SEISMIC TRANSIENT WITH LOW FREQUENCIES AT SHORT DISTANCES

CASE HISTORY: TUNNEL BLASTING IN URBAN SITE AT *ISOLA LIRI* (ITALY)

by

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Abstract

This article deals with the excavation of a tunnel below the town of *Isola Liri*, near *Frosinone*, in central Italy.

The tunnel was driven into a conglomerate formation, of lacustrine-fluvial origins, consisting in carbonate clasts with a sandy-silty matrix and calcitic cement. "Drilling and blasting" had to be adopted in place of a tunnel boring machine which had showed uneconomical performances. Good advance speed rates were achieved notwithstanding the presence of some above structures to safeguard. The nearest structure (an old votive chapel) was less than 10 meters (33 ft.) far from the tunnel crown; the nearest residential structure was at about 15 m (49 ft.).

Due to the dynamic characteristics of the propagation medium, unusually low predominant frequencies of the seismic transient were recorded at distances ranging from 10 to 90 m (33 to 295 ft.). Particular attention had therefore to be taken for the adoption of the peak ground velocity safety limit.

Continuous monitoring was performed while excavating. Measured data were computed with a two independent variables' power regression: "v_{MAX}" (peak ground velocity) as dependent, "R" (distance) and "Q_{MAX}" (charge weight) independent variables. FFT was also calculated. Results are exposed and discussed.

INTRODUCTION

The tunnel is part of an interceptor which function is to link, in case of overflow, the upper and the lower section of the *Liri* river, by-passing *Isola Liri*. This town was, in fact, frequently flooded during winter seasons.

Tables, figures and photos are following the text.

A first section of the tunnel was driven by means of a tunnel boring machine. This showed uneconomical results because of the unexpected local increasing of rock drillability resistance and because of the high friction angle of the comminuted rock. This last factor induced frequent breakage in the hauling system. The contractor decided so to complete the excavation by "drilling and blasting", with your author acting as a consultant.

THE TUNNEL AND THE SITE

The tunnel runs below a peripheral area of the town (figure 1). His transversal section was horse-shoe shaped: height was 5.75 m (18.86 ft.), width 6.5 m (21.32 ft.), crown was a circle centered 2.5 m (8.2 ft.) over the floor with a bending radius of 3.4 m (11 ft.), piers, 2.4 m (7.87 ft.) high, were standing.

Over the tunnel were placed some structures that had to be safeguarded (numbered from 1 to 9 in figure 1, photos from 1 to 5). Those consisted in villas and country houses, up to three levels over the ground surface, and in one old little votive chapel (number 2 in figure 1, photo 2). Some of those were, more or less, damaged by a recent earthquake (IRPINIA, November 23, 1980) that was felt in the area with an intensity of V MCS (Mercalli, Cancani, Sieberg scale) and left cracks in both curtain and partition walls.

GEOLOGY

Morphology was characterized by hilly relief, gently shaped on top, sharply and abruptly in the sides.

The formation consisted in a yellow conglomerate with rounded limestone clasts, from 5 to 10 cm (from 2 to 4 in), silty-sandy matrix and calcitic cement (figure 2, photo 7, 8). The formation has grown in deposing and erosion cycles into a lacustrine-fluvial environment (from Pleistocene to recent times).

Thick was generally high and the formation assumed lithoid characteristics. Cohesion changed quickly in consequence of calcite and clay presence. Locally were met sub vertical fractures, opened up to 10 cm (4 in) and filled with soft clay.

Sedimentary joints, whose dip ranged from 10° to 20°, in a direction orthogonal to the tunnel axis, were distinguishable because of the different pigmentation (due to iron oxide content).

Values of the geotechnical parameters of the rock were assumed to be the following:

• mass weight:	$2.2 \div 2.5$ t/m^3;
• Young modulus:	$15 \div 30$ GPa;
• friction angle:	$30° \div 35°$;
• longitudinal waves velocity:	$2{,}000 \div 3{,}500$ m/s.

SAFETY LIMITS FOR BLAST INDUCED GROUND VIBRATION

The presence, at short distance, of structures to be safeguarded, imposed the control of blast induced ground vibrations below prefixed threshold values.

In lack of specific national regulations it was referred to the DIN 4150, part III. The following threshold values were so initially adopted:

• residential buildings:	20 mm/s (0.79 in/s);
• chapel:	10 mm/s (0.39 in/s).

A peak ground velocity decay law, characteristic of the site (geological formations, blast design, explosive, seismic path length and above ground morphology, etc.), was not known. Reference was so made to a conservative "general purpose" decay law. This was computed with data measured many tunnel blasting. Taking as reference the 95% confidence limit curve it was adopted a safety scaled distance "SDs" equal to 40 $m/kg^{0.5}$ for the chapel and 27.7 $m/kg^{0.5}$ for the residential structures. The maximum explosive charge blasted per delay was than improved by the factor 1/EF, where EF is the ratio between the weight strength of TUTAGEX, a water gel from ITALESPLOSIVI (table 1) utilized for the tunnel excavation, and that of the "reference" explosive in the "general purpose" decay law.

After the first shots it was clear that the values of the predominant frequency of the seismic transient induced by the blast, was lower than expected. The threshold peak ground velocity limit for residential structures was so reduced to 15 mm/s (0.6 in/s).

All the blasts were monitored and the safety scaled distance was gradually reduced. The last rounds were blasted with a SDs = 13.3 $m/kg^{0.63}$.

RESULTS OF BLAST VIBRATION MONITORING

Blast vibration were monitored by means of digital seismographs VMS 500 (by THOMAS INSTRUMENTS INC. - USA). Vertical, horizontal longitudinal and horizontal transversal components of the ground particle velocity were recorded.

Geophones were placed inside the nearest structures, in the corner of the curtain walls. For the first hundred shots were recorded both seismic data (wave forms, ...), distance and charging data in order to compute a decay law. For the following shots were only recorded the seismic data to verify that the threshold value was not exceeded.

The recorded data (table 2, figure from 3 to 7) were processed in a power regression with velocity "v_{MAX}" dependent variable, "R" distance, or seismic path length, and "Q_{MAX}" weight of the explosive charge which has induced the peak particle value "v_{MAX}", as independent variables (table 3, figure 7).

The high frequencies, characteristics of the blast at such short distances (in massive limestone the predominant frequency generally overpass the 150 ÷ 250 Hz) were heavily filtered by the conglomerate, with energy transfer to the lower frequency components of the wave train.

COMPLAINS

Complain came just from one person. His house was at a minimum distance of 100 m (328 ft.) from the tunnel but "*disease to the house structure showed by horizontal and* *vertical cracks in the first floor walls*", started when the blasts were 170 m (557.6 ft.) far.

That house, two levels up to the ground surface, was built in two times, a second body adjoining the first one. The curtain walls (concrete brick made) carried the structure; the floors were made with steel bars and pots.

The peak ground velocity in the nearby of the house has not exceeded the value of 1 mm/s (0.039 in/s). At sight no induced cracking was (obviously) evident. On request to show the damages that people pointed on a vertical crack between the two adjoining bodies (photo 6). This, clearly depending on structure's settlement, was fill with aged dirty and was, in non recent times, partially coated.

CONCLUSIONS

Tunneling method flexibility.

The tunnel boring machine is little adaptable to rock mass geotechnical parameters' variations. This may bring to negative economical results. On the contrary the "drilling and blasting" technique is extremely adaptable. With any equipment's modification (maybe just the bits) it is possible to blast a round in a very hard rock and next in a soft and plastic rock.

Presence of low frequency harmonic components.

Particular attention must be taken in defining peak velocity safety limits, when blasting in soft rocks. The predominant frequency can be much lower than expected, even at very short distance.

Complains.

It is really impossible to avoid complains when blasting ("clever" people are everywhere). Preliminary project and continuos monitoring can, nevertheless, drive almost to zero the risks for the contractor, to pay for damages.

Acknowledgments.

The writer would like to acknowledge Dr. Ing. Antonio D'Andrea, technical director of the FERROCEMENTO SPA, the general contractor that executed the job, for having allowed the publication of this article.

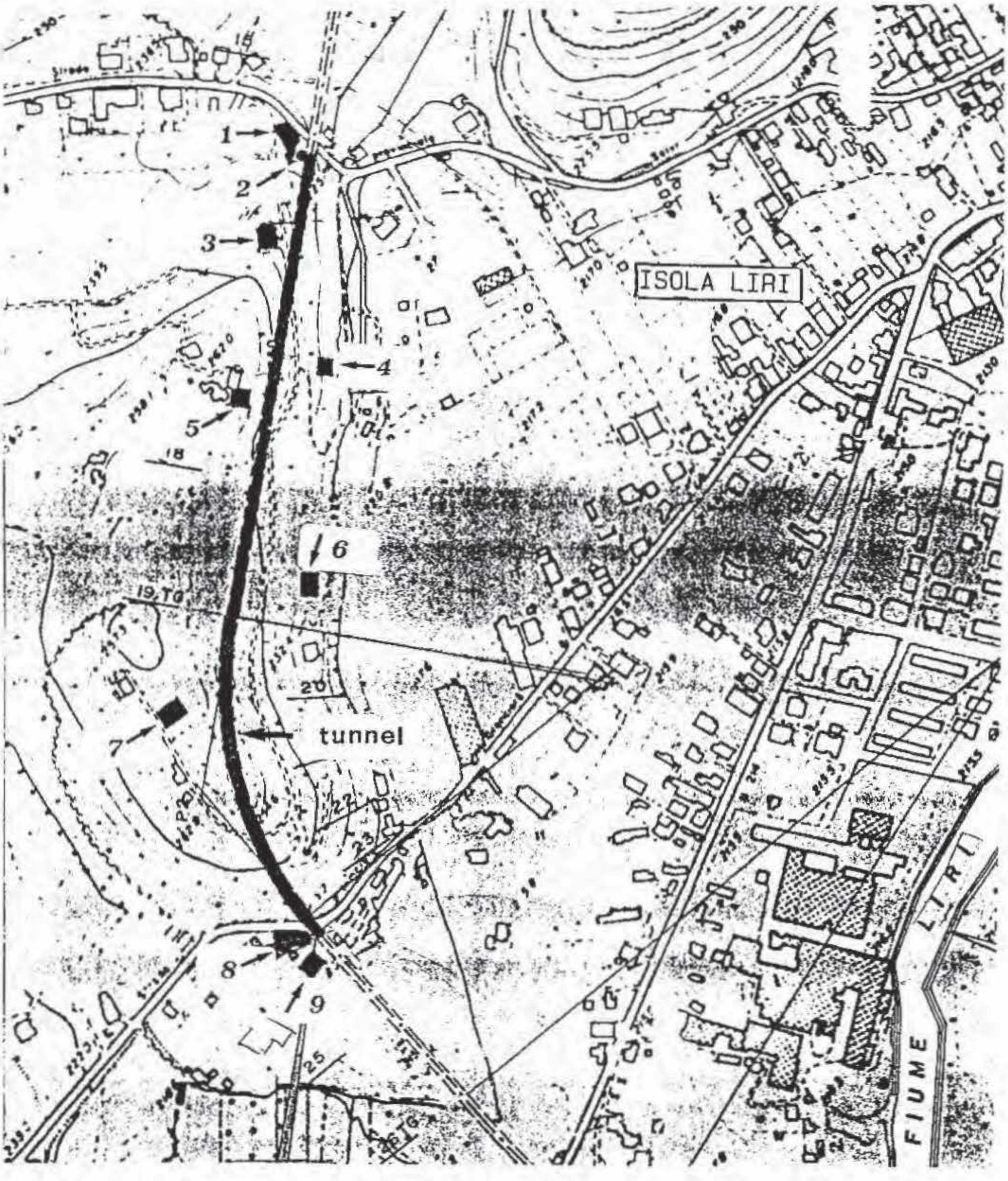

Figure 1. Planimetry of the tunnel and trace of the nearest above standing structures to be safeguarded (numbered from 1 to 9).

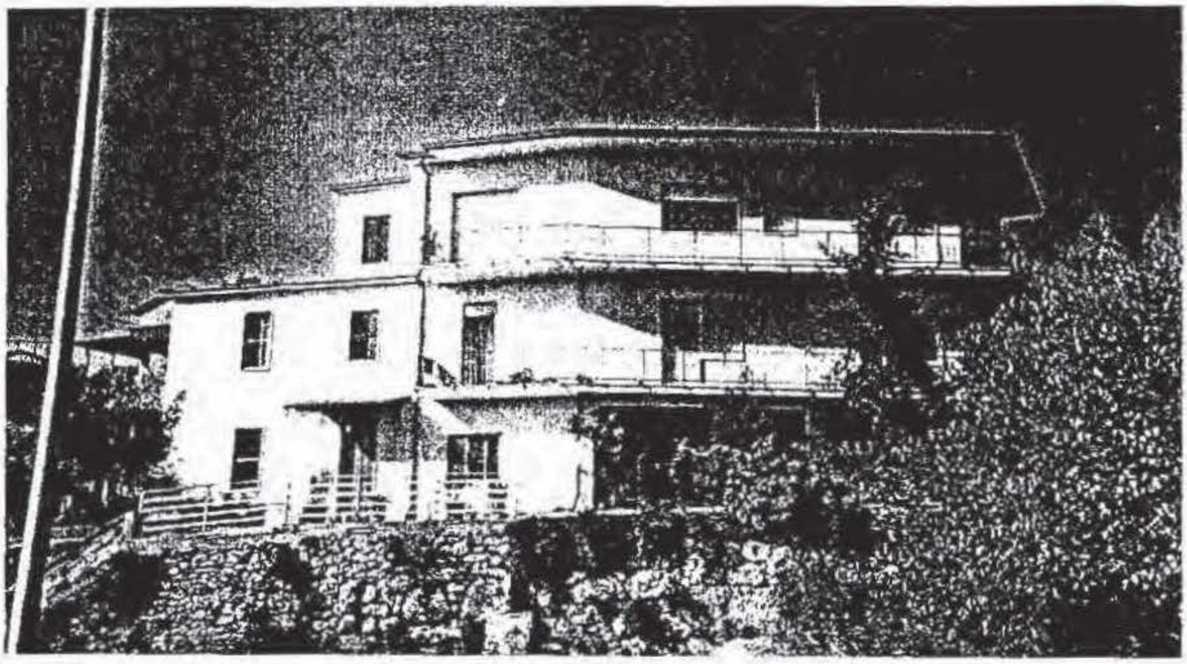

Photo 1 Structure n.1

Photo 2 Structure n.2 (votive chapel).

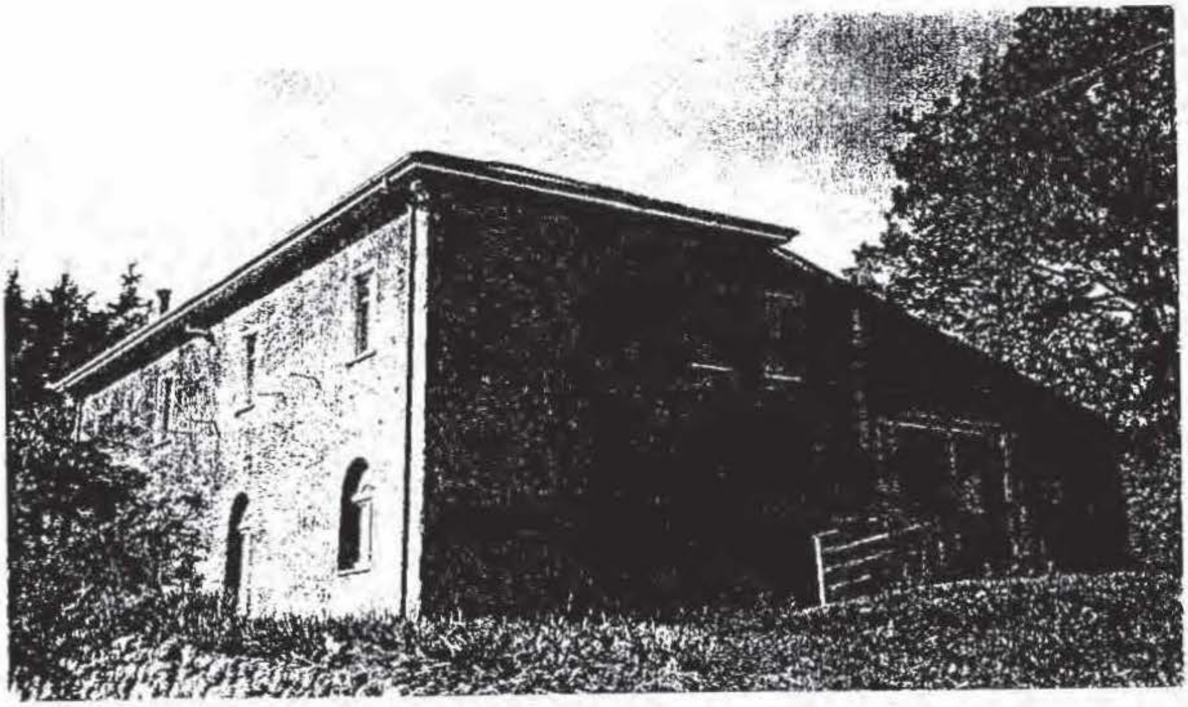

Photo 3 Structure n.3

Photo 4 Structure n.5.

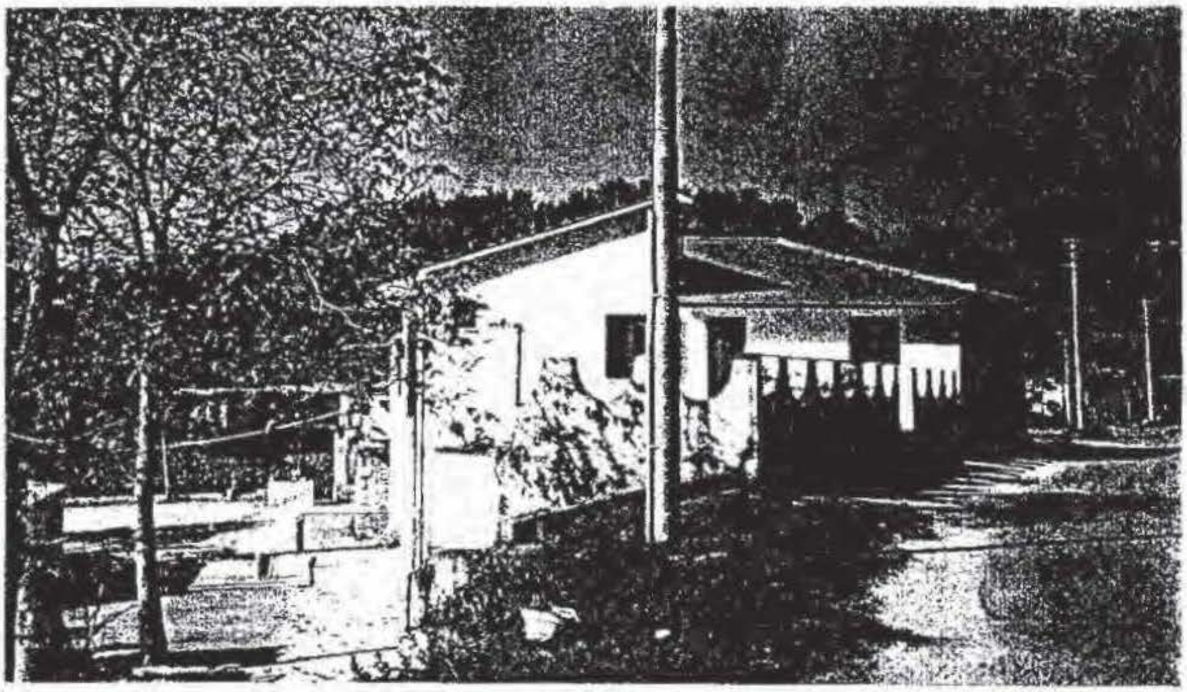

Photo 5 Structure n.9

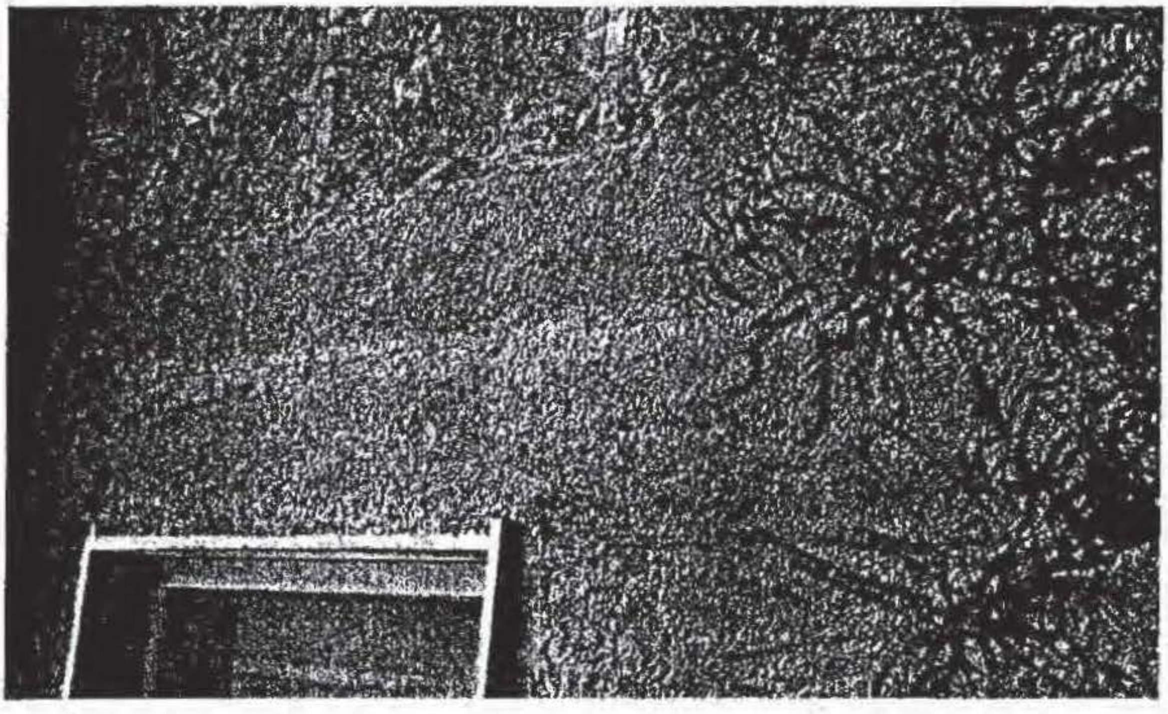

Photo 6 Fracture between the two adjoining bodies in the house of the people that complained for damages.

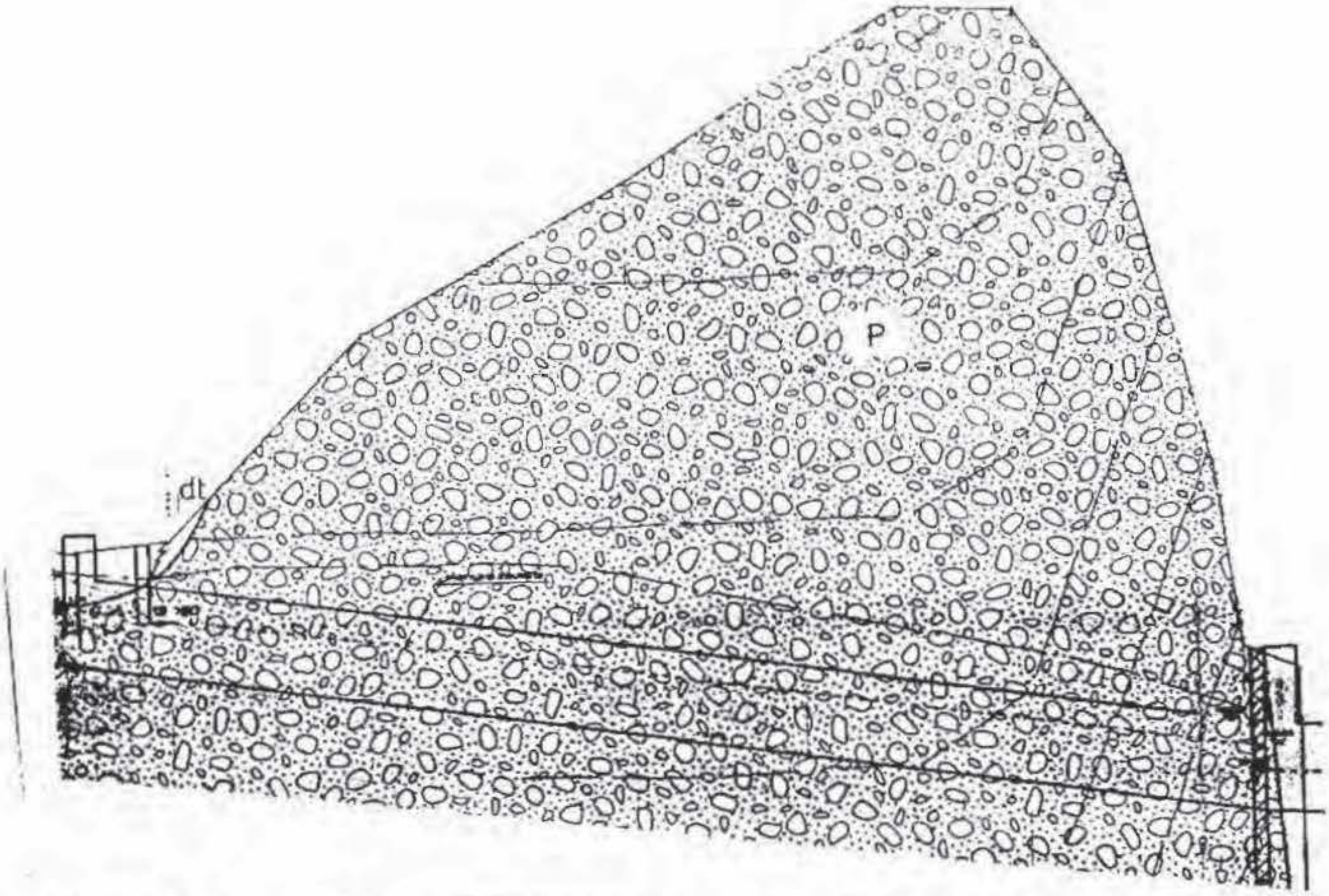

Figure 2. Geological section of the tunnel (vertical longitudinal). The formation consisted in yellow conglomerate of lacustrine-fluvial origins "P" (form Pleistocene to recent times).

Table 1. Characteristics of TUTAGEX 110 water gel explosive.

Density	1150 kg/m^3
Specific energy per unit mass	2.79 MJ/kg
Detonation velocity	4,000 m/s
Weight strength	85%

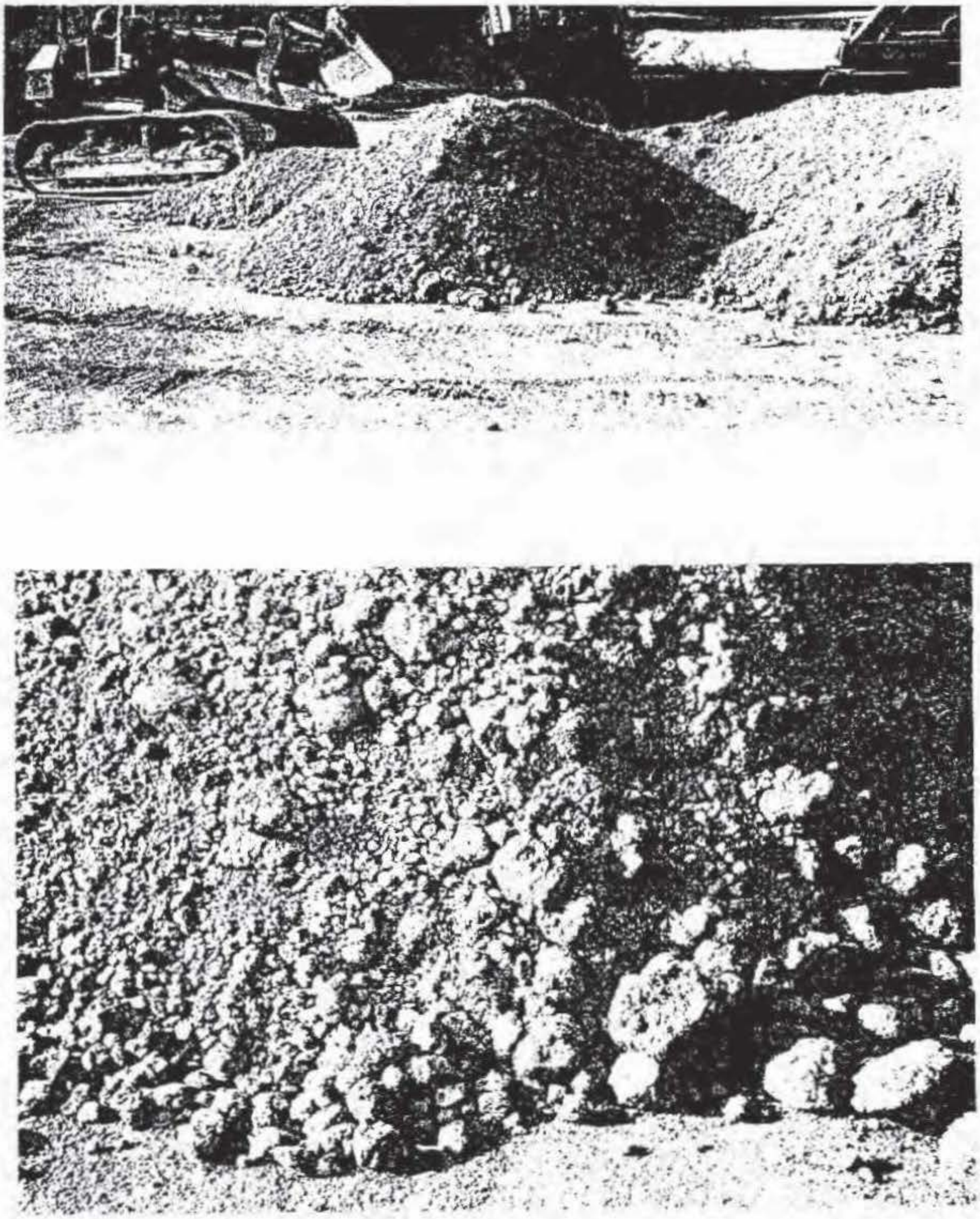

Photo 7 & 8 Conglomerate in much after the blast.

Table 2. Data recorded during tunnel blasting.

n°	vV (mm/s)	vT (mm/s)	vR (mm/s)	fV (Hz)	fT (Hz)	fR (Hz)	v VECT (mm/s)	R (m)	Q (Kg)
1	3.68	2.23	2.00	28	37	30	4.35	25	1.4
2	6.47	9.71	16.07	47	23	27	17.67	11	0.9
3	51.23	30.02	31.47	30	18	23	60.14	11	4.2
4	4.68	3.01	3.46	23	27	30	5.84	38	3.3
5	3.79	5.02	4.57	19	23	20	5.55	27	3.0
6	2.45	1.22	1.45	102	39	30	2.47	42	3.0
7	14.62	3.46	4.79	73	22	22	15.52	40	4.2
8	7.47	1.22	1.89	85	47	37	7.49	45	3.6
9	8.14	3.12	2.56	85	19	32	8.17	38	3.6
10	8.81	2.79	3.01	73	16	24	8.84	36	3.6
11	9.59	2.56	4.13	85	18	28	9.90	34	3.6
12	7.81	2.34	3.12	37	39	32	8.13	32	3.6
13	7.47	3.01	3.57	73	34	43	7.50	30	3.6
14	8.48	4.13	3.46	37	23	17	8.55	28	3.6
15	11.72	3.34	4.35	102	30	39	11.76	27	7.2
16	8.14	3.34	4.01	73	34	27	8.30	26	3.6
17	9.48	3.90	4.68	85	39	37	9.61	25	3.6
18	9.15	4.91	8.92	64	51	32	9.31	24	3.6
19	7.59	3.34	6.58	128	73	27	7.69	24	3.6
20	9.37	3.34	9.71	102	73	30	11.07	23	3.6
21	9.59	5.02	7.36	85	64	73	10.73	23	3.6
22	10.71	5.24	9.37	85	73	27	12.32	23	3.6
23	10.15	5.80	7.47	57	64	64	12.39	24	3.6
24	12.72	8.03	7.81	23	64	57	15.58	24	3.6
25	11.83	8.03	7.59	39	43	64	14.66	25	3.6
26	11.38	6.69	7.59	85	43	57	12.39	26	3.6
27	12.27	7.36	7.92	64	39	57	14.43	27	3.6
28	9.26	6.02	6.92	85	43	57	10.20	28	3.6
29	10.38	4.57	5.80	102	57	51	10.49	30	3.6
30	9.93	4.91	6.69	85	30	23	10.00	31	3.6
31	8.81	3.90	5.02	102	43	64	9.74	32	3.6
32	6.25	3.23	4.91	102	32	26	6.56	33	3.6
33	9.48	3.12	4.13	85	85	22	9.58	34	7.2
34	11.49	4.24	4.68	85	64	22	11.53	36	8.0
35	5.69	3.01	4.91	85	39	24	5.83	37	3.6
36	5.46	3.79	4.35	73	28	27	5.70	38	3.6
37	4.79	3.23	4.91	73	39	32	5.49	40	3.6
38	4.24	3.46	3.46	102	32	30	4.84	41	3.6
39	4.01	4.01	3.90	34	37	37	5.71	43	3.6
40	2.90	3.68	3.57	32	39	37	4.85	45	3.6
41	3.46	2.79	3.12	64	37	30	3.77	46	3.6
42	3.23	2.45	2.79	73	43	47	3.74	47	3.6
43	3.23	3.68	2.90	64	47	20	4.73	49	3.6
44	2.45	3.12	2.12	102	47	39	3.88	51	3.6
45	2.67	4.57	2.12	57	39	20	4.84	53	3.6

Table 2 Data recorded during tunnel blasting.

n°	vV (mm/s)	vT (mm/s)	vR (mm/s)	fV (Hz)	fT (Hz)	fR (Hz)	v VECT (mm/s)	R (m)	Q (Kg)
46	2.23	3.90	1.67	85	47	39	4.25	55	3.6
47	2.56	3.46	1.89	102	43	39	4.53	57	4.4
48	2.79	2.00	1.45	128	43	34	3.26	59	4.4
49	1.56	2.00	1.45	51	43	43	2.66	62	3.6
50	2.00	1.56	1.33	128	39	43	2.49	65	3.6
51	2.23	1.67	1.89	128	57	22	2.80	67	4.4
52	2.23	1.33	1.45	128	64	23	2.54	69	4.4
53	2.34	1.67	1.67	128	512	256	2.81	71	4.4
54	2.23	1.89	1.45	57	39	37	2.46	73	4.4
55	2.34	1.56	1.67	102	39	37	2.62	75	4.4
56	2.45	1.89	1.78	51	47	39	2.86	78	4.4
57	2.00	1.45	1.45	47	37	43	2.20	80	4.4
58	1.89	1.11	1.22	85	128	39	2.06	82	4.4
59	1.56	0.89	1.11	102	102	37	1.75	84	4.4
60	1.78	0.66	0.89	57	102	43	1.84	86	4.4
61	1.56	0.78	0.89	73	85	43	1.66	88	4.4
62	1.56	1.33	1.45	64	37	57	2.06	90	4.4
63	14.17	3.46	2.56	102	64	64	14.32	46	10.8
64	10.26	3.01	2.67	102	64	64	10.39	45	10.8
65	11.27	3.57	3.90	102	85	73	11.45	44	7.2
66	13.76	4.35	4.91	128	27	64	13.74	44	10.8
67	10.15	3.57	2.45	128	39	57	10.32	43	7.2
68	3.23	0.78	0.78	64	47	47	3.38	43	3.6
69	13.05	4.79	3.01	128	85	64	13.09	42	10.8
70	10.60	3.46	3.23	128	57	26	10.72	42	7.2
71	14.17	6.58	5.91	57	43	43	14.21	42	10.8
72	16.18	6.80	6.58	73	27	39	16.39	42	10.8
73	4.13	2.45	4.01	102	43	39	4.65	43	3.6
74	15.85	6.58	7.81	85	28	20	16.46	43	10.8
75	6.58	3.57	6.69	57	34	28	8.09	43	4.8
76	5.91	3.57	3.68	85	102	43	6.63	44	4.8
77	7.92	4.57	5.02	102	85	28	9.09	44	6.6
78	5.58	3.34	4.35	85	34	24	6.35	45	4.8
79	5.69	4.35	4.91	13	51	28	6.60	46	4.8
80	6.92	5.02	4.01	102	30	28	7.76	47	6.6
81	6.69	3.90	4.13	13	64	47	8.39	48	4.8
82	8.25	4.35	3.57	102	85	34	8.79	48	5.4
83	6.58	3.79	3.46	102	73	43	7.73	49	4.8
84	5.58	3.46	3.90	85	102	51	7.03	50	4.8
85	5.35	3.23	4.24	85	28	27	6.39	51	4.8
86	6.25	3.57	3.90	85	34	51	6.40	52	4.8
87	6.80	2.90	4.24	73	27	51	7.93	53	5.4
88	6.25	3.01	4.13	85	51	51	7.14	54	5.4
89	7.36	2.67	5.02	73	57	47	8.17	55	6.4
90	6.47	3.34	4.01	73	34	57	7.32	56	6.4

Table 2 Data recorded during tunnel blasting.

n°	vV (mm/s)	vT (mm/s)	vR (mm/s)	fV (Hz)	fT (Hz)	fR (Hz)	v VECT (mm/s)	R (m)	Q (Kg)
91	4.68	2.34	3.46	47	128	57	5.42	58	4.8
92	5.24	2.67	4.79	102	73	51	7.18	59	4.8
93	5.46	3.01	4.13	85	57	57	6.80	60	4.8
94	4.24	3.46	3.46	51	51	51	5.06	62	4.8
95	4.57	3.68	4.01	47	64	57	5.87	63	4.8
96	3.79	3.01	3.57	43	57	64	4.44	65	4.8
97	3.34	2.56	2.90	43	57	64	3.79	66	4.8
98	2.90	2.45	3.46	51	51	51	4.33	68	4.8
99	6.69	1.78	2.23	85	39	57	6.78	45	3.6
100	8.59	3.79	6.47	47	512	512	9.14	26	3.6
101	9.15	4.68	7.81	9	85	20	11.21	22	3.6
102	12.50	6.25	10.28	9	23	18	14.58	23	3.6
103	12.27	7.81	7.36	20	73	73	15.61	23	3.6
104	2.90	1.33	2.34	64	73	57	2.96	74	4.8
105	2.90	1.45	2.90	64	47	51	3.02	78	4.8
st dev	5.72	3.09	3.59	30.26	67.14	52.24	6.67	17.76	1.91
mean	7.16	3.78	4.44	75.20	59.14	47.10	8.11	45.80	4.73
min	1.56	0.66	0.78	9.00	16.00	17.00	1.66	11.00	0.94
max	51.23	30.02	31.47	128.00	512.00	512.00	60.14	90.00	10.80

Table 3. Result of statistical computations of the data recorded during tunnel blasting.

	v VECT	vV	vT	vR
Standard error of the measured value "s" (mm/s)	1.28	1.29	1.42	1.44
Correlation coefficient "r"	0.92	0.93	0.79	0.82
Number of measures	105	105	105	105
Degree of freedom	102	102	102	102
R, Q$_{MAX}$ coefficients	-1.45, 0.92	-1.52, 1.14	-1.16, 0.53	-1.31, 0.45
Standard error of R, Q$_{MAX}$ coefficients	0.06, 0.07	0.06, 0.07	0.09, 0.10	0.09, 0.11
Equation of decay law (50% probability)	393 DS$^{-1.45}$	311 SD$^{-1.52}$	113 DS$^{-1.16}$	252 DS$^{-1.31}$
Equation of decay law (95% probability)	648 DS$^{-1.45}$	490 DS$^{-1.52}$	188 DS1$^{-1.16}$	470 DS $^{-1.31}$
c (Q exponent in SD)	0.63	0.75	0.46	0.34

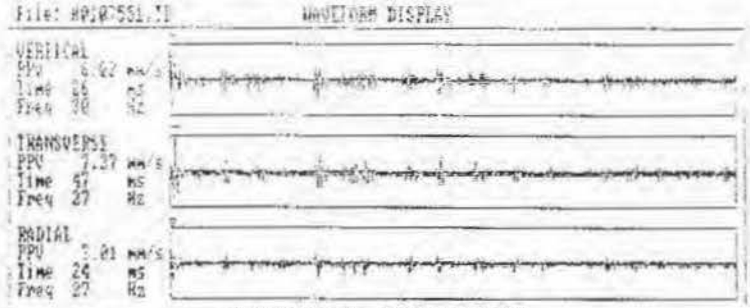

Figure 3. Wave form recorded ...

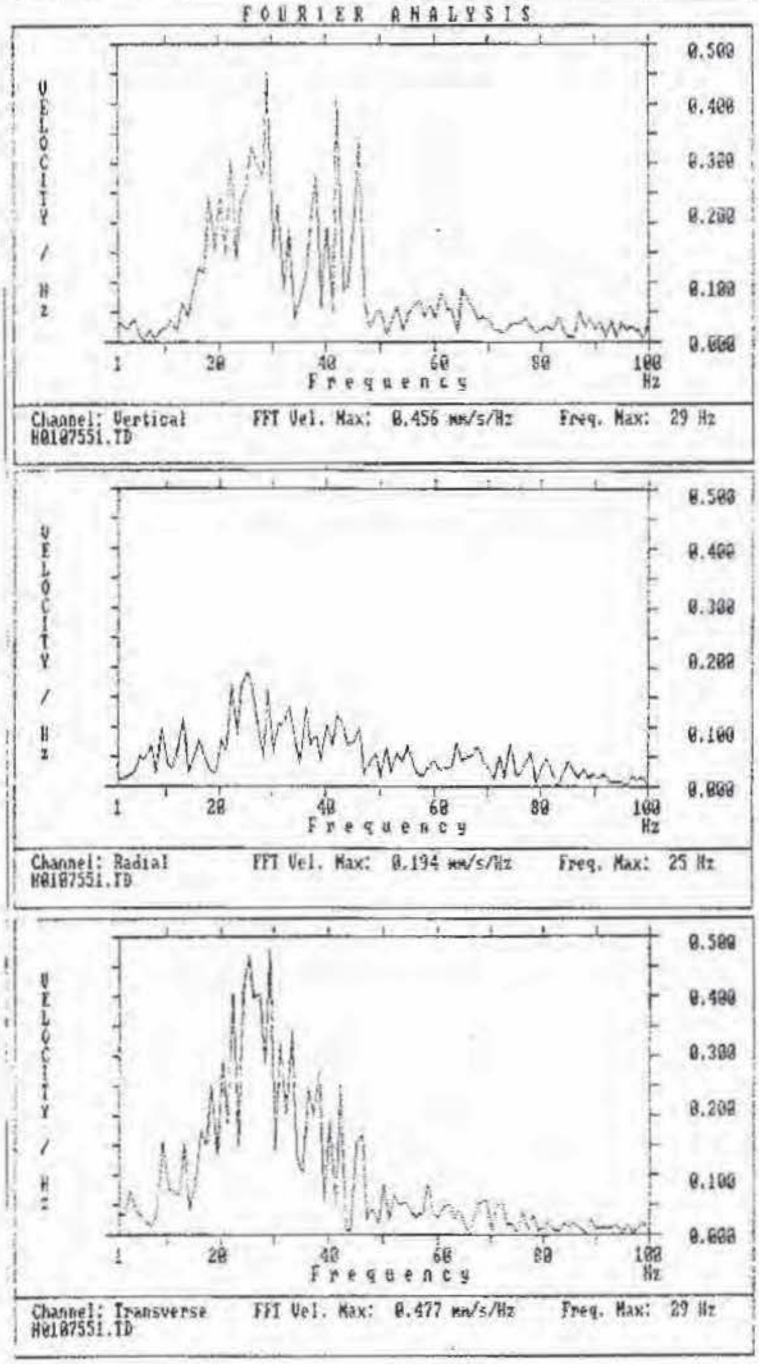

Figure 4. ... and Fourier analysis of the vertical, horizontal transversal and horizontal radial components of the ground particle velocity.

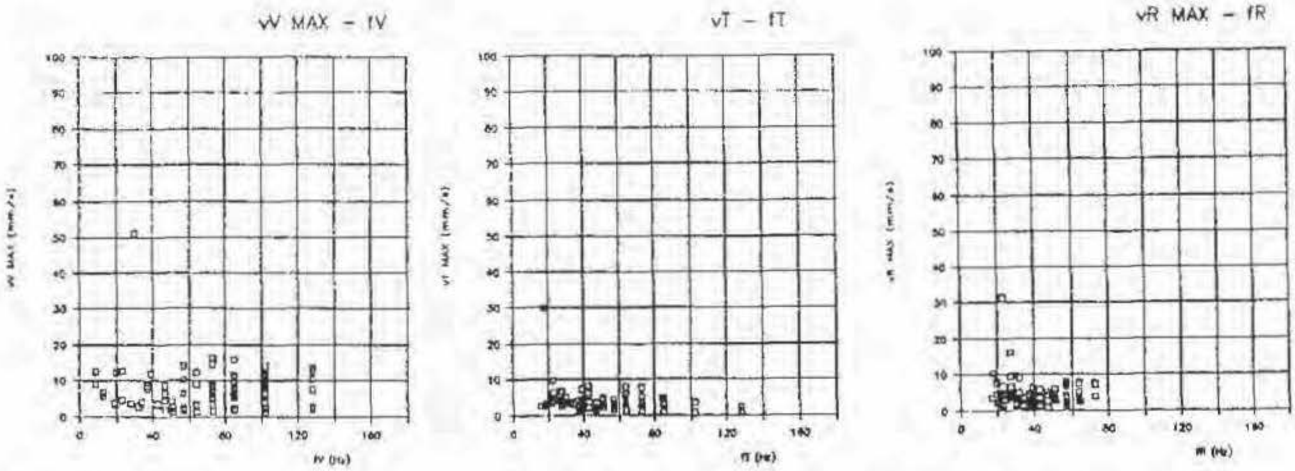

Figure 5. Peak values of the vertical (vV MAX), horizontal transversal (vT MAX) and horizontal radial (vR MAX) components of the ground particle velocity and their predominant frequencies (fV, fT, fR)

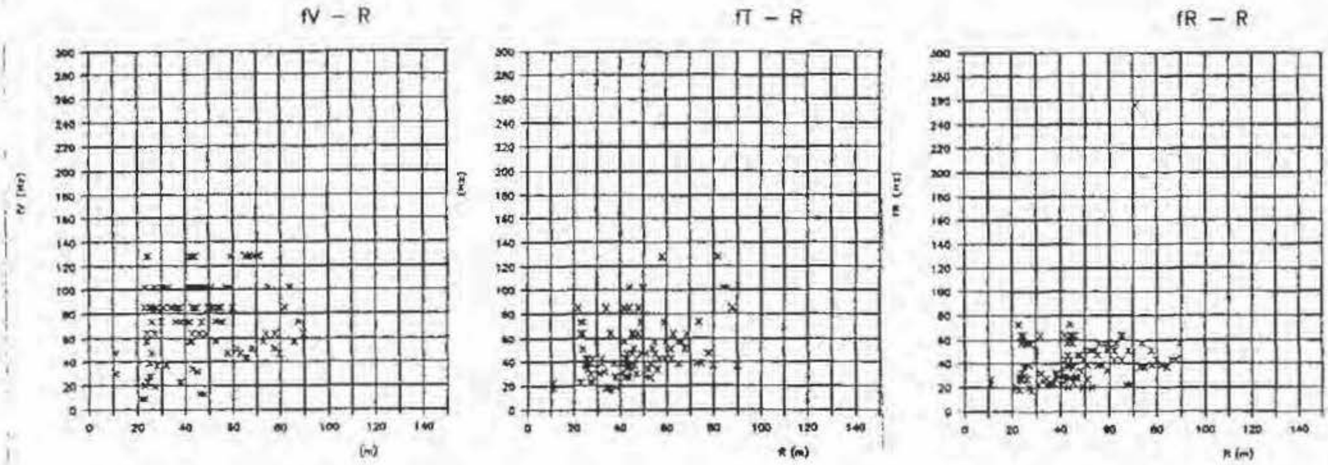

Figure 6. Predominant frequency of the peak values of the vertical (fV), horizontal transversal (fT) and horizontal radial (fR) components of the particle velocity, measured at various distances (R) from the shot.

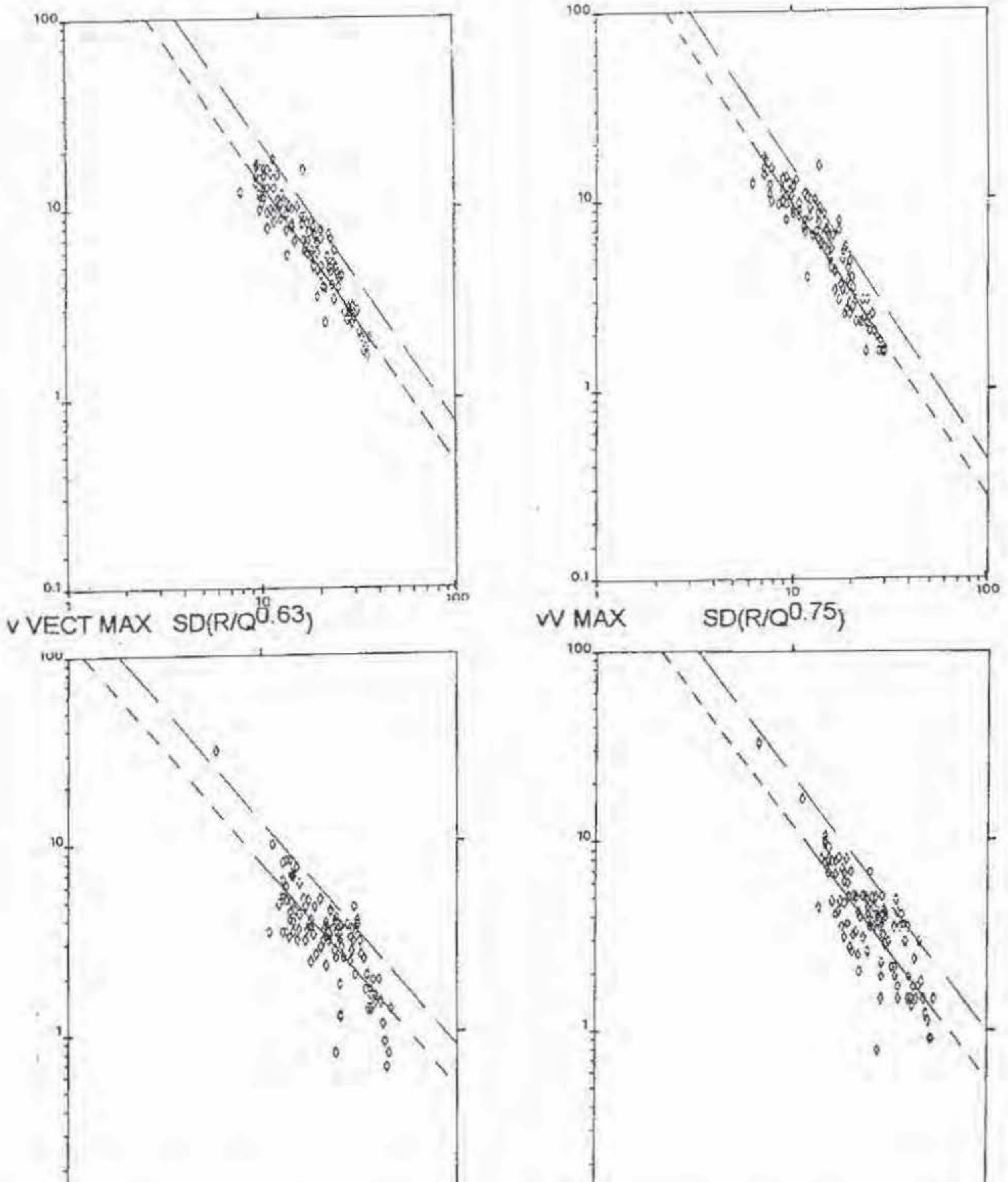

Figure 7. Decay laws of peak particle velocity (50% and 95% probability curves).

PROCEEDINGS
OF THE
NINETEENTH ANNUAL CONFERENCE ON
EXPLOSIVES
AND BLASTING TECHNIQUE

January 31 - February 4, 1993
San Diego, California, U.S.A.

INTERNATIONAL SOCIETY OF EXPLOSIVES ENGINEERS