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# Session 6 - MAINTENANCE AND REPAIR
## Keynote address

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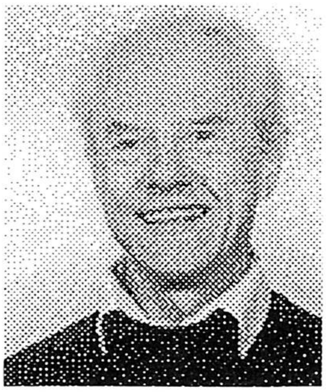

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**Summary**

The maintenance and repair processes on underground structures show the peculiarity that one of the structure faces is in contact with the ground. It is not visible, and not easily accessible. The main risk concerns water inflows and damages they are likely to produce. Another risk is the possible voids and decompressed zones, at the contact between ground and lining. The condition of the structure must be followed up on a regular basis, by means of non destructive (sonic, electric, magnetic, deformation measurements) or destructive (boreholes, cores and diagraphies) investigation methods.
ITA (International Tunnelling Association) published in 1991 a recommendation of the 'Damaging Effects of Water on Tunnels during Working Life'. This Association is preparing now the publication of a guide on repair methods.

Our session is devoted to the maintenance and repair of underground structures. Our paper is drafted on behalf of the International Tunnelling Association and its Working Group #6 on 'Maintenance and Repair of Underground Structures'.

## 1. Which structures are actually concerned?

Many purposes can be served by the underground infrastructures: These can be sewerage collectors, pressure gas ducts, water ducts; technical galleries for the passage of electric cables and tubes; pressure water ducts to supply hydro-power plants; metro tunnels, railway tunnels, road tunnels; underground caverns: metro stations, hydro-power plants, liquid gas or hydrocarbide storage caverns, Olympic pools, etc.

**These structures are quite differing regarding their excavation mode, the composition of their external and internal structure, their inner equipment. But all have a common character: They are built in the subsoil (or under water for immersed tunnel caissons).**

Regarding maintenance, their common characteristics are that they are submitted to an aggressive surrounding medium, situated on one side only of the structure wall, and that a free access is not possible to the rear side of this wall, to examine it or repair it.

Therefore, we will not consider here the structure parts which are not in direct contact with the ground. For these latter - either structures or equipment - we consider that they are subject to the usual maintenance and repair techniques developed for the structures in the open, bridges or buildings for instance.

Regarding this, it can be noticed that bridge foundations, located in the ground and non totally inspectable by their nature, could be assimilated to underground structures.

Moreover, we have to distinguish the structures that cannot be inspected by the personnel (tubes, ducts, and galleries under 1.5-2 m in diameter) from those that can be. We will pay particular attention to these latter. The first ones call for very special investigation and repair techniques, which are beyond our present purpose.

Among the various underground structures, if considering the construction methods, we must differentiate the excavated tunnels, the cut-and-covers and the immersed tunnels. In the following this distinction will be emphasised only when necessary for the proper understanding of repair modes that can be considered.

**To summarise, we are concerned here by:**
**- the long galleries, collectors and tunnels (road, metro, rail)**
**- either excavated, or cut-and-cover, or immersed caissons**
**- and we are interested only in the structure elements in contact with the surrounding ground (or water)**

## 2. Which is the extent of the problem, which are the risks that may be feared?

We must distinguish the old structures from the newest ones.

### 2.1 The old structures

In the 19th century, then in the first half of the 20th century, the excavated structures generally were lined with masonry or brickwork. The construction proceeded by excavating small galleries supported by wooden piles and planks. Between the masonry vault and the ground, the contact was not always very close, because voids were filled in with stones, mortar poured without extrusion, even perishable materials, such as wood. The encountered disorders then can be of two types:

- the ground, badly confined by the masonry, is getting decompressed, destabilised. Thus the masonry itself rests wrongly on the ground and can break up, resulting in possible crumbling or collapsing;

- the underground water circulation induces a progressive dissolution of the mortar bonding the masonry elements; the joints get weaker; the water inflows inside the gallery are increasing. In addition of the inconvenience brought by these water inflows to all inner structures and equipment, such dissolution can lead to the decay of the structure.

To summarise, for the old structures:
- **walls are in masonry or brickwork;**
- **the contact with the ground is not always well ensured;**
- **the lining is not quite waterproof and the joints can get dissolved.**

## 2.2 The recent structures

Essentially since the second half of the 20th century, they are lined with framed concrete, either unreinforced or reinforced, or with prefabricated segments for the shield-driven tunnels. Also, during the construction process, precautions are taken on the one part to ensure a good confinement of ground, and on the other part to guarantee a proper inner waterproofing.

To summarise, for the recent structures:
- **the walls are in framed concrete, or made of prefabricated, generally concrete segments;**
- **the contact to the ground is properly ensured;**
- **the lining is theoretically waterproof, except in some weak points (construction joints, shrinkage cracks).**

## 2.3 Which damages can be feared most generally?

### *2.3.1 The first enemy is water.*

As a first reason, due its only presence: On a carriageway, it can make the surface sliding; on overhead lines, it can induce short-circuits. By its presence in the air loaded with acid ions released by the combustion engine vehicles, it is a source of a particularly severe corrosion. For instance, attacks to aluminium frames, ruined in less than 10 years, have been recorded in the French-Italian Mont-Blanc tunnel. In winter it can freeze and produce stalagmites and stalactites, both of them likely to cause damages or accidents.

Then, as a chemical agent weakening the lining: The water circulation, if water is very pure or corrosive to the lining, can widen the newly formed cracks and induces an increased output; this phenomenon worsens progressively. It can dissolve the ground behind the lining (gypseous ground or weathered dolomite).

In some extreme cases this could lead to a long-range decay of the structure.

**It should be noticed, however, a strong difference with the bridge structures; the underground walls generally are not in pre-stressed concrete and often are unreinforced. They do not induce the same fear of cable or reinforcement corrosion.**

Finally, if ideally the aim *a priori* is to obtain a properly waterproofed structure, it can be admitted that waterproofing cannot be total, and has not to be. Relevant recommendations have been published on this.

### *2.3.2 Then, the possible voids between the ground and the lining*

They have already been mentioned: On the one part they can host water circulation (see above). On the other part, at their location, the lining does not lean upon the ground. This can have two consequences:

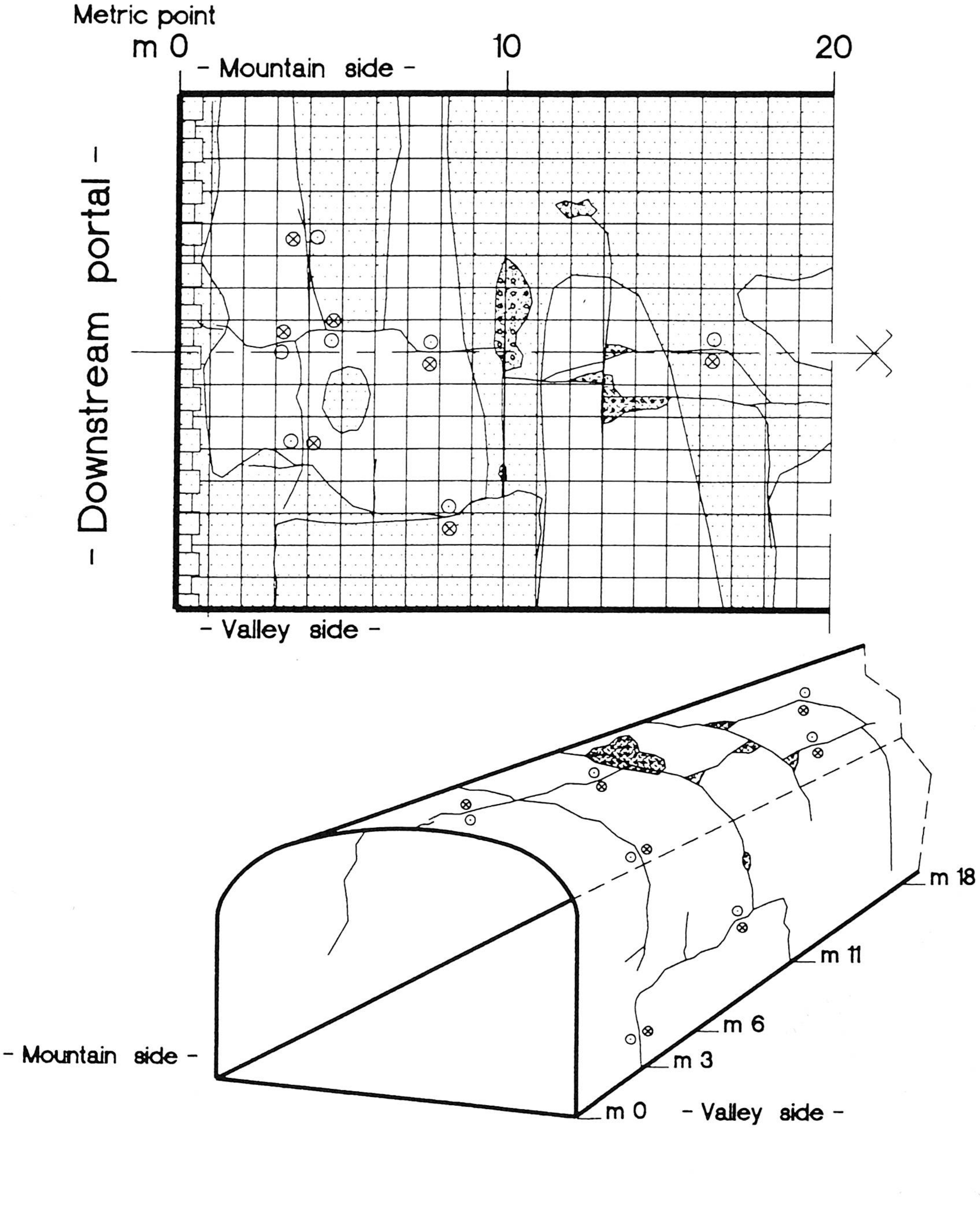



*Fig. 1 Representation of cracking affecting a concrete tunnel portal*

First, the unconfined ground, which is also submitted to stresses from the ground load, is then submitted to very unsymmetrical efforts (the stress deviator is high). It may get weathered, loose its self-supporting qualities, and the volume of voids in the contact zone with the lining may expand.

Also, in this zone, the lining itself is not confined. If submitted to high tearing efforts it can be led to break up.

The permeability of a rock mass can be increased by several powers 10 near the tunnel. This is the case for drill-and-blast tunnels, where no special precautions have been taken and where rock is cracked up to 1 to 2 metres in depth. This can be encountered on depths of about one radius in some deep tunnels where the stresses near the wall exceed the rock strength, especially if the breaking comes with dilatancy. As the opening of cracks is more marked when their longitudinal orientation is parallel to the wall, permeability develops mainly in the longitudinal direction. We must therefore keep in mind that the ground at the periphery of certain tunnels can be considered as a longitudinal drain.

Therefore it is essential to check, already at the construction phase, that no voids are left between the ground and the lining; then, during the structure working life, that possible water movements and dissolution are not likely to produce some.

*2.3.3 Lastly, the ground itself can press increasingly on the lining with time (case of some grounds)*
Most deformations in the lining, especially towards the cavity inside, correspond to comprehensive ground-lining movements, which must also be monitored very closely. They can correspond to insufficiencies in the lining bearing capacity, which did not exist when the structure was put into operation. They can result from a progressive deterioration with time of the geotechnical ground characteristics, due to the decompression caused by the construction process (softening phenomenon). The ground pressure, especially on the invert, can also augment if ground is likely to swell when saturated with water (swelling ground).

## 3. The main investigation methods

We differentiate the direct, visual establishments and the indirect establishments. These latter obviously concern the hidden parts of the structure, including the contact zone with the ground.

### 3.1 The direct establishments

They concern first the water inflows, then the cracks, lastly the lining deformations.

*3.1.1 Water inflows*
They can be seen immediately, except when too small and therefore corresponding to water quantities that evaporate as they reach the intrados. They correspond either to wet spots, or to seeping or flowing along cracks, or to seeping or flowing along construction joints.

*3.1.2 The lining deformations*
They generally are convergences, i.e. displacements of the lining inwards the structure. If there is any suspicion about their occurrence, they must be measured and their evolution followed up carefully.

According to the geological and geotechnical nature of the ground, adequate investigations will be conducted using non destructive geophysical investigations and boring and coring, until the phenomenon is fully understood and the remedies defined.

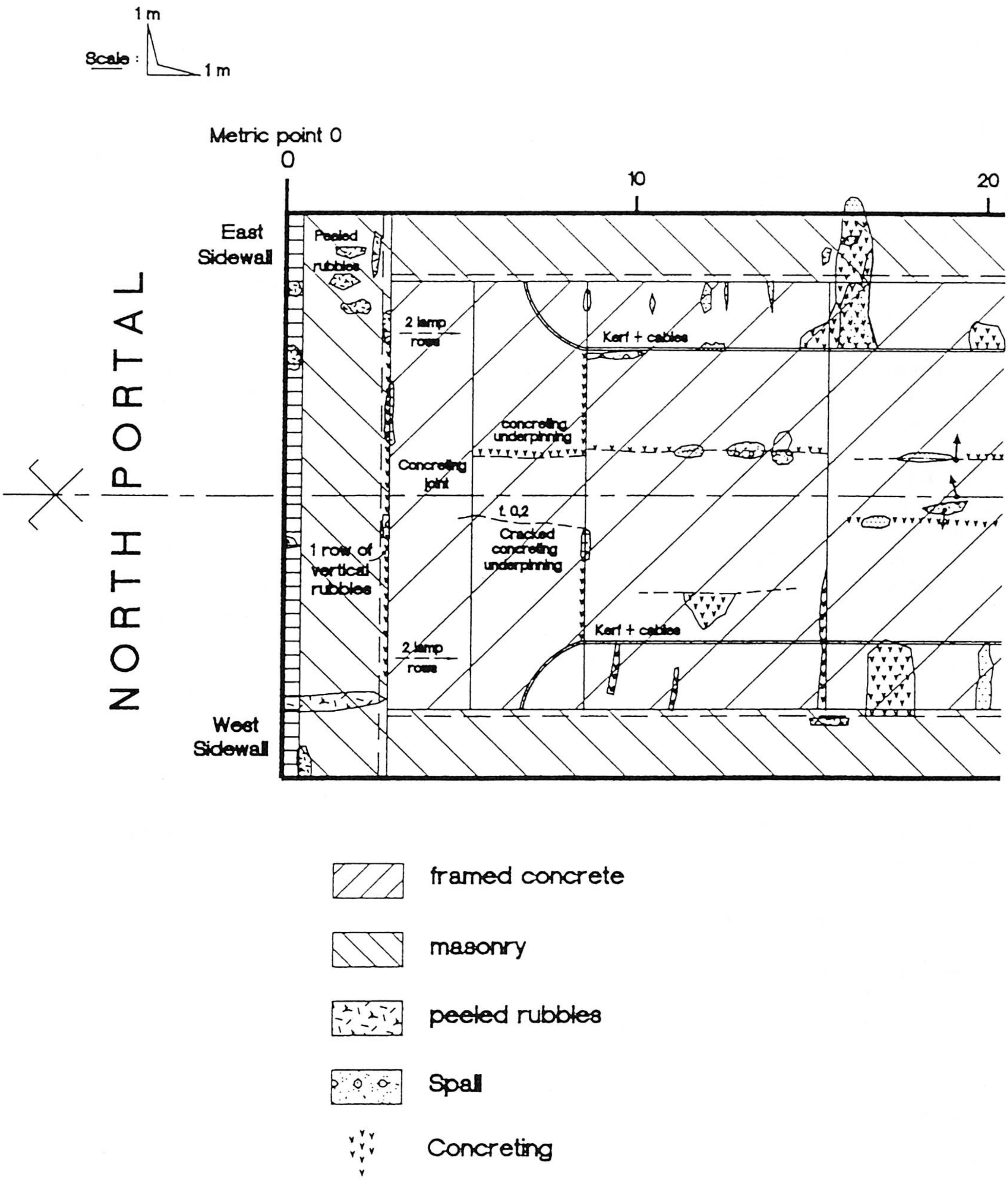



*Fig. 2 Excerpt from the intrados survey of SISTERON tunnel, France*

### 3.2 The indirect establishments

As soon as the direct establishments let assume that disorders are likely to occur, or as soon as they are feared in one particular zone, it can be wished to know if voids exist behind the lining; or which is the ground nature; or if the lining is reinforced and how.

We must state that here the term 'lining' means both the inside lining of the structure and the preliminary support installed during the construction process. It can show a most varying composition according to the ground nature. It can be made of steel ribs and sprayed concrete for instance. If no detailed and accurate drawings are available, the nature of ribs is not known, neither their distance or sprayed concrete thickness. Unfortunately this happens frequently.

The geophysical methods - radar, electric measurements, sonic measurements - aim at answering these questions.

## 4. QICW evaluation (Quality Index for Civil Works)

This is an example of what is currently done in France to quantify the quality condition of structures.

The Ministry of Equipment, Transportation and Tourism (Road Directorate) launched in 1992 a process of evaluation and synthesis of costs to maintain and reinstate the public national road patrimony.

The road network was classified into six categories, for which the NRQI (National Road Quality Image) is measured each year. An identical process is conducted for the Civil Works patrimony, assessed at 18,400 bridges with span over 2 m.

The Road Directorate charged CETU (Tunnels Design Centre to the Ministry of Equipment) of performing this task for tunnels and of assessing the cost of reinstatement of the existing patrimony whilst distinguishing civil engineering parts and equipment, taking account of the major role of the surrounding ground in this type of structure.

### 4.1 Method fundamental

The Quality Image for Civil Works (tunnels) differentiates portals, lining, and auxiliary objects. The type of lining is an essential criterion to evaluate the condition of the structure, insofar as the possible failures that may affect it are specific. The auxiliary objects include the ventilation ducts, excavated technical rooms, shafts and galleries, by-passes, along with the waterproofing, drainage and sewerage elements.

The tunnel classification is based on a general quotation of their structure through the evaluation of the condition of their constitutive parts.

• Class 1 correspond to the apparently good condition structures, which only require the usual maintenance processes, as defined in the national instruction on survey of civil works (leaflet #40)
• Class 2 gathers those structures which require a specialised maintenance process or minor repairs
Class 2: no emergency

## Q.I.C.W. - Tunnels

**QUOTATION METHOD
CIVIL ENGINEERING**

| Class | Structures | Water inflows |
|---|---|---|
| 1 | Good condition | Dry |
| 2 | Specialised maintenance required | Unendangering water |
| 2E | Evolution must be checked | Strong water output must be checked |
| 2S | People's safety endangered | |
| 3 | Important disorders | Weakened stability |
| 3U | Urgent intervention | Urgent intervention |

## Q.I.C.W. - Tunnels

**QUOTATION METHOD
EQUIPMENT**

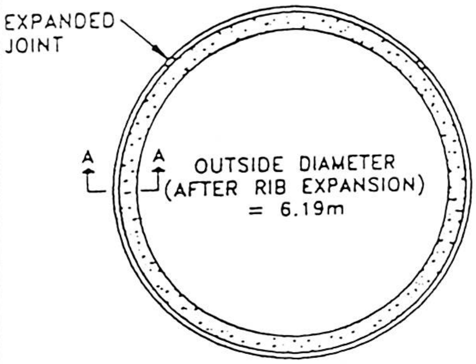
| CLASS Average working life = A.W.L. | INDEX E | S | U |
|---|---|---|---|
| 1 Age < A.W.L. | | | |
| 2 Age < A.W.L. + 5 years | Evolution must be checked | Safety involved | Urgent intervention |
| 3 Age > A.W.L. + 5 years | Evolution must be checked | Safety involved | Urgent intervention |

*Fig. 3 Q.I.C.W. - Tunnels. Quotation method: civil engineering and equipment*

COUNTRY CANADA

| Classification | |
|---|---|
| Classification | WATER STOPPAGE |
| Method | CRACK INJECTION |
| **Outline of tunnel** | |
| Type | SUBWAY |
| Tunnelling method | TBM |
| Length of service | 10 YEARS |
| Lining materials | (Primary) STEEL RIBS/ WOODEN LAGGING |
| | (Secondary) CAST-IN-PLACE CONCRETE |
| Degree of leakage | DRIP |
| Location of leakage | SIDEWALLS |
| Presence of frost | NO |

Cross-section of tunnel (Add geological information if available) GLACIAL TILL



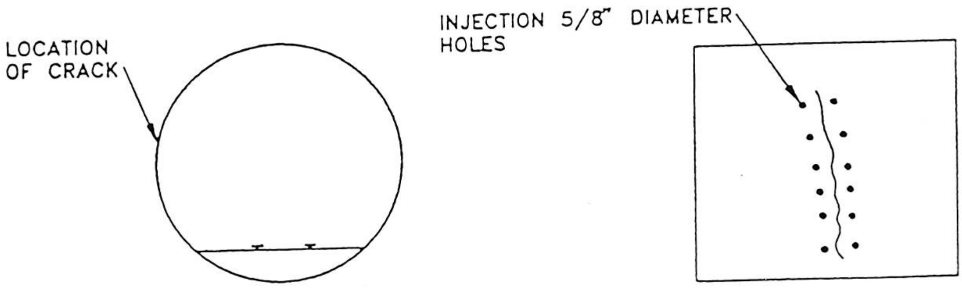

Special conditions in the choice of method
- LIMITATION OF CLEARANCE
- SMALL TOOLS ONLY NEEDED

Description of trouble caused by water leakage
PREVENTION OF DETERIORATION OF ELECTRICAL EQUIPMENT

Materials used
CHEMICAL GROUT

Outline of method
INJECTION HOLES ARE DRILLED AT 30° ANGLE TO THE CRACK. HOLES ARE DRILLED ON BOTH SIDES OF THE CRACK AND THEN ARE INJECTED WITH A CHEMICAL GROUT THAT EXPANDS AND SEALS CRACK WHEN IT COMES INTO CONTACT WITH WATER.

Schema of method




Evaluation of method (workability, cost, etc.)
METHOD IS TIME CONSUMING AND EXPENSIVE

Post-repair Inspection Observations
CRACKS HAVE MINOR LEAKS AFTER 10 YEARS

*Fig. 4 Example of measures against water leakage in tunnel*

Class 2E: emergency to prevent the quick development of more important disorders by evolution (E)
Class 2S: emergency to guarantee safety (S) to the users
• Class 3 corresponds to the structures the general stability of which is likely to be endangered, thus require repair works
Class 3: no emergency
Class 3U: emergency to perform the works due to unsafe conditions to the users, or risk of quick evolution of the disorders.

It should be noticed that repair works for tunnels Class 3 must often be undertaken only after investigations - boring and auscultation - for a better adaptation to the frequently poorly known local geotechnical conditions. The findings of the QICW evaluation are recorded on a document peculiar to each structure, stating the functional or background characteristics that may affect its condition, the dates of detailed inspections, and the allotted synthesis class.

## 5. Repairs: the ITA working programme

ITA published in 1991 a 'Report on the Damaging Effects of Water on Tunnels during their Working Like' (T&UST, Issue No.1, 1991). This report was elaborated by Working Group #6 on 'Maintenance and Repair of Underground Structures'.

This document is currently being updated, complemented and extended.

It will consist of two parts:

### 5.1 Methods for counteracting water flows through tunnel walls

*5.1.1 Introduction*
Setting the scene. Mention water problems report. Outline scope, methodology and contents of report. Presumes, failures of design, workmanship or materials, and identification of a problem.

*5.1.2 Objectives of counteractive measures*
Differing tunnel uses have differing infiltration/tolerance limits. The effects of infiltration are different for various ground conditions and linings. In some cases exfiltration is a problem. For each tunnel, therefore, the objective must be determined before design of remedial work commences. "Absolutely dry. Free of dripping. Drippings permitted, total inflow restricted". WG has distinguished four main categories of remedial work for inflows: list only, refer to following.

*5.1.3 Categories of counteractive measures*
Four categories:
- conduction - where it is acceptable to allow controlled drainage of the water towards the tunnel invert, for channelling along the tunnel towards a sump for disposal
- surface sealing - measures undertaken at the inner surface of the lining
- lining reinstatement - measures undertaken to establish or re-establish the impermeability of the lining
- elimination at source - measures undertaken outside the lining.

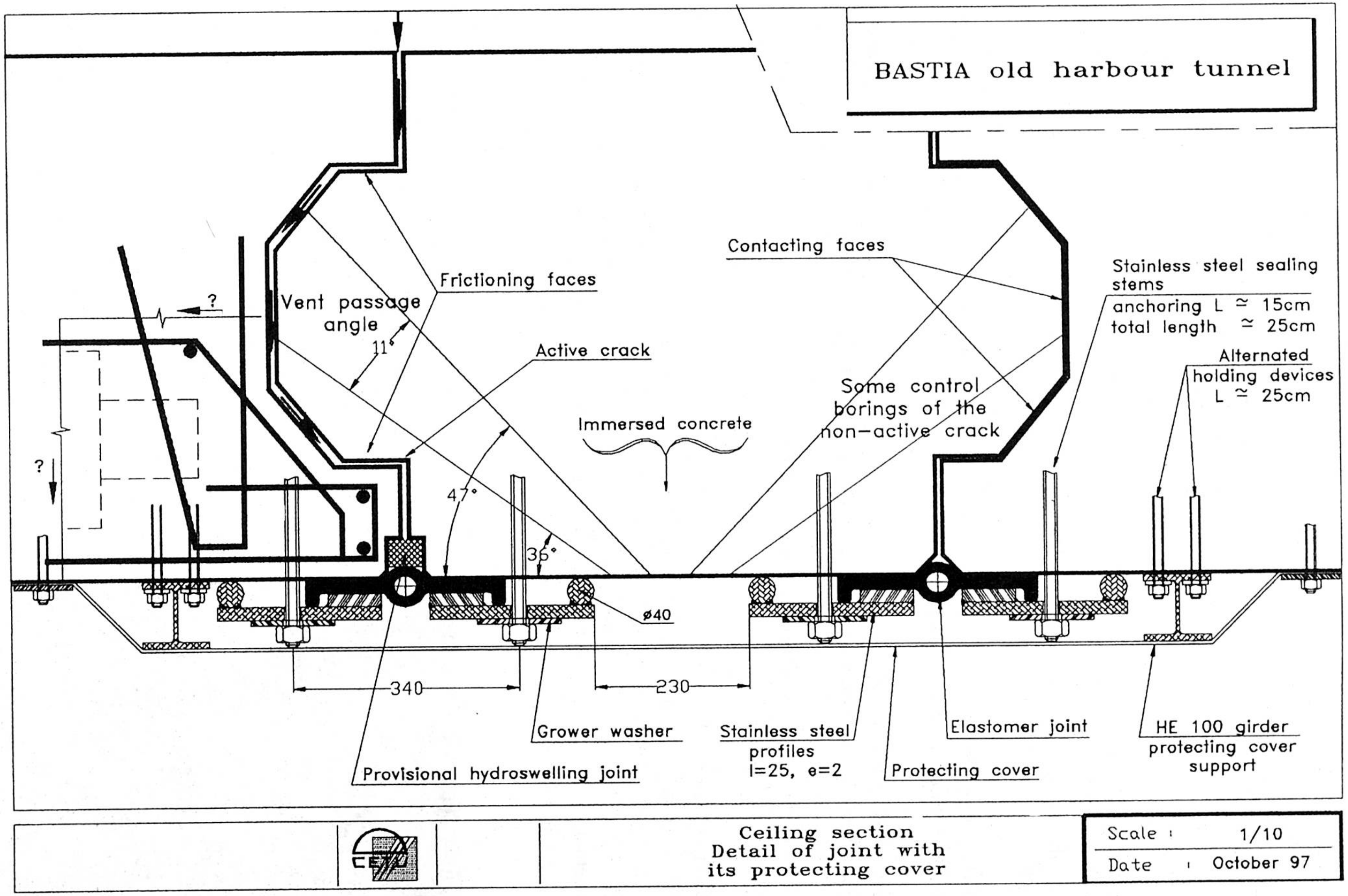



*Fig. 5 BASTIA old harbour tunnel. Ceiling section: detail of joint with its protecting cover*

These apply differently to different types of lining:
- masonry and brickwork
- sprayed or cast-in-situ concrete
- segmental steel, cast iron or concrete

Also depend on space availability. Unlined tunnels a special case, only first and last categories apply. Application discussed under separate headings. Sometimes used together.

*5.1.4 Conduction methods*

Free-standing inner shell
Channelling (with or without external drainage)
Membrane and inner protective lining

**5.2 Study on performance of applied materials for repair of damage to tunnels linings (excluding sealing of water leakage)**

Once the draft of the first Part was well advanced, it was judged that the other main causes of damages affecting the tunnel linings and their repairs should not be disregarded. Among these:

*5.2.1 Attack of concrete and reinforced concrete linings by acids resulting from moisture and exhaust gases of vehicles*

*5.2.2 Consequences of a fire*

A recent, impressive example is the fire of a lorry-transporting train in the Channel tunnel. The lining was partly damaged or destroyed on a length of 500 m. The repair work consisted of curing the damaged concrete, using a pneumatic hammer and pressure water jets; the reinforcement was kept; it was re-covered with sprayed concrete. The temperature was presumed to exceed 1000°C.

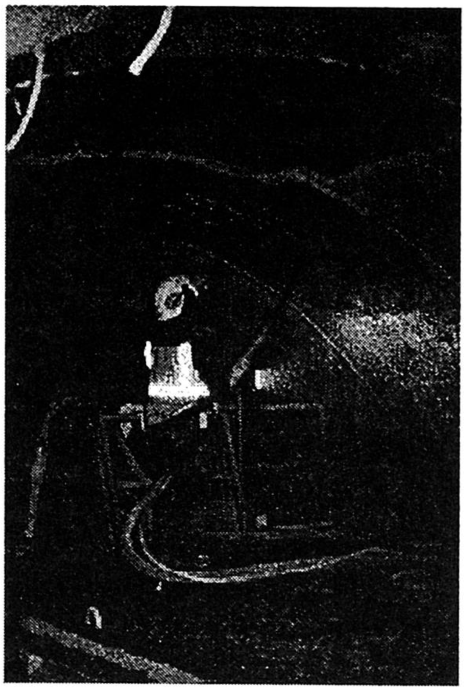


*Fig. 6 Channel tunnel, after the fire of 18 November 1996*
*Repair of lining with sprayed concrete*

The PIARC (World Road Association) Road Tunnels Committee defined the temperature curves to be considered in case of a fire in a road tunnel (see PIARC Publication on Fire and Smoke Control, 1998). This Association made an agreement with ITA, so that ITA investigate the damages likely to be caused to the structures by fire and how to cope with them. These two topics will be developed by the ITA Working Group #6 from 1998.

Other possible causes of damages to linings will be considered, e.g. 'Qualification of Engineers for Carrying out Underground Inspections and Assessment of Repair Needs'.

*5.2.3 Repair cost*

The conditions the tunnels are submitted to are so differing that it is impossible to quote an average repair cost. We can mention two examples.

• Boston Road Tunnels (see Henry Russel - ITA WG#6)
The reinforced concrete linings were attacked by acids from the vehicle exhaust gases, dissolved in seepage water. The cost of repair works was: 4700 ECU per linear metre of tube.

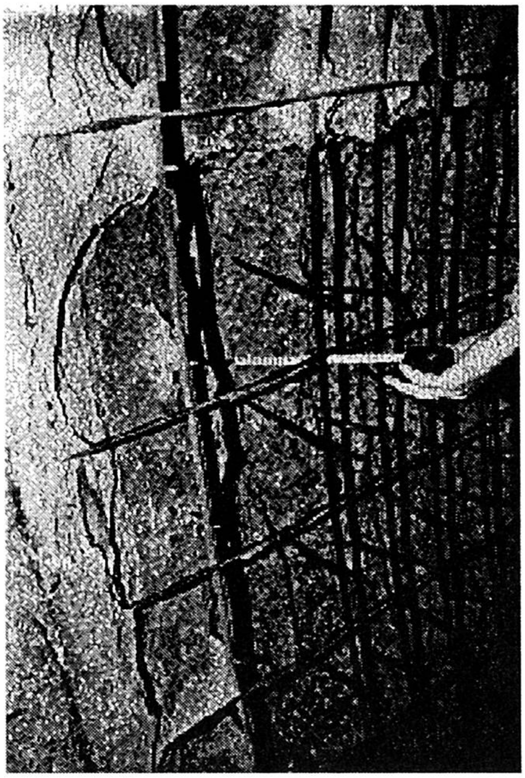


*Fig.7 Channel tunnel, after the fire of 18 November 1996.*
*After curing of the concrete surface spalling, the reinforcement is maintained.*

• The 40 tubes of road tunnels on the Nice and Menton belt motorway (see RGRA, Special Issue #1, 1991): Their total length is 19 km. They are lined with unreinforced framed concrete. The ventilation - if any - is longitudinal. Fifteen to twenty-five years after their opening they need civil engineering repairs assessed 2200 ECU per linear metre of tube in average. The expenses will be distributed over 15 years. **This gives 150 ECU per metre and per year, i.e. about 1% of the construction cost of the structure.**

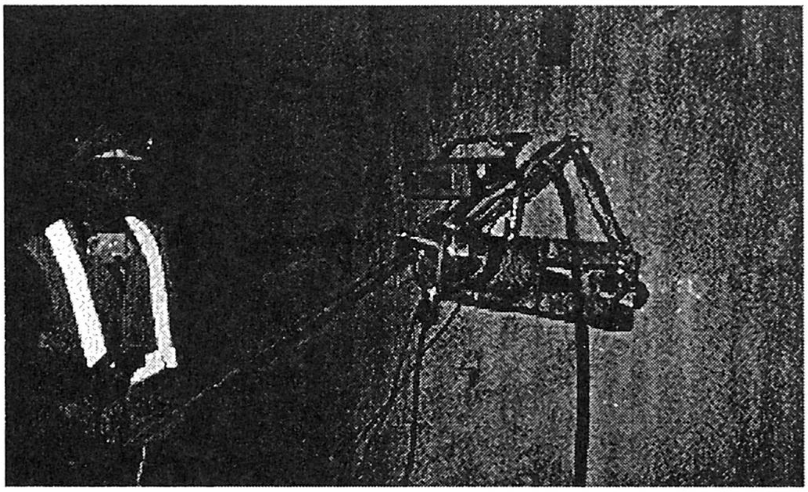


*Fig. 8 After sprayed concreting, tearing tests on pins to test the equipment securing conditions*

The assessment method of the quality of a lining, as used in France (QICW, Quality Index for Civil Works) also leads to the necessity **to plan a civil engineering maintenance budget, every year, of about 1% of the structure construction cost.**

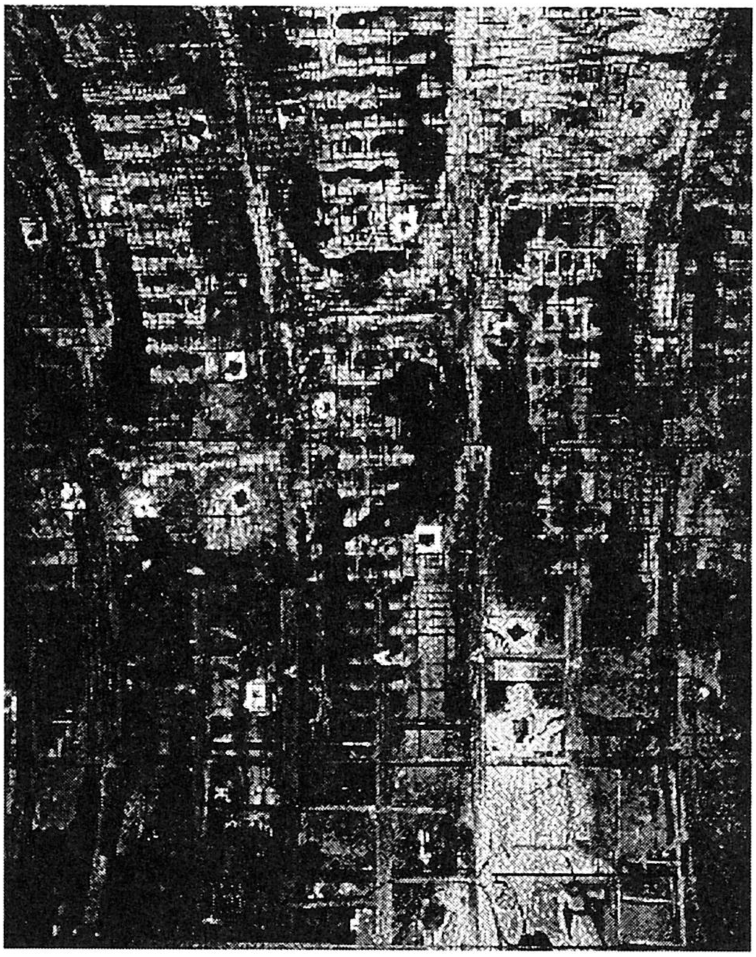


*Fig. 9 Channel tunnel, after the fire of 18 November 1996*
*Rings 19797 to 800, south side. Middle of Zone 3, the most damaged.*
*The ribs are being removed, after reinforcing with systematic bolting.*

## 6. Conclusions

The cruciality of corrosion problems on the underground structure linings is rather badly known for the modern tunnels, which are too recent. The efficiency of the curing watertightness devices, even if good on short-range (1 to 3 years) must always be estimated on long-range, i.e. 10 years and more. There now, the results are fairly poorer. Everything , therefore, must be undertaken, already at the design stage, to ensure an excellent watertightness, adapted to the peculiar needs of the structure. Fortunately concrete is increasingly improving, increasingly waterproof: For road tunnels with framed linings, most countries have initiated a wide use of polyvinyl continuous waterproofing sheets. The oldest are only about thirty years old and their integrity shows no doubt yet (but for how long?).

Suitable investigation means are available to understand the nature of a lining on a zone of restricted surface: Core borings, boring diagraphies generally bring the required information.

On the other part, if a long length of structure must be investigated quickly, non destructive methods must be called for. Their capacity to give the precise location in space of a possible incident is still restricted. Whilst they are invaluable to make a first diagnosis on the ground condition behind the lining, they must always be complemented with core borings in the doubtful zones.

It is the art of engineers, as expressed in their recommendations, to define the construction methods, then the repair methods, which will remain efficient several tens years after their achievement. But at this moment, unfortunately, the original designers generally are no more here to judge it.

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