunnel.

The ring road around Tokyo, Japan, (Plate 11) is partly underground in bored tunnel and cut and cover to re-route traffic from the local roads and to reduce noise, pollution and congestion.

The historic town of Lewes, in the south-east of England, UK, is intensely congested and a major road was placed in bored tunnel to avoid the demolition of old houses and to reduce the effect on the environment.

At the insistence of citizen groups, a single, 406m long, 19.5m diameter tunnel with road traffic on two levels, and pedestrians and cyclists on the third upper level, was constructed through the Mount Baker Ridge in Seattle, USA (Plate 12) to minimise the environmental effects on the overlying residential area and the land take.

In Boston, USA, the Central Artery Expressway (Plates 13 and 14) was built between 1951 and 1959 to provide access to the downtown part of the City and major arterial roads. The alignment passed through depressed areas of the City to minimise the costs. A large part of the route was on elevated structures. As the City expanded, the corridor of land adjacent to the expressway became a more depressed area compared to the rest of Boston.

When the elevated structures were in need of major renovation there was the opportunity to place the expressway underground which has not only improved the environment of this historic area of Boston but will allow large areas of open space to be laid out for public use. In addition other large parcels of land will be available for commercial and housing development as the price of real estate increases. The tunnel has been designed for additional loading equivalent to six storey buildings where the alignment passes below the parcels of land earmarked for development, maintaining its aim of sustainable development.

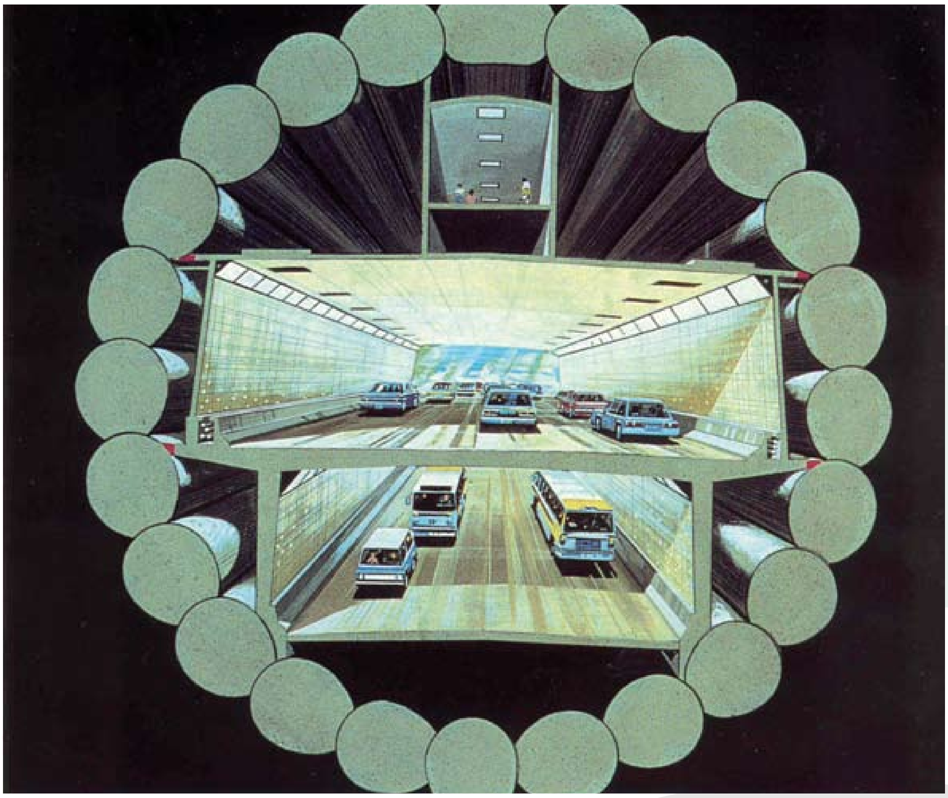

Plate 12 - Mount Baker Ridge Road Tunnel, Seattle, USA

Plate 13 - Boston Central Artery Expressway (before), USA

Plate 14 – Boston Central Artery Expressway (after), USA

Cut and Cover Tunnels for Environmental Improvements

There are many instances of cut and cover tunnels being constructed to reduce noise, pollution, congestion and their impact in cities, towns and villages. With cut and cover tunnels there is the opportunity to develop the land above for sustainable development.

In Heidelberg, Germany, the existing road along the river was placed in cut and cover and the area above was laid out for recreation, pedestrians and cyclist. In Düsseldorf, Germany, (Plates 15 and 16) a similar scheme along the Rhine also provides additional car parking possibilities.

In Norway, the Horten – Borre cut and cover tunnel was constructed in soft clay through a populated area to improve the environment.

In Tokyo and in other Japanese cities (Plates 17 and 18), the cut and cover tunnel have been chosen in preference to elevated highways in congested areas to reduce the impact of the new highway. To improve the tunnel ventilation and to reduce pollution at the ends of the tunnels and at shafts, the cut and cover tunnels often have partly open roofs.

In The Netherlands Route 14 was placed underground at Voorburg to improve the environment with houses, offices and open spaces built above.

Plate 15 - Congestion in Düsseldorf, Germany

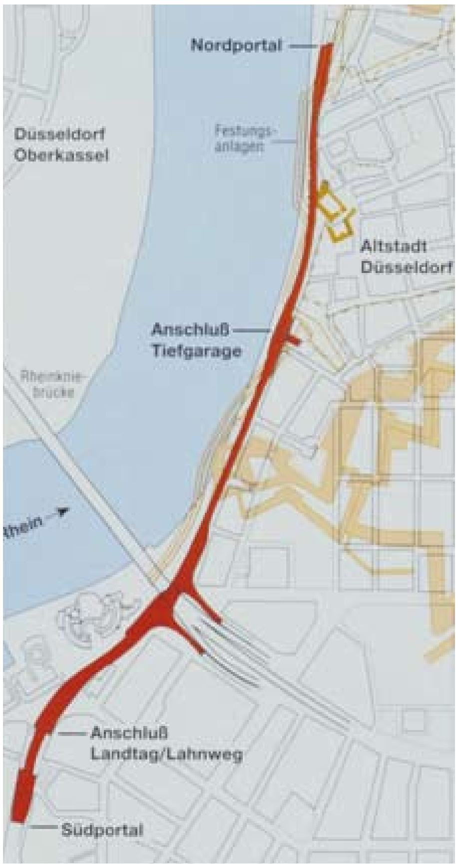

Plate 16 – Rheinuferstrasse Tuunel, Düsseldorf

Plate 17 - Cut and Cover tunnel, Tokyo, Japan

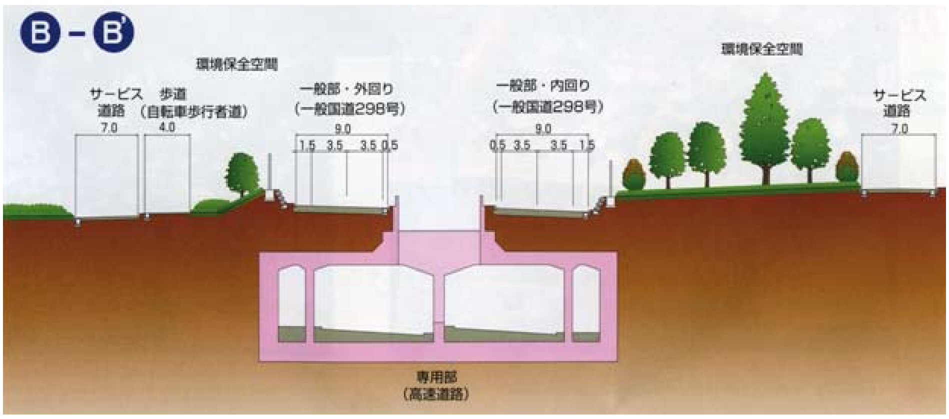

Plate 18 - Cross Section cut and cover tunnel, Tokyo, Japan

The 1.5km long Limehouse Link in the London Docklands, UK, was placed underground due to environmental, sustainable development and traffic reasons. By careful planning only three buildings had to be demolished along the route. The cut and cover tunnel was designed to take five storey buildings on the surface for future sustainable development above the tunnel.

The Holmesdale Tunnel (Plate 19) on the M25 north of London, UK, passed along a corridor bounded by a residential development. The area above the tunnel was revitalised with an allweather playing surface and tennis courts for the local residents.

TUNNELS IN HISTORICAL URBAN OR RURAL AREAS

A number of highway projects have been constructed, or are being developed, underground solely on account of environmental reasons. The reasons for going underground have been because of: Archaeological sites, historical cultural areas, historic old towns, special sites of scientific interest, or conservation areas.

In Sydney, Australia, the Harbour Tunnel was constructed below ground to avoid environment impact on the Opera House and the Botanical gardens. The M3 East Tunnel in Sydney was placed in tunnel when passing through the environmental sensitive Wolli Creek Valley.

In Sao Paulo, Brazil, twin tunnels were driven under the main City Ibirapuers Park to protect the park trees and vegetation. The access ramps and ventilation towers had to be 300m from the park. While in the City of Brno, Czech Republic, twin tunnels were constructed for an expressway under the Husovice Hill to protect the natural formation and the environment.

Plate 19 – The Holmesdale Tunnel, London, UK

Plate 20 - Heysent Tunnel, Australia

In Cairo, Egypt, the El Azhar road tunnel (Plate 21) has twin 2.7km long bored tunnels and was constructed as a part of the general plan for the preservation and development of the historic Fatimid area of Cairo, dating back to the 10th Century and being the Islamic Cultural centre of the City. Following the opening of the scheme the aim is the demolition of the existing elevated structures along the route and the creation of a vehicular free area for tourism and pedestrians as well as the improvement the environmental conditions in this important area. At the present time, although the twin tunnels are in operation, the pedestrian area has yet to be fulfilled.

The third ring road around Moscow, Russia, has a 2.2km long tunnel under the Lefortovo memorial for history, culture and architecture and also runs under the River Yauza and the parkland as well. The Krasnopresnensky project, an artery connecting Moscow to the outer ring road, is currently being constructed in tunnel under the unique Silver Forest reserve and will be opened in 2008.

In Istanbul, Turkey, the Kisikli Tunnel was constructed to preserve a 400 year old Abdullah Mosque within an historical area, a school and a nearby forest.

Stonehenge, UK, is a 4000 year old stone circle which is an UNESCO World Heritage Site of immense archaeological significance. The busy A303 trunk road from London to the west country passes south of the site, while another major road passes to the north. The 50km of the A303 to the east of Stonehenge to London are dual carriageway.

As part of the upgrading of the A303 the length south of Stonehenge will also become a dual carriageway. The original scheme to have an at grade dual carriageway was unacceptable to English Heritage, who run the Stonehenge site, and also to the National Trust, who owns the surrounding land. After considerable studies and investigations the Government chose a preferred alignment with a 2km long cut and cover tunnel past Stonehenge to preserve the historic Heritage Site (Plate 22). An alternative in bored tunnel has also been developed. The whole project is currently delayed on account of the high predicted costs.

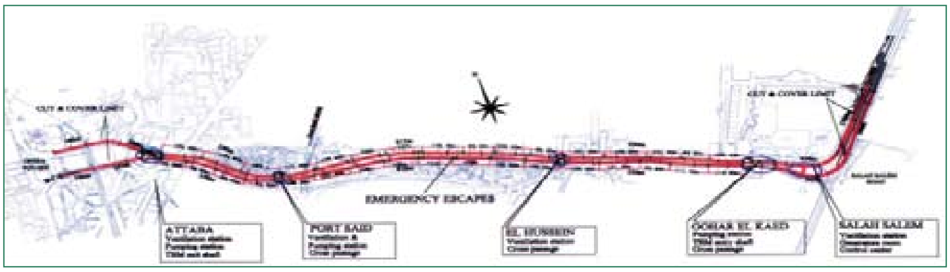

Plate 21 - El Azhar Tunnel, Cairo, Egypt

Plate 22 - Stonehenge, UK, after tunnel construction of the proposed tunnel

The Bell Common Tunnel (Plate 23), on the M25, orbital road around the north east of London, UK, was placed underground for environmental reasons as a section passed through the northern part of Epping Forest. The Conservators of the forest, the Corporation of the City of London, wished the alignment to minimise the effects on the forest environment. After considering alternative routes the Conservators, whilst accepting the need for route, would not accept the preferred route and would only agree to a route to the north with a 200m cut and cover tunnel through the forest. Since then the cricket pitch has been reinstated above the tunnel.

North of Auckland the ALPURT Section 2 State Highway 1 crosses environmental sensitive bush covered terrain. The original scheme had a 40m deep cut and cover which has been redesigned as a bored tunnel to reduce the environmental impact. The construction phase has begun.

Plate 23 – Bell Common Tunnel, London, UK

OTHER ROUTES IN SEMI-URBAN AND RURAL AREAS

The third category of Highway Projects covered a number of schemes in both semi-urban and rural areas where a section of new road alignments were placed underground for different, particularly environmental reasons.

The Highway into Adelaide, Australia, was a tortuous and steep narrow down hill road which had a very high accidents rate. This route has now been replaced by a more direct tunnel alignment which improves the environment.

The Imigrantes Highway 4 (Plate 24), from Sao Paulo, Brazil, to Santos seaport passes through the protected World Heritage Mata Atlântica forest. Planners for the second phase of parallel lanes gave priority to tunnels over viaducts. Completed in 2002, the combined length of tunnels was doubled to 8.2km. In recognition of its environmental awareness and aggressive protection of the environment, the project has received considerable worldwide recognition and awards.

In Oporto, Portugal, a highway and pedestrian tunnel was constructed under the Matosinlios port to reduce traffic conflicts in the harbour and to improve the environment.

The National Route 1 north of Capetown, South Africa, was upgraded in the 1980s and passed through the Fynbos Bione area, 70km to the north of Capetown. A cutting would have required extensive construction work in the ecologically sensitive area and so a 3.9km long tunnel was chosen to minimise these environmental effects.

Two highway schemes in Istanbul, Turkey, were placed underground on account of environmental reasons. The first was set in an unstable area as well as in a forest avoiding large and unsightly cuttings. The second has preserved a forest area. On the Black Sea Coastal route, Turkey, four tunnels were constructed along the route for environmental reasons.

Here two tunnels had the function to maintain the existing shoreline or beach and forest areas (Plate 25) while the other two tunnels were placed in unstable ground, under agricultural land and tea gardens to avoid very large and unsightly cuttings.

Plate 24 - Satellite view of Imigrantes Highway, Brazil

Plate 25 - Hopa Sarp Tunnel on the Black Sea, Turkey

Details of 18 projects from 9 Member Nations were submitted under this sector in both bored and cut and cover tunnels. The projects comprise:

- New railways in mountainous areas to take traffic off the roads to reduce congestion, noise and pollution on adjacent roads
- New railways in urban areas to minimise environmental effects in sensitive areas
- New high speed railways

NEW RAILWAYS IN MOUNTAINOUS AREAS

In Austria five railway routes have been extended in mountainous areas, mainly in tunnel, to relieve the existing mountainous roads of congestion and pollution. Approximately 13km of bored tunnel and over 5km of cut and cover tunnel have been constructed for these five projects.

NEW RAILWAYS IN URBAN AREAS TO MINIMISE ENVIRONMENTAL EFFECTS IN SENSITIVE AREAS

In Brisbane, Australia, a total length of 2km of new railway has been placed underground in a number of tunnels, for social, heritage and environmental reasons. In Japan several kilometres of new railway have been placed underground to reduce noise, vibration and pollution to the local areas.

The Asker – Jong Tunnel, Norway, which was opened in 2006, runs below populated and sensitive recreation areas and an extension closer to the city will be constructed for the same reasons.

Malmö is located at the southern tip of Sweden on the eastside of the Oresund. The opening of the Oresund crossing between Denmark and Sweden in 2000 provided a road and rail link between the two countries. At the present time the rail link passes around Malmö and enters into the Malmö terminal station. The Malmö Citytunnel (Plate 26), whose construction commenced in 2005, will bring the rail link directly into Malmö with two suburban stations within Malmö. The new rail link passes some environmental

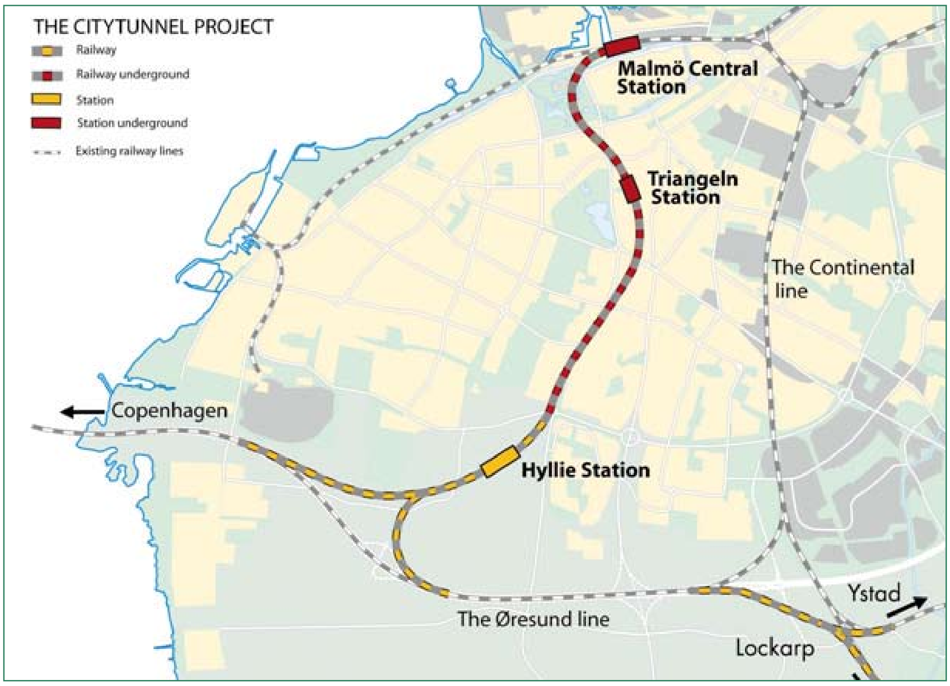

Plate 26 - Malmo City Tunnel, Sweden

sensitive areas and could not be constructed in cut and cover or in cutting. The new underground route under Malmö will substantially reduce the number of trains on the existing route around Malmö, and reduce its current noise and other environmental problems.

NEW HIGH SPEED RAILWAYS

Lengths of alignment of new high speed railways are more and more being placed underground on account of environmental reasons.

The line between Vienna and Salzburg, Austria, has recently been built to reduce road traffic and to improve the environment. The Sieberg tunnel along this route is 6.5km long. The alignment for the high speed railway at Melk, Austria, now bypasses the town in a 2.8km long tunnel to minimise the environmental effects of the high speed line.

The Balla Hill tunnel on the Slovenian Hungarian railway is located in the vicinity of Nagyakos village in Hungary. The original scheme was the construction of an alignment in deep cutting through a nature reserve. The 375m long tunnel is called «a tunnel of environmental protection».

The first bored tunnel in The Netherlands was built in the early 1990s. Recently four projects have been partly constructed in tunnel for environmental reasons. Two of the tunnels on the Betuwroute high speed railway were not originally designed to be in tunnel. At Zevenaar, the Pannerdens Kanal tunnel was originally a bridge, but was changed to a bored tunnel to reduce environmental effects during the construction and operation. The Botlek tunnel in Rotterdam was originally an immersed tunnel under the harbour, but was changed to a bored tunnel on account of environmental reasons. The Sophia tunnel, the third tunnel along the route, was chosen to save an environmentally vulnerable area and to reduce environmental effects during the construction and operation.

The 7.2km long Groene Hart tunnel (Plate 27) on the new high speed railway from Amsterdam to Rotterdam is well known for being placed underground solely for environmental reasons. The route between Amsterdam and Rotterdam passes through some of the most densely populated areas of The Netherlands. The Groene Hart is the one of the last greenbelt areas.

To the east of Leiden is one of the remaining rural landscapes in this area of The Netherlands. The «Groene Hart», or Green Heart, is a traditional farm landscape and a decision was taken to place the alignment in a tunnel to preserve the rural atmosphere by reason of the environment.

The high speed railway Eidsvoll tunnel, Norway, was constructed, in an unusual way for Norway, through soft ground to avoid disturbance to a churchyard and an historical area.

The Channel Tunnel Rail Link, UK, has had a chequered career. The first proposal in the early 1970s placed long lengths underground as it was developed supposedly for environmental reason and eventually its ever increasing cost led to the cancellation of the Channel Tunnel in 1974. The Scheme was revived in he late 1980's and a concession to design, construct and operate the railway, was awarded in 1996.

On Section 1 of the Channel Tunnel, there were a number of short cut and cover tunnels, ranging from 120 to 360m in length, which were placed underground in sensitive areas for environmental reasons. At Mersham village, the cut and cover tunnel was constructed to lessen the impact of the high speed link on the village and in addition reunited the village which had been cut in two by the existing railway. The cut and cover construction was covered by a meadow and gave a safer environment for the local school.

Plate 27 - Groene Hart Railway Tunnel, The Netherlands

Twelve projects from 5 Member Nations were submitted under this sector. The storage projects varied from wine, paper, LPG, gas, oil, petroleum, chemicals, low, to moderately active and high level nuclear waste. There was one emplacement project for high level nuclear waste and one disposal projects for industrial waste from zinc and nickel production and for general waste.

The facilities are located in caverns or tunnels and were constructed in sandstone, granite, gneiss or quartz, with the largest excavated cavern 27m wide by 21m high and 175m long. In salt domes, the maximum height of a cavern, for strategic petroleum reserves, is over 840m high.

The main environmental reasons for going underground were:

- Safety and reduced risk of fire
- The safe and controlled storage or emplacement and the avoidance of pollution of aquifers or fjords

SAFETY AND REDUCED RISK

Following a fire at a surface storage facility for LPG close to Sydney Airport, Australia, a decision was taken to store LPG underground in a cavern for safety reasons and to reduce the risk of fire. In the Czech Republic a similar facility, the Haje-Pribam underground storage for gas, was constructed near Pribam. The storage is arranged in tunnels of total length of 45km long with a 13 - 15m^2 cross section. In the USA, the Louisiana Avery Island strategic petroleum reserve is placed in caverns in salt domes.

SAFE AND CONTROLLED STORAGE OR EMPLACEMENT AND THE AVOIDANCE OF POLLUTION OF AQUIFERS AND FJORDS

In Norway and Sweden there are a number of schemes where caverns have been constructed for safe and controlled storage or emplacement of waste. Both countries have facilities for the safe storage of nuclear waste.

In Norway, the Himdalen (Plates 28 and 29) repository for low and medium active nuclear waste has been planned for an operational period to 2030. The repository is based upon the safe and reliable storage in four caverns for 1000 years. Each cavern is 12m wide by 12.5m high and 54.5m long. The waste, in drums, is placed and cast into concrete and protected from water seepage by impervious cover and sealing. The caverns are drained and the concept is based upon inward gradient to prevent contamination of the ground water.

Plate 28 - Himdalen, Norway

In Norway there have also been a number of facilities for the storage of waste in caverns to prevent accidental and environmental problems caused by leakage into the local aquifers or the fjords. The Falconbridge Nikkelverk facility in Norway is for the safe and controlled disposal of the waste from the production of nickel. Five caverns have been constructed with capacities of 11,000m^3 to 83,000m^3.

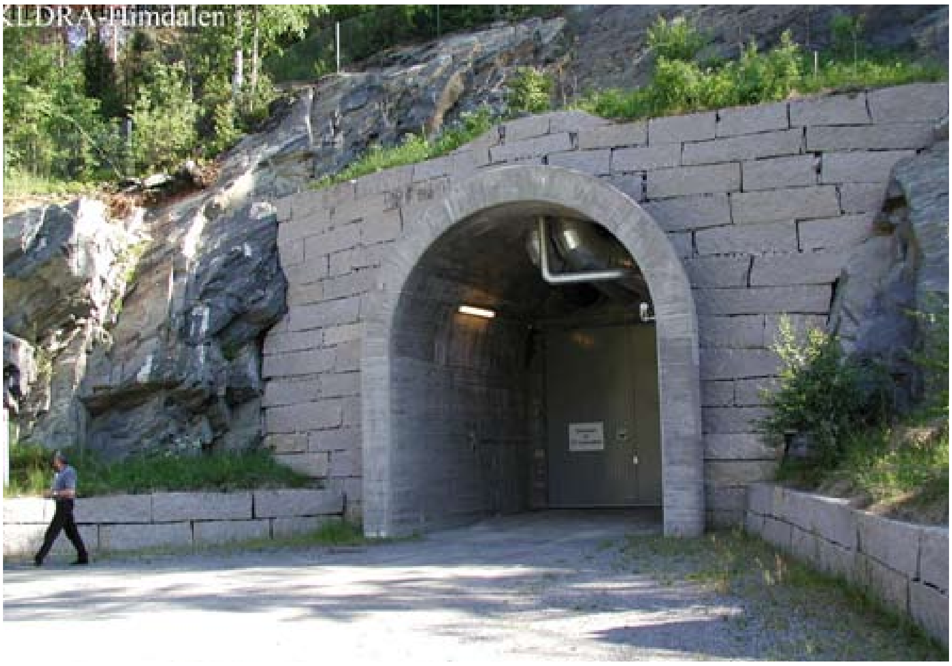

Plate 29 - Entrance to Himdalen, Norway

Plate 30 - Plan of Zinc Underground Storage Facility at Odda, Norway

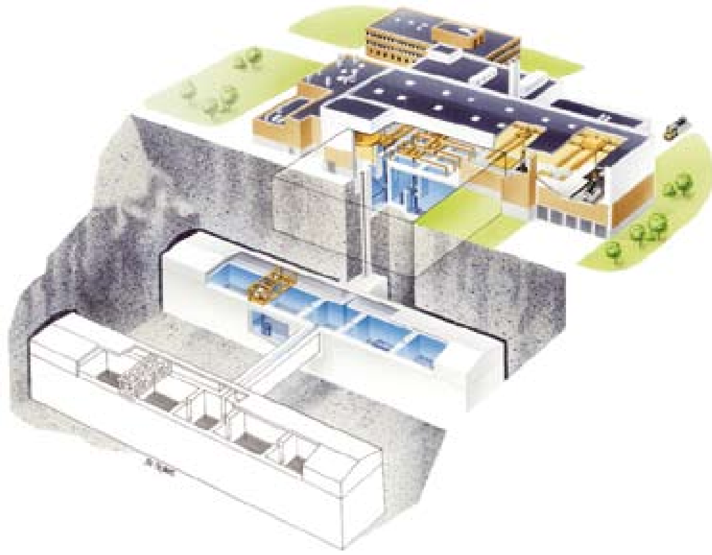

Plate 31 - Clab Facility, Sweden

At Odda, Norway, (Plate 30) the industrial waste from the production of zinc is placed in rock caverns. The first six caverns and cavern No. 8 each have a capacity of 70,000m² each corresponding to the waste from one years production, while caverns Nos 7 and 9 to 12 have double the capacity. «Jumbo Caverns» with a capacity of up to 650,000m² are currently planned.

At Lindesnes, Norway, there are storage tanks in rock caverns for chemicals to prevent accidental leakage of the materials. At Halden, Norway, there is a facility for the storage of paper together with a railway shunting yard, to safeguard the recreational areas along the sea coastline. The crushing plant, rock quarry and waste disposal facility at Stendafjellet, Norway, was constructed in a series of tunnels constructed to reduce pollution of the nearby fjord and reduced pollution and noise.

The Oskarshamn CLAB facility, Sweden (Plate 31), consists of two caverns for the interim storage of spent nuclear fuel. The facility is adjacent to the Äspö hard rock laboratory, a research site for the final deep storage of high level waste.

The Yucca Mountain facility in Nevada, USA, for the emplacement and retrieval of high level nuclear waste is located in a tunnel and has been designed for future development. The facility is protected by engineering barriers for the longterm isolation from the environment.

A different form of storage is the storage of wines in caverns in California, Washington, Oregon and North Carolina, USA. Over 120 caverns have been constructed from plan areas of 15m² to 5,000m² but typically 50m². They have been constructed in various rock and soil strata. Underground storage reduces evaporation of the wine and there are substantial benefits with the underground storage. Although the capital costs are high the running costs are dramatically reduced and more economical in the long term. The facilities often have special chambers for visitors, receptions, musical and other events.

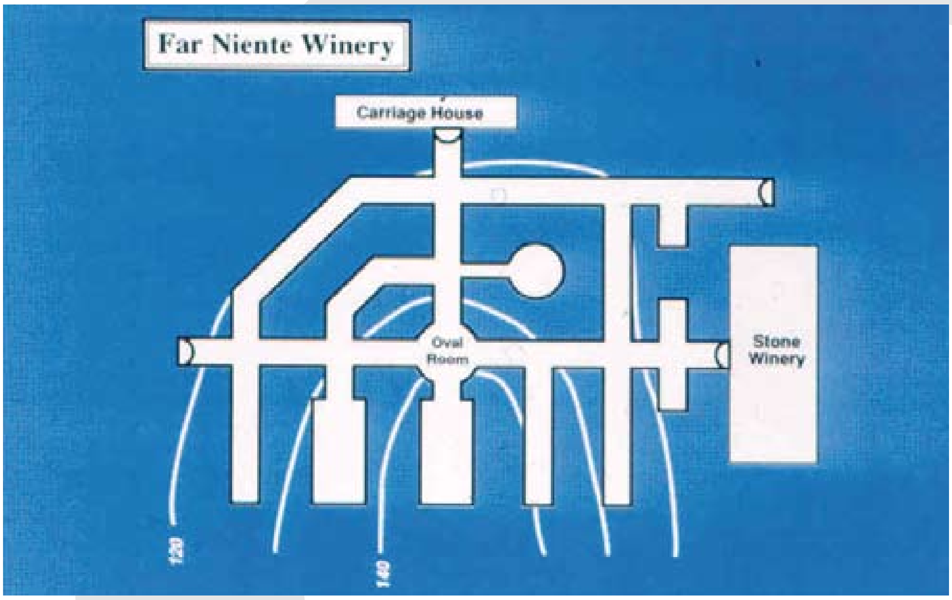

Plate 32 - Plan of Wine Storage Facility

Thirteen projects from 6 Member Nations were submitted under this sector. The projects have been divided into sewage treatment plants, storm water facilities and clean water projects.

SEWAGE TREATMENT PLANTS

In Norway, many sewage treatment works have been placed in caverns or tunnels to reduce the pollution of the fjords. Three of the plants are in Trondheim and one each in Oslo, Kragero and Porsgrunn. One such plant is the Knarrdalstrand and – Blide treatment plant (Plate 33).

At Lidingo, in Sweden, a water treatment plant has been placed underground in 2 caverns as an alternative to a surface plant. In Scotland, UK, the Broomfield treatment works was placed completely below ground level by cut and cover as it was in an Area of Outstanding Natural Beauty and a surface works would not have been acceptable.

WATER STORAGE FACILITIES

Sewage systems often take surface water which may overflow during or after heavy rainfall causing major environmental concerns and problems. The provision of underground stormwater caverns, tunnels or cut and cover structures where the surplus water can be temporarily stored are now quite common. After the heavy rainfall the water is allowed to flow, or is pumped, into the treatment works for treatment in the normal way.

There have been concerns for many years that there is pollution in the Sydney Harbour, Australia, during storms. The Sydney Northside Storage facility has been constructed to reduce the pollution and was opened in advance of the Sydney Olympic games in 2000. The facility has 20km of tunnel between 3.8m and 6.6m in diameter.

In Oslo, Norway, the Lysaker outfall system stores water during storms to prevent pollution of the sea shore.

Plate 33 - Knarrdalstrand and – Blide Treatment Plant, Norway

CLEAN WATER PROJECTS

At Alesund, Norway, a clean water storage facility has been placed underground in the urban area. While in Boston, USA, the water supply system was placed in 27km of tunnel because of environmental concerns in the densely populated area of Boston.

>> Underground facilities in urban or rural projects

Seven projects from 4 Member Nations countries fall into this sector. There are interesting projects for public underground facilities which ranges from underground car parks in caverns to the storage of the national archives.

In Sydney, Australia, the Conservatorium of Music was originally built within the Botanical gardens. An extension to the Conservatorium was constructed in a cavern underground to preserve the Royal Botanical Gardens and to retain archaeological site.

In Norway three extremely different schemes were illustrated; an underground car park at Molde, a repository for the National Archives in two caverns in Olso and the Olympic ice skating arena at Gjøvik with a span of 62m. There are also several underground sport halls, swimming halls combined with underground civil defence caverns and bomb shelters.

An interesting underground facility, the Svalbard Global Seed vault, in Norway, has been constructed in the permafrost and will have the capacity to house more than four million unique types of seed from around the world. The facility provides three identical storage halls each of approximately 1,250m^3 located 120m into the permafrost. They will be kept at a constant temperature of -18ºC.

In Moscow, Russia, the Okhotny Ryad (Plates 34 and 35) shopping centre in the very heart of the City, near to Red Square, is underground and can be entered from the subway, car parks and hotels. There are three levels and over 100 shops, restaurants cafes, banks etc., which are attracting large daily crowds.

The Large Hadron Collider at CERN between Switzerland and France has recently constructed a number of new caverns for the installation of equipment during the updating of the system as they were less environmentally sensitive underground.

Plate 34 - Okhotny Ryad, Moscow, Russia

Plate 35 - Okhotny Ryad, Moscow, Russia © tsereteli.ru

SUBWAY PROJECT

Six projects from 3 Member Nations illustrate environmental concerns and sustainable developments on subway projects. In Brasilia, Brazil, the South Wing Subway Link was placed below ground under an area of forest where there were 6000 protected trees. The stations were allowed to be constructed by means of cut and cover, but all removed trees had to be replanted.

The subway system in Bochum, Germany, was placed underground to relieve the urban area of congestion and noise. While in Japan three sections of the public transport system or elevated railway were placed underground to reduce vibration, noise and to improve the landscape. In addition the removal of elevated structures improved the general appearance of open areas.

In San Diego, USA, the Mission Valley East Extension ran close to the College University, an adjacent area of redevelopment and the State Highway. The route was changed to go underground with a station conveniently located at the Students Union with access to the adjacent redevelopment site. The higher cost and longer route had longterm and sustainable development benefits that outweighed the alternative elevated route along the state highway.

SERVICES

Two groups of projects from 2 Member Nations are in this category for service tunnels. In Sweden at Solna a high voltage cable tunnel was constructed to reduce the effects of the magnetic field on public health.

In London, UK, many cable tunnels have been constructed across the city to take high voltage cables to reduce the environmental impact and for security reasons. One of the recent projects is the Dartford cable tunnel. Instead of crossing the River Thames using pylons, the high voltage cables were placed in a tunnel which was completed in 2006.

For the Olympic Games in London in 2012 it is necessary to move 52 unsightly electricity pylons and cables over and near the Olympic Park, to allow the construction of the Park. These cables have now been placed in a two new cable tunnels which were completed in 2008.

MINING PROJECTS

Mining, both open cast and at depth, has been carried out for many centuries. On the one hand open cast mining may be cheaper, but it has a major effect on the environment. The Rana Mines in northern Norway which were initially open cast have now gone underground to save the environment. There is an unusual situation in mid Norway with the Røros Copper mines (Plates 36 and 37) which opened in 1645 and closed in 1975.

The mining waste heaps from the melting stoves and the city of Røros are now protected as historical sites and are an UNESCO World Heritage site. Although the spoil areas are contaminated, removal of material is prohibited. The sites are monitored with seepage measurement and sampling.

The Etropole, Negurshtitza Elllatzite, Bulgaria, copper works has a tunnel to take the polluted water away from the river to avoid pollution.

Plate 36 - Røros copper mines

Plate 37 - Røros City

RECOMMENDATIONS

Finally when clients are evaluating whether to place a given project underground for environmental or sustainable development reasons, this Working Group provides a check list (Appendix A) of environmental considerations for the client to consider during the Planning, Construction, Operations, and Post Operations stages of the project, which require diligent studies, investigations , modelling and monitoring during the course of the project to manage risks. The main categories of the checklist are as follows:

- Management and Organisation Considerations
- Architectural and Landscaping Considerations
- Water Issues
- Air Issues
- Ground Contamination
- Noise and Vibrations
- Natural Biotopes
- Natural Resources

This Working Group intends to provide recommendations and examples to the above checklist in the future. The checklist may not be entirely comprehensive since some items may be specific and vary by country and project. The checklist is intended as an aid to the client in decision making, in alternative analyses, and in evaluating the challenges and solutions for project management.

APPENDIX A: CHECKLIST OF KEY TOPICS TO CONSIDER WHEN MANAGING AN UNDERGROUND OR TUNNEL PROJECT.

Management and Organisation Considerations

- Requirements and Guidelines/Criteria
- Environmental Risk Assessments
- Environmental Impact Assessments
- Environmental Monitoring
- Jurisdictional and regulatory agencies

Architectural and Landscaping Considerations

- Permanent structures and tunnel entrances
- Construction sites, access roads and tunnel spoil deposit areas
- Public environment, residential areas, internal and external
- Historical and cultural sites
- External issues
  - Tunnel spoil deposits
  - Access roads and construction plant
  - Tunnel entrances, portals
  - Ventilation towers
- Internal issues
  - Lighting and colours
  - Internal climate
  - Shape and visual effects
  - Various effects

Water Issues

- Marine water
- Freshwater, lakes, streams, rivers, wetland, etc.
- Groundwater
- Settlement and deformation
- Waste, spill water and pollution
- Recipients
- Chemical/grout materials to control water

Air Issues

- Construction equipment and activities
- Gases from blasting
- Traffic pollution
- Dust
- Radiation
- Local climate

Ground Contamination

- Hazardous waste or contaminated ground

Noise and Vibrations

- Construction methods and equipment
- Mechanical excavation
- Blasting excavation
- Ventilation fans
- Construction mucking equipment
- Traffic noise

Natural Biotopes

- Vegetation
- Wildlife
- Freshwater biotopes
- Marine biotopes
- Wetlands, ponds, and lakes

Natural Resources

- Freshwater resources
- Groundwater resources
- Mineral and material resources
- Forest production and farmland

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