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Integrity checking methodology for Monte Bianco tunnel

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INTEGRITY CHECKING METHODOLOGY FOR MONTE BIANCO TUNNEL

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SPEA - INGEGNERIA EUROPEA, ISMES, GEOCONSULT

At the beginning of 1987 a series of non destructive tests, was made in order to define the integrity of the Italian part of the tunnel of Monte Bianco and therefore decide the appropriate for restoration.

This survey campaign was aimed at defining:

- existing deteriorations
- mechanics of tunnel lining
- state of tension of tunnel lining
- state of stress and integrity of the rock behind the tunnel lining
- contact rock-tunnel lining

The utilised methodology for integrity checking is exposed togheter with the two phases of investigations:

- preliminary global investigation (survey and radar)
- local finalised investigations (ultrasonic speed, sclerometer, windsor gun, boring and laboratory tests, flat-jack tests and tension tripping, sonic logging and cross-hole measurements.

Results of investigations are partially exposed and two defferent numerical classification systems are presented, by means of "damage index" in order to try and to give an objective evaluation of the integrity of different sections of tunnel.

1. INTRODUCTION

In 1986, Spea - Ingegneria Europea, with the collaboration of Geoconsult and ISMES, carried out, on behalf of Società Italiana per il Traforo del Monte Bianco, a campaign of mostly non-destructive tests at the Italian end of the Mont Blanc tunnel, to check its structural soundness and provide for necessary repairs.

The global-approach operative methodology used for this job seems to the writers to be especially interesting although evidently open to improvements in the future. It is however felt that it can represent a basis for discussion and a guideline for an overall check of the soundness of the many tunnels of the Italian road, motorway and railway networks.

2. METHODOLOGICAL APPROACH

Careful investigation of the more significant characteristics of a tunnel, such as:

- current state of decay
- the mechanical characteristics of the concrete lining
- the stress pattern of the lining
- the structural and mechanical properties and stresses of the rock mass behind the lining
- the characteristics of the rock-lining interface

is needed to diagnose its soundness.

The method followed to check the static conditions of the tunnel is outlined in Fig. 1.

The campaign was organized in two stages. In the first stage, the damaged zones were identified and classified; in the second stage, the static conditions of the structure were analyzed in detail.

FIRST STAGE

First of all, a historical research was carried out to gather all the information, chiefly of a geological character (Fig. 2), necessary to determine the construction and maintenance problems of the structure. Then, the entire Italian section was visually inspected to determine the lining's superficial damage (cracks, superficial alterations of the concrete, water seepage, etc.), using motor vehicles with special equipment, so as to explore the entire surface of the tunnel.

Besides examining the lining surface, tests were made to check the conditions of the rock-lining interface. The radar detection technique, based on the reflection of electromagnetic waves at the interface between materials having different dielectric constants, proved to be especially effective. Gaps between the lining and the rock mass generate a reflected signal, clearly visible in the recordings (fig. 3). Other radar signal reflections occur in the presence of moisture or concrete decay or in the presence of metal bodies (wirenets, ribs). This type of checking can reach a depth of 2-3 m from the lining surface, and can therefore detect possible faults in the rock mass (cavities or wide

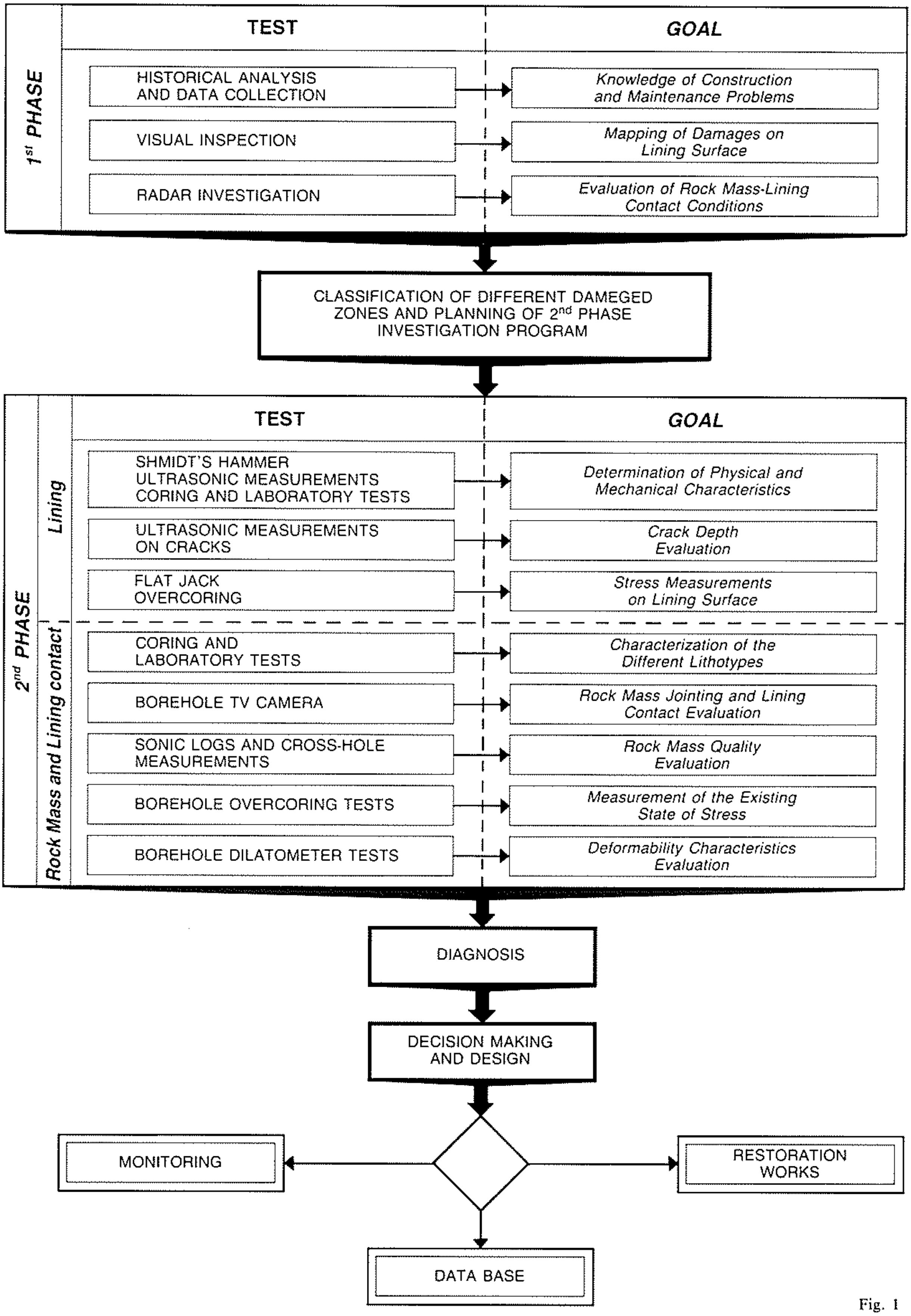

1st PHASE
TEST
GOAL
HISTORICAL ANALYSIS AND DATA COLLECTION
Knowledge of Construction and Maintenance Problems
VISUAL INSPECTION
Mapping of Damages on Lining Surface
RADAR INVESTIGATION
Evaluation of Rock Mass-Lining Contact Conditions
CLASSIFICATION OF DIFFERENT DAMEGED ZONES AND PLANNING OF 2nd PHASE INVESTIGATION PROGRAM
2nd PHASE
Lining
Rock Mass and Lining contact
TEST
GOAL
SHMIDT'S HAMMER
ULTRASONIC MEASUREMENTS
CORING AND LABORATORY TESTS
Determination of Physical and Mechanical Characteristics
ULTRASONIC MEASUREMENTS ON CRACKS
Crack Depth Evaluation
FLAT JACK
OVERCORING
Stress Measurements on Lining Surface
CORING AND LABORATORY TESTS
Characterization of the Different Lithotypes
BOREHOLE TV CAMERA
Rock Mass Jointing and Lining Contact Evaluation
SONIC LOGS AND CROSS-HOLE MEASUREMENTS
Rock Mass Quality Evaluation
BOREHOLE OVERCORING TESTS
Measurement of the Existing State of Stress
BOREHOLE DILATOMETER TESTS
Deformability Characteristics Evaluation
DIAGNOSIS
DECISION MAKING AND DESIGN
MONITORING
RESTORATION WORKS
DATA BASE

Fig. 1

cracks). The radar readings were taken with a suitably equipped mobile laboratory, fitted with an orientable arm carriyng the antenna that generates and receives the electromagnetic waves (300-900 MHz).
Occasionally, the thermovisual detection technique was also used to examine certain areas evidently affected by water seepage.

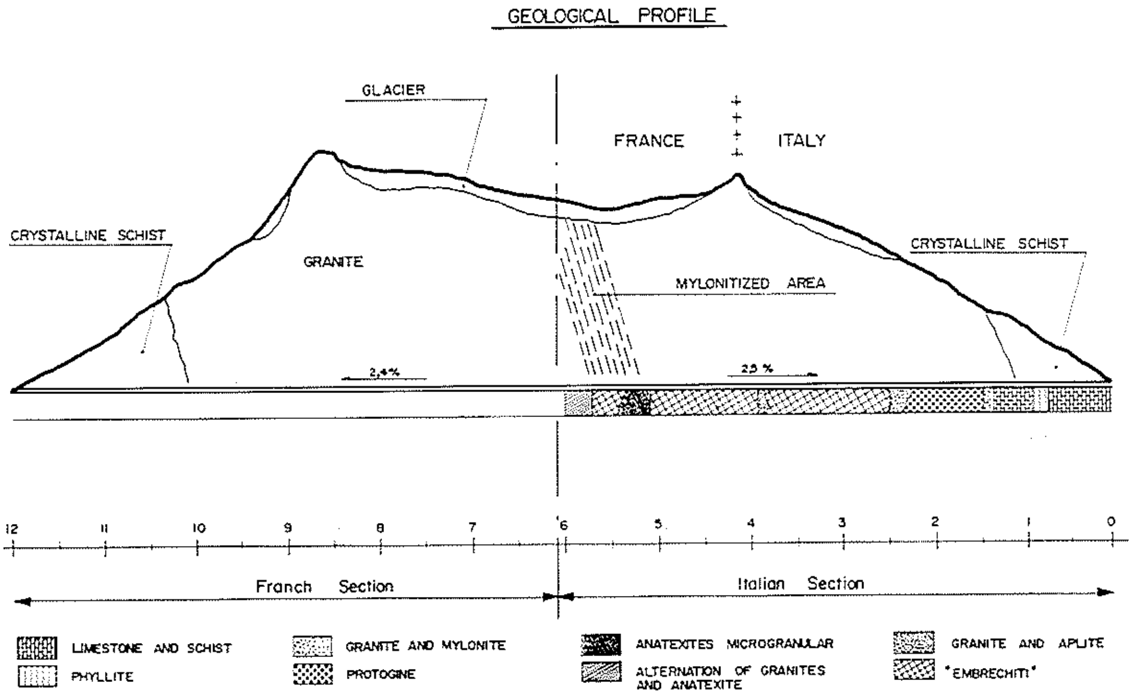


Fig. 2

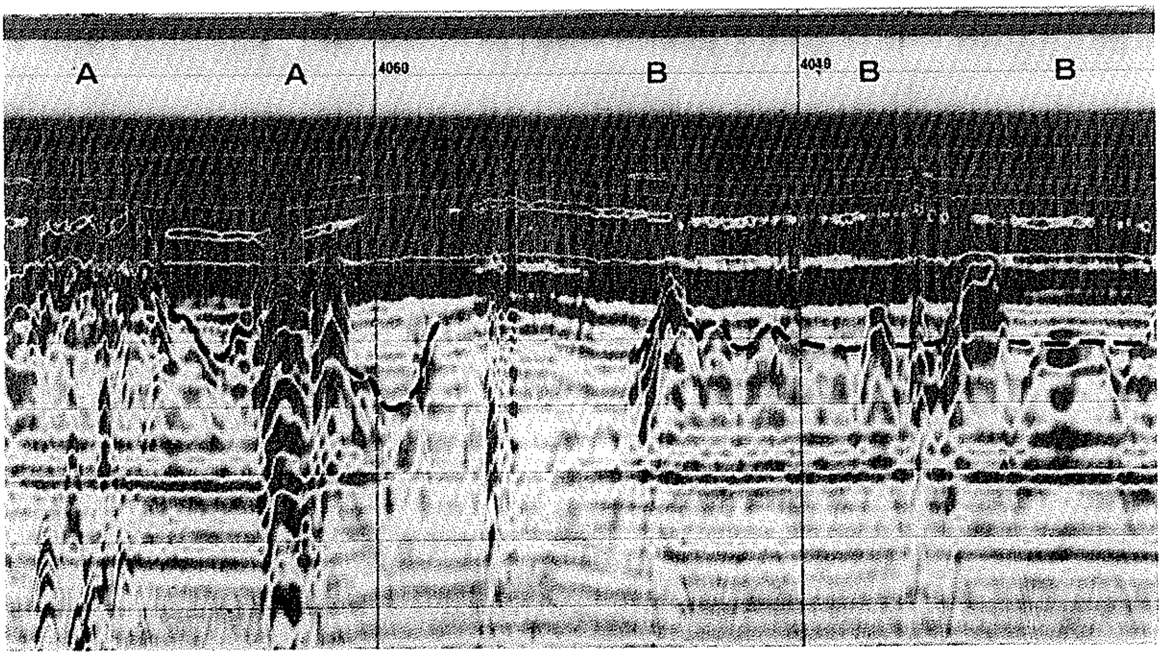


Fig. 3

CLASSIFICATION OF DIFFERENTLY DAMAGED ZONES AND PLANNING OF THE 2ND STAGE OF THE INVESTIGATION

The data collected during the first stage led to classifying the areas into highly damaged, damaged and slightly damaged, and made it possible to draw up a more detailed, targeted investigation plan.

Specifically:

- In the highly damaged areas, all the tests required to determine the state of decay were carried out as thor-oughly as possible.
- In the damaged areas, only the measurements and tests required to obtain information on the type of decay were made.
- In the slightly damaged areas, only the mechanical properties of the concrete lining were examined by a combination of ultrasonic tests, hardness tests and Windsor gun measurements.

Dynamic tests were carried out tentatively in certain sections by recording the structure's response to the excitation force generated by a vibrator with constant-amplitude sinusoidal force or by a train of ultrasonic pulses.

SECOND STAGE

Analysis of the Static Conditions of the Lining

Tests were first made on the site and in the laboratory to evaluate the physical and mechanical characteristics of the concrete of the tunnel lining. The tests included ultrasonic and hardness tests on the concrete surface and lab tests on samples taken by coring.

The depth of the lining cracks was determined with ultrasonic tests, by positioning the emitter and receiver at opposite sides of the crack.

The measure of the state of stress in the lining was especially interesting for evaluating the static conditions of the lining. The measurements were made by the stress-release technique. According to a first test method, stress relieving was achieved by making a plane cut perpendicular to the wall and the original stress pattern was reinstated by inserting a thin, flat jack (Fig.4). This made it possible to determine the stress pattern in a direction perpendicular to the jack plane.

By another technique, stress release was obtained by overcoring. In this case, the strain measured during release permitted evaluating the planar stress pattern at the test spot, when the material characteristics, E and , are known.

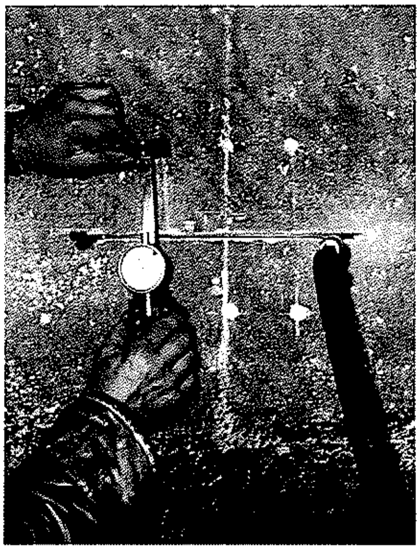


Fig. 4

Analysis of the Characteristics of the Rock Mass and Rock-Lining Interface

In the areas where the radar detector indicated anomalies at rock-lining interface, samples were taken by mechanical coring. The samples were taken at a depth sufficient to investigate also the structural characteristics of the rock mass in the bore. Lab tests were carried out on the cores to identify the characteristics of the concrete and of the rocks.
The following tests were made in the bores:

- TV-camera probing for visual inspection (with front and lateral objectives) of the conditions of the lining and of the structural characteristics of the rock mass.
- Sonic logs and cross-hole measurements, to evaluate in detail the sound velocity in the rock mass and at lining-rock interface.
- Borehole overcoring tests, to measure the stress conditions in the rock mass at various distances from the bore, by a doorstopper technique.
- Dilatomieter tests determining the deformability modulus of the rock mass.

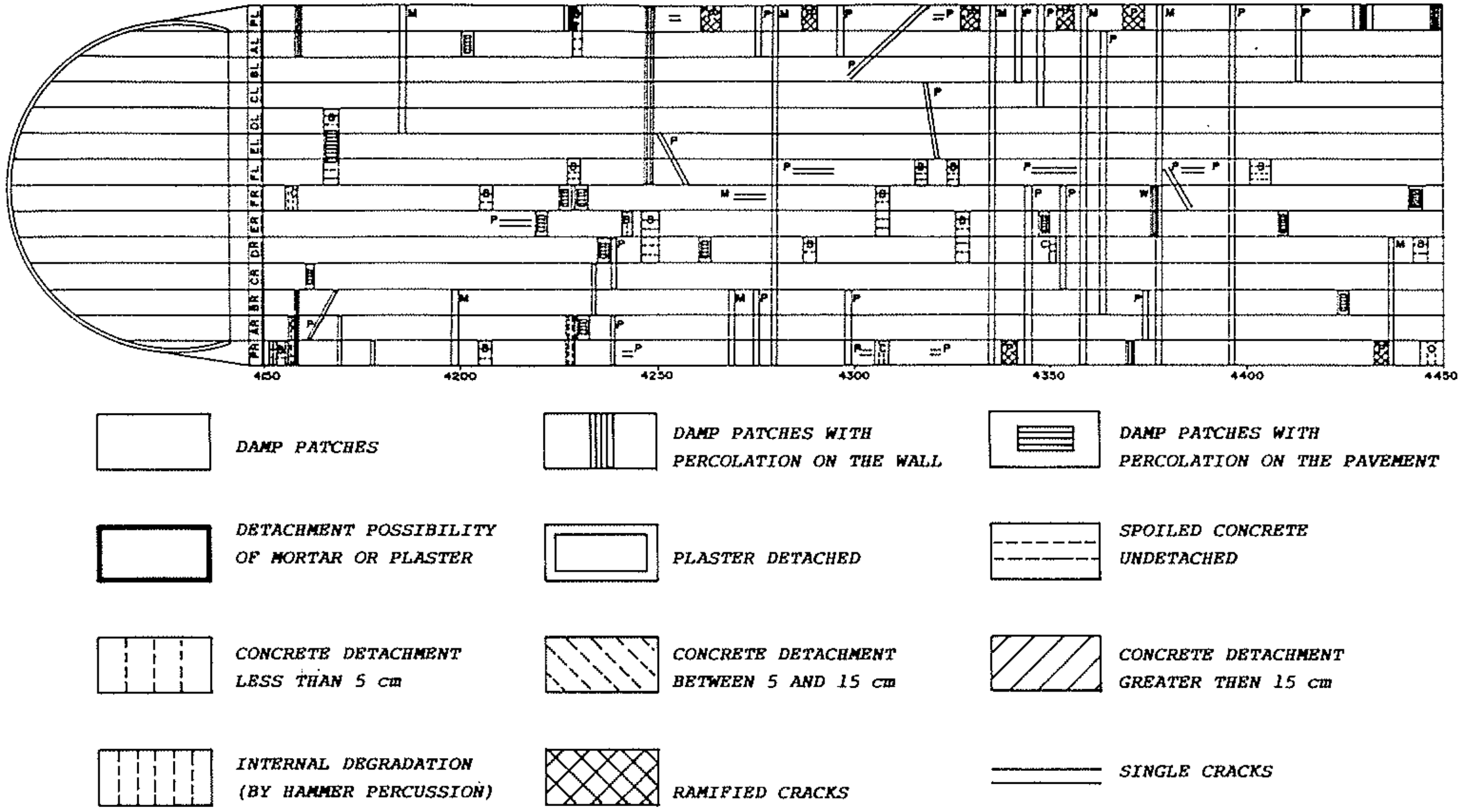
DIAGNOSIS

After the first-stage and second-stage tests, a clear, detailed diagnosis of the inspected sections of the tunnel could be drawn up. This made it possible to decide on the consolidation operations needed and to go over to the planning stage.
In general, concurrently with the stage of repair planning, a plan for structure monitoring could be set up.

3. RESULT OF THE INVESTIGATION

The results of the visual examination were entered on a graph by subdividing the lining perimeter into 14 sections, each having - the first and last excepted - an equal plane-projected width (Fig. 5).
The damages were classified by a combination of graphic symbols and an alphabetic notation, so as to identify the damage (e.g., by its extension) better, or evidence its danger-ousness (e.g., concrete decay).
The results of the radar tests were processed by sections of 250 m each, and the sum total of the tunnel lengths that had yielded a disturbed radar signal was calculated and expressed as a percentage of total length.
The percentage of the total length of the tunnel affected by the damages found by visual inspection was also calculated every 250 m.
As apparent from Fig. 6, in which these percentage values are compared, damage of any kind is more likely to be detected by radar than by the naked eye. The percentage of anomalies detected by the instrument is 10 to 40% greater than that detected by the naked eye; in some cases, this difference exceeds 50%, with a peak at 70%.

DISTRESS BY VISUAL INSPECTION



A: *SOUND CONCRETE*
B: *SPOILED CONCRETE NOT PRESENTING COLAPSING DANGER IN A SHORT TERM*
C: *SPOILED CONCRETE WITH WASPS' NEST AND MANUALLY REMOVABLE GRAVEL*
D: *SPOILED CONCRETE WITH PATCHES DETACHMENT DANGER*
G: *DETACHMENT POSSIBILITY OF PLASTER*

W: *DETACHMENT POSSIBILITY OF SEALING MORTAR*
K: *PRESENCE OF DRAIN*
P: *CAPILLARY CRACK*
M: *MEDIUM CRACK*
L: *LARGE CRACK*

Fig. 5

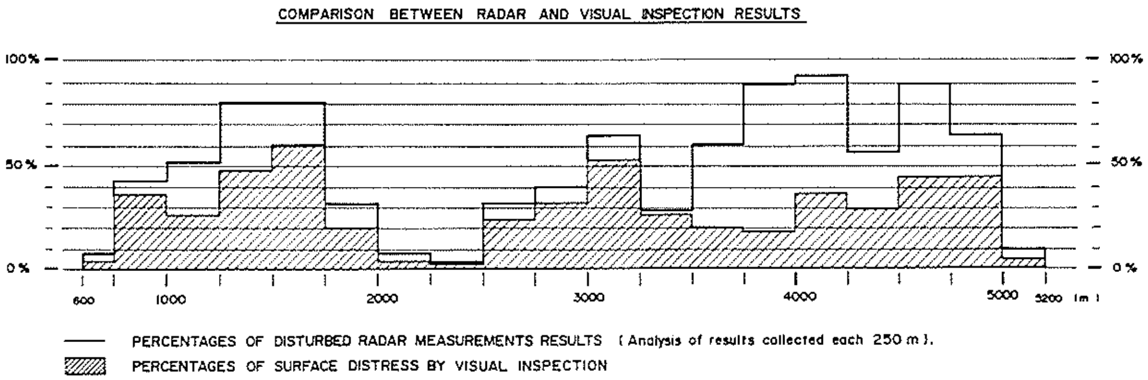


Fig. 6

The distribution of the three different types of areas illustrated before was determined from the results of these preliminary investigations, so that the second-stage investigations could be planned.

In particular, approx. 20% of the entire length was classified as highly damaged, 30% as damaged and the rest as slightly damaged.

The results of all the first-stage and second-stage tests on the various types of sections were then analyzed to obtain a global evaluation of the soundness of each section.

Fig. 7 is part of a drawing showing the results of the tests, the evaluation of the soundness of the tunnel sections and the repairs planned.

4. NUMERICAL CLASSIFICATION SYSTEM

In order to judge the global soundness of the tunnel in the sections believed to be homogeneous, in the most objective way and independently from the whims and skills of the individual technicians, we tried to rank such soundness by numerical values to be considered as "global severeness factors." For this purpose, we followed two different methods.

The first, simplified method considers, for each tunnel section, only those damages above a preset threshold, each being given its "severeness index".

When determining the indices, the implications of each type of damage on the static and functional performance of the tunnel were taken into account.

Specifically, the damages considered in this stage and their severeness indices "i" are:

Distressed concrete thickness	i = 1
Gunite and/or concrete detachments	i = 2
Moisture areas	i = 2
Single or ramified cracks	i = 3
Bad rock/lining interface	i = 3
Fractured rock mass	i = 4

INVESTIGATIONS MEASUREMENT RESULTS, INTEGRITY EVALUATION AND SUGGESTED REPAIRING WORKS

		UNIT	4150 4450	4450 4700	4700 5000	5000 5300	5300
Distress	Moisture areas	—	MEDIUM	MEDIUM	MEDIUM	FEW	MEDIUM
	"Gunite" disjunctions	—	FEW	ABSENT	ABSENT	FEW	ABSENT
	Concrete lining disjunctions	—	MEDIUM	MANY	MANY	MANY	FEW
	Singles cracks	—	MANY TRANSVERSAL	MEDIUM TRANSVERSAL	FEW TRANSVERSAL	MEDIUM TRANSVERSAL	MEDIUM TRANSVERSAL
	Ramified cracks	—	MEDIUM	MEDIUM	MEDIUM	MEDIUM	FEW
Mechanical concrete features	Young modulus (lab)	(Kg/cm^2)	185.000 ÷ 344.300	–	178.000	166.300 ÷ 283.800	130.400 ÷ 283.800
	Compression strength	(Kg/cm^2)	128 ÷ 467	–	118	120 ÷ 440	141 ÷ 449
	Sonic speed	(m/sec)	1700 ÷ 3100	–	1500 ÷ 2000	1400 ÷ 3500	1000 ÷ 3000
	Distressed concrete thickness	—	3 ÷ 8	–	7 ÷ 10	3 ÷ 9	4 ÷ 12
Stress on lining	Max. vertical stress	(Kg/cm^2)	22.2 (M) 33.9 (L)	–	– 15.0 (L)	6.1 (M) 17.4 (L)	9.1 (M) 11.9 (L)
	Min. vertical stress	(Kg/cm^2)	0 (M) 5.5 (L)	–	–	2.3 (M) 11.9 (L)	4.6 (M) –
	Orizontal stress	(Kg/cm^2)	12	–	8	5	7
	Young modulus (site)	(Kg/cm^2)	104.000	–	–	68.000	144.000
Lining cracks	Cracks width	(mm)	0.3 ÷ 0.7	–	–	–	0.3 ÷ 0.4
	Cracks depth	(mm)	80 ÷ 490	–	–	–	90 ÷ 130
	Cracks length	(m)	2 ÷ 10	3 ÷ 5	2 ÷ 4	2 ÷ 10	2 ÷ 10
Rock-lining contact	Evaluation	—	BAD	BAD	BAD	GOOD	–
Rock mass conditions	Average vertical stress	(Kg/cm^2)	300	–	–	–	–
	Sonic speed	(m/sec)	Vc=5700÷6000 Vch=5700÷6000	–	–	–	–
	Integrity conditions	—	MEDIUM FRACTURED ROCK	–	–	–	–
	Max. cracks width	(cm)	2	–	–	–	–

(M) = BY FLATJACK TEST
(L) = BY OVERCORING TEST

Vc = ULTRASONIC SPEED IN SONIC LOGS
Vch = ULTRASONIC SPEED IN CROSS-HOLES MEASUREMENTS

INVESTIGATIONS MEASUREMENT RESULTS

	4150 4450	4450 4700	4700 5000	5000 5300	5300
PRELIMINARY EVALUATION	POOR	MEDIOCRE	MEDIOCRE	MEDIOCRE	MEDIOCRE
ACTUAL INTEGRITY EVALUATION	POOR	MEDIOCRE	MEDIOCRE	MEDIOCRE	SUFFICIENT

INTEGRITY EVALUATION

	4150 4450	4450 4700	4700 5000	5000 5300	5300
Drainages					
Local concrete scarification and restoration	▨	▨	▨	▨	
Crack injection and monitoring	▨			▨	▨
Steel ribs and rock bolts after monitoring					
Cavity injection where necessary	▨	▨	▨		
Concrete surface restoring	▨	▨	▨	▨	▨

SUGGESTED REPAIRING WORKS

Fig. 7

To define the sereveness indices quantitatively, we used the scales shown in Table 1.

In this first method, only the damages having a high index were taken into consideration. In addition, we took into account concrete decay when greater than 6 cm, concrete stresses when greater than 30 kg/cm and the presence of crushed rock.

The global severeness factors were calculated as the sum of the individual "severeness indices"; therefore, they can range from 0, for a tunnel section in top condition, to 15 for a section significantly affected by all the types of damages indicated above.

In this way, the diagram of Table 2 was drawn up and a global evaluation of the soundness of the various tunnel sections was given. The scale used for this evaluation in the simplified method is the following:

Section soundness evaluation	Severeness factor
Good (G)	0 - 2
Sufficient (S)	3 - 5
Mediocre (M)	6 - 8
Poor (P)	9 - 12
Very poor (VP)	> 12

In the second evaluation method, we considered all the damages detected during the various investigations, and ranked each of them with the same severeness index "i" mentioned above and with a ponderal index "J", which accounts for the importance of the individual damage.

Moreover, we distinguished between the loosening of gunite and that of the lining itself, and between a simple and a ramified crack.

SCALE FOR DAMAGE QUANTITY EVALUATION

Quantity evaluation	*Absent*	*Low*	*Medium*	*High*
- Detachments of plaster and/or concrete	*0-2*	*3-5*	*6-10*	*> 10*
- Moisture areas	*0-5*	*6-10*	*10-20*	*> 20*
- Single and/or ramified cracks	*0-2*	*2-5*	*5-10*	*> 10*
- Presence of voids at rock-lining contact	*0-2*	*3-10*	*11-20*	*> 20*

$$\text{Damage quantity (\%)} = \frac{\text{Total length of the damaged zones}}{\text{Total length of the investigated zone}}$$

Tab. 1

INTEGRITY TUNNEL EVALUATION AS 1st METHODOLOGY

Distress	Damage Index	0–100	100–300	300–450	450–700	700–750	750–900	900–1200	1200–1600	1600–2000	2000–2600	2600–3000	3000–3600	3600–4150	4150–4450	4450–4700	4700–5000	5000–5300	5300–5810
Distressed concrete thickness	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	1
Gunite or concrete detachment	2	0	2	0	0	2	0	0	2	2	2	0	0	0	0	2	2	2	0
Moisture areas	2	0	2	2	2	0	0	0	0	0	0	2	2	0	0	0	0	0	0
Singles or ramified cracks	3	0	0	0	3	3	3	0	0	0	0	0	0	0	3	0	0	0	3
Bad rock-lining contact	3	0	0	0	0	0	0	3	3	0	0	0	0	3	3	3	3	0	0
Fractured rock mass	4	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Damage factor		0	4	2	9	5	3	3	5	3	2	3	2	3	7	5	6	3	4
Total evaluation		G	S	G	P	S	S	S	S	S	G	S	G	S	M	S	M	S	S

Tab. 2

DAMAGE QUANTITY INDEX "J

Damage	*Damage quantity evaluation*	*Damage quantity index "J"*
- Spoiled concrete	*Thickness 1÷4 cm.*	*1*
	5÷7 cm.	*2*
	8÷10 cm.	*3*
	>10 cm.	*4*
-Detachment of plaster and/or concrete *- Damp patches* *- Single ramified cracks*	*Absent*	*0*
	Low	*1*
	Medium	*2*
	High	*3*
- Presence of voids at rock-lining contact	*Absent of low*	*0*
	Medium	*1*
	High	*2*
- Rock mass condition	*Compact*	*0*
	Medium fractured	*1*
	Fractured	*2*

Tab. 3

The ponderal indices "J" appear in Table 3.
It was thus possible to draw up Table 4, in which the ponderal index shows at the top and the product ixJ at the bottom, for each section and for the various damages.
It can be that in this case the severeness factor may range from 0 to 48.
The evaluation scale in this method is the following:

Section soundness evaluation	Severeness factor
Good (G)	0 - 10
Sufficient (S)	11 - 20
Mediocre (M)	21 - 30
Poor (P)	31 - 40
Very poor (VP)	> 40

When the diagram of Table 4 is compared against that of Table 3, the results of both methods are fairly consistent but do not always coincide.
Since the method is still in the experimental stage, the most pessimistic evaluations of the various sections were conservatively considered. This was taken into account when planning the maintenance operations.
The method herein illustrated should still be considered as experimental, as said before, and is therefore open to modifications and improvements, both as concerns the definition of severeness and ponderal indices and as concerns the evaluation scale of the soundness of the various sections.
These values may be adjusted in the future on the basis of the results of other diagnostic campaigns and chiefly of the long-term results of repair work done on other tunnels.

INTEGRITY TUNNEL EVALUTATION AS 2nd METHODOLOGY

Distress	Damage Index	0–100	100–300	300–450	450–700	700–750	750–900	900–1200	1200–1600	1600–2000	2000–2600	2600–3000	3000–3600	3600–4150	4150–4450	4450–4700	4700–5000	5000–5300	5300–5810
Distressed concrete thickness	1	1 1	2 2	2 2	2 2	2 2	0 0	0 0	0 0	2 2	0 0	3 3	0 0	0 0	3 3	0 0	3 3	3 3	4 4
Gunite detachment	1	0 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	0 0	0 0	0 0	0 0	0 0	1 1	0 0	0 0	1 1	0 0
Concrete lining detachment	2	2 4	3 6	2 4	1 2	3 6	1 2	2 4	3 6	3 6	3 6	2 4	1 2	2 4	2 4	3 6	3 6	3 6	1 2
Moisture areas	2	0 0	3 6	2 4	3 6	1 2	2 4	2 4	1 2	2 4	2 4	3 6	3 6	2 4	2 4	2 4	2 4	1 2	2 4
Single cracks	2	2 4	2 4	1 2	3 6	3 6	2 4	2 4	1 2	1 2	1 2	2 4	1 2	1 2	3 6	2 4	1 2	2 4	2 4
Ramified cracks	3	0 0	0 0	0 0	1 3	0 0	3 9	0 0	0 0	0 0	1 3	2 6	0 0	0 0	2 6	2 6	2 6	2 6	1 3
Rock-lining contact	3	0 0	0 0	0 0	0 0	0 0	0 0	2 6	2 6	1 3	0 0	0 0	1 3	2 6	2 6	2 6	2 6	0 0	0 0
Quality of rock mass	4	0 0	0 0	2 8	2 8	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 4	0 0	0 0	0 0	0 0
Damage factor		9	18	20	27	16	20	19	17	17	15	23	13	16	34	26	27	22	17
Total evaluation		G	S	S	M	S	S	S	S	S	S	M	S	S	P	M	M	M	S

Tab. 4