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FRIULI EARTHQUAKES 1976
STRONG MOTION ACCELEROGRAPH RECORDS

by

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SUMMARY

This paper presents the basic tectonic and seismological characteristics of Friuli as well as the data of recorded accelerograms of the earthquakes that occured on May 6. and September 15, 1976 and their stronger aftershocks.

The earthquakes which occured during 1976 in Friuli originate from the known seismogene zone Friuli-Carnia. In this zone, which is the place of intersection of the regional longitudinal faults with the transversal fault zone connected to the valley of the Taligamento River, expressive geological distructions occured during the latest geological history.

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1. INTRODUCTION

Structure design criteria for zones of high seismic activity should be defined from the data concerning ground motion and response of structures during strong earthquakes. The strong motion phenomenon involves almost always numerous questions which cannot be answered exactly due to the lack of instruments capable to record the earthquake intensities and response of structures. Without such a record, the damage and behaviour of structure during strong earthquakes cannot be compared to the seismic design criteria nor proper decisions concerning rational repair and reconstruction could be made. Special difficulties arise when earthquakes do net create large visible damage. In such a case, the usefulness of the structure should be checked by special and expensive inspection.

The only procedure for obtaining such data is installation of strong motion instruments. Therefore, in 1973, Yugoslavia was covered by a strong motion instrument network consisting accelerographs and seismoscopes (Fig. 1), which was realised by the Institute of Earthquake Engineering and Engineering Seismology at the University "Kiril and Metodij" in Skopje.

In Yugoslavia the Friuli earthquakes were felt in an area with a radius of 250km from the epicentres. As it is evident in Fig. 1, this area had been covered by a large number of accelerographs and seismoscopes which were in an operating state during the earthquakes. Within few days after the earthquake of May 6. three temporary accelerographs were additionally installed at the following locations: Breginj, Kobarid and Robic (Fig. 2), which were most severely affected by the earthquake. A number of aftershocks have triggered these instruments.

The earthquakes of May 6. and September 15, 1976 that occured in Friuli, northeast Italy, close to the Italian-Yugoslav border, and the numerous aftershocks have caused enormous loss in goods and human lives, particularly in Italy. In Yugoslavia, these earthquakes created considerable damage in material properties, especially in the north-western part of Slovenia (Posocje), where some villages as Breginj, Podbela and others were completely destroyed.

2. THE YUGOSLAV STRONG MOTION INSTRUMENT NETWORK

One of the largest strong-motion instrument networks in Europe is the accelerograph and seismoscope network installed in Yugoslavia. This network of instruments provides basic information required for predicting the dynamic response of various types of structures, building Code´s improvement, understanding of the ground effects, as well as for better investigation and perceiving of the consequencies caused by earthquakes.

The distribution of the strong-motion instruments on the territory of Yugoslavia is based on previous studies of the geological-tectonic structure and the seismicity of the country. According to these studies it has been concluded that, in the first stage of realization of this project, the instrument network for recording of strong earthquakes should contain 136 accelerographs, 150 seismoscopes and a certain number of accelerographs for recording of maximum acceleration.

The selection of detail locations (Fig. 1) for installation of these instruments makes possible to obtain records on: 1) bedrock, 2) on the surface of a characteristic soil (alluvial and deluvial sediments), 3) on structures (multistorey buildings, dams, bridges etc.).

In this way, the designed network enables obtaining of such data by measuring the radiation pattern of the seismic waves, the effects of the soil conditions and the response of structures.

The Yugoslav network of strong motion instruments mainly contains two types of instruments: accelerographs SMA-1, produced by Kinemetrics, USA, and seismometers of WM-1 type, manufactured by the Astronomic-Geophysical Observatory of Ljubljana, Yugoslavia.

3. SEISMICITY AND TECTONICS OF FRIULI

The region of Friuli-Carnia which includes the area from the east of Veneto to the Yugoslav border and from the Austrian border to the Adriatic Sea, is well known seismic zone which during this century has been affected by strong earthquakes with magnitudes M = 5.0, several times.

This region is subdivided into the Carnic Range, Tolmeco Alps, Julian Alps in Italy, Carnic Pre-Alps, Julian Pre-Alps in Italy and the Friuli plane with Gorizia and Trieste Karst.

Carnic Pre-Alps and Julian Pre-Alps region with an adjucent part of the Friuli plane for the pleistoseistic part of the destructive May 6, 1976 earthquake, as well as September 15, 1976 events and the subsequent series of aftershocks with strong evidence of migration of foci and a specific energy release. Aftershock series of both events show strong variation in numbers, magnitude distribution, variation of coordinates in space and possibly in foci mechanisms.

The tectonics of the Friulian Alps is rather complex and varies strongly from zone to zone. The more conspicious structural elements that crop out in this region show immediately their predominantly east-west direction, in accordance with the general course of the Southern Alps. Eastwards, this direction is inclined towards NW-SE, which becomes striking and dominant in some parts of the Julian Pre-Alps and the Gorizia-Trieste Carst, where the orientation is typical Dinaride (Martines, 1975).

According to Ribaric (1977) the seismicity of this region is as follows:

Friuli-Carnia region is subjected to strong earthquakes which can be traced back for centuries. Some of the events reached a magnitude well over M = 6. Earthquakes in the Friuli-Carnia zone east from Dolomites (Veneto zone) are mainly concentrated around a triabgle formed by Tolmezzo zone, Tramonti di Sopra and Gemona zone. Other typical earthquake zones in this region are the zones of Cividale (Cedad) Montreale and some unequally distributed zones west of Udine (Videm).

To the west of Friuli-Carnia region in Veneto, there are several seismogene zones with potentials of producing seismic events with intensities 9°MCS or bigger (region Elago di S.Croce, Gansiglio, Liedolo). The south-western part of the North-Eastern Italy is also seismic, most of the events being attributed to the seismic activity in the Earth´s crust beneath the valley of Po river.

To the east, in Yugoslavia, typical seismogene zones in continuation with the west-east directed faults of the Friuli Pre-Alps and Julian Pre-Alps are found in the region of Tolmin, whereas southwards this direction changes into north-west-southwest (Dinaride direction). Zones of Ljubljana, Idrija, Ilirska Bistrica-Klana and Rijeka are typical earthquake origin areas with possible magnitudes over 6,5 but however with a small possibility of occurence. As evident from the time distribution of strong shocks in the region, calm periods exist, however they are lately followed by strong seismic motions (Fig. 3). After the series of 1959 events, no stronger earthquakes were recorded in the period from 1963 to 1975. Finally, the energy release culminated in the May 6, 1976 earthquake and the subsequent earthquakes of the fall 1976 and string 1977 (Fig. 4).

Similar situation is noticed after the April 1939 event in Moggio Udinese. After 15 year calm period, stronger seismic activity was observed, culminating in Tolmezzo in April 26, 1959 earthquake.

In the period from 1950 to June 18, 1975 21 earthquakes have been recorded in a zone with radius of 25 km from the supposed epicenter of the May 6, 1976 earthquake. In spite of the fact that the data about epicentral coordinates are possibly far from being accurate, it is evident that in general, the active seismic periods in this region are followed by calm periods, in support to the C.F.Richter's definition of sporadic seismicity (1971).

The picture of irregularity of occurence of stronger earthquakes is also persistent in the case of larger time intervals and areas under consi-eration and it is valid for this particular region, too.

4. STRONG MOTION ACCELEROGRAPH RECORDS

In the period from May 6. through September 15, 1976 32 accelerograph records and 6 seismoscope records have been obtained from the Yugoslav strong motion network.

Table 1. gives adata of the more important recorded earthquakes with maximum acceleration lartger than 5% g.

EARTHQUAKE DATA TABLE 1.

Accelero-graph Station	Date	Time H	Time M	Epicentre Coordinates		M	Epic. Dist. App.km	Max. Rec. Acc.(g)
Ljubljana INFIM	May 6,76	20	00	46.31 N	13.31 E	6.2	100	0.040
Ljubljana ZIMK	May 6,76	20	00	"	"	6.2	100	0.022
Breginj	June 8,76	12	14	46.28 N	13.27 E	4.3	25-30	0.103
Kobarid	Sept.11,76	16	31	46.32 N	13.18 E	5.4	35-40	0.101
Breginj	Sept.11,76	16	31	"	"	5.4	25-30	0.171
Kobarid	Sept.11,76	16	35			5.5	35-40	0.099
Breginj	Sept.11,76	16	35			5.5	25-30	0.123
Robic	Sept.11,76	16	35			5.5	30-35	0.057
Robic	Sept.13,76	18	55			4.1	30-35	0.050
Breginj	Sept.15,76	03	15	46.32 N	13.16 E	5.9	25-30	0.525
Kobarid	Sept.15,76	03	15	"	"	5.9	35-40	0.126
Robic	Sept.15,76	03	15	"	"	5.9	30-35	0.105
Breginj	Sept.15,76	04	39			4.6	25-30	0.071
Kobarid	Sept.15,76	09	21	46.33 N	13.17 E	5.7	35-40	0.143
Breginj	Sept.15,76	09	21	"	"	5.7	25-30	0.419
Robic	Sept.15,76	09	21	"	"	5.7	30-35	0.088

4.1 The Earthquake of May 6, 1976

Fig. 5 shows the isolines of the May 6, 1976 earthquake. As it can be seen this earthquake was felt on a larger territory of Yugoslavia. The same figure shows also the state of the strong motion instrument network in Yugoslavia during the earthquake. A total number of 5 accelerographs and 7 seismoscopes had been installed in the area where the earthquake was manifested with $I \geq VI$ degrees according to the MCS scale.

The earthquake of May 6, 1976 activated 7 accelerographs and 4 seismoscopes altogether. Both activated accelerographs are located in Ljubljana on a distance of cca 100 km from the epicenter of the earthquake. The peak acceleration of the earthquake recorded in Ljubljana was 004 g (Fig. 4). Table 1. shows the basic data of this earthquake obtained from the records of these accelerographs and the seismological data obtained from the records of the Yugoslav seismological stations in Ljubljana, Zagreb and Skopje. This earthquake has also been recorded by two seismoscopes installed inTolmin at a distance of cca 40 km and two in Ljubljana at a distance of cca 100 km from the epicentre. Fig. 7 shows the seismoscope records obtained inTolmin and Ljubljana.

On one of the seismoscopes, type WM-1 manufactured by Astronomic Geophysical Observatory in Ljubljana, installed in Ljubljana a record with double amplitude of 1.8 sm was obtained. If we consider that the natural period of the seismoscope is 0.75 sec. damping 10% from the critical, and the sensitivity of the instrument of about 6.0 sm/rad. the obtained value of the acceleration spectrum of Sv = 17.6 sm/sec corresponds to the intensity of an earthquake of 7 degrees according to the MCS scale (Ribaric 1977). The evaluated intensity in Ljubljana of 6-7 degrees completely corresponds to this record, which, as it can be seen on Fig. 7 has an irregular shape. The instrument was installed in a one-story buolding with foundations in a relatively bad soil conditions. The composition of the undersurface structure of the terrain is the following: clay, marshy soil with clay intercalations and high ground water table (h = 0.5 + 1.0 m.). On the same instrument was obtained a record from the earthquake of September 15, 1976 at 09 hour and 21 min. The value of the acceleration spectrum of this record was Sv = 3.9 sm/sec. which is several times smaller than that of May 4, 1976, although the magnitude was M = 5.7 in comparison to 6.2 of the eartquake of May 4, 1976.

4.2 Some Bigger Aftershocks During the period May 6, to September 15, 1976

Considerable number of aftershocks with magnitude of M = 3.6 to M = 5.5 which occurred during the period from May 10 to September 15, 1976 have been recorded by the additianally installed accelerographs in Breginj, Kobarid and Robic.

Theble 2. gives data on the location and number of triggering of each accelerograph separately, during this period, as well as the maximum recorded acceleration of these aftershocks.

TABLE 2.

Instrument Location	Type of Soil	Approximate Epicentral Distance	Number of triggering	Maximum recorded acceleration	
				Horiz.	Vert.
Breginj	Soft glacial morene deposits h=5.10 m. above limestone	25-30	4	0.171	0.052
Kobarid	Soft -Dolomite with 0.5 to 2.5 proluvial deposits	35-40	8	0.101	0.058
Robic	Rock -Hard massive limestone (Dolomite)	30-35	4	0.057	0.025

The maximal acceleration at Breginj and Kobarid was caused by the aftershocks of September 11, 1976 at 6.31 p.m. with M = 5.4 and at Robic by the aftershock of September 11, 1976 at 4.35 with M =5.5. Seismoscope records of the above aftershocks are not available.

The remaining instruments located on an area in radius of 100 km from the epicenter of these aftershocks were not triggered. All instruments were in a good working condition controlled -ach month.

4.3 The Earthquake of September 15, 1976

The earthquake which occured on September 15, 1976 was the strongest one after the earthquake of May 6, 1976. Both strong earthquakes at 3.15 a.m. (M = 5.9) and at 9.21 a.m. (M = 5.7) as well as the numerous aftershocks which occured at the same day caused great material damage in Italy as well as in Posocje (Yugoslavia). The occurence of these earthquake was a surprise both for the seismologists and earthquake engineers because such events in this part of Europe are not known in the seismological history.

These earthquakes were also recorded by the accelerographs installes at Breginj, Kobarid and Robic, and the seismoscopes at Tolmin and Ljubljana.

Five earthquakes were recorded at Breginj, six at Kobarid and three at Robic, all in September 15, 1976.

TABLE 3.

Location of accelerograph	Epicentral distance in (km)	Magnitude	Maximal acceleration (g)		
			N-S	V	E-N
Earthquake of September 11, 1976 at 3.15 a.m. (GMT)					
Breginj	25-30	5,9	0.487	0.198	0.525
Kobarid	35-40	5,9	0.108	0,088	0,126
Robic	30-35	5,9	0.105	0.049	0.074
Earthquake of September 15, 1976 at 9.21 a.m. (GMT)					
Breginj	25-30	7,7	0.166	0.126	0.419
Kobarid	35-40	5,7	0.143	0.065	0.109
Robic	30-35	5.7	0.088	0.046	0.058

The records of the earthquake of 3.15 a.m. (M = 5.9) and 9.21 a.m. (M = 5.7) which were recorded by all the three accelerographs at the same time are of special interest Table 3. shows the data of these earthquakes.

As it can be seen from the above table, the instrument at Breginj recorded two very important records (Figs. 8 and 9) with maximum acceleration of 0.525 g i.e. 0.419 g, which is of special interest for the earthquake engineers. Further more, because the instrument is located at a distance of cca 25-30 km from the epicenter in a structure which didnot suffer significant structural damage due to these earthquakes, while all other structures in Breginj were completely destroyed. At the same time, at Kobarid and Robic, which are at almost the same distance from the epicenter, acceleration of 0.126 g and 0.109g, i.e. 0.105 g and 0.088 g was recorded.

5. REZULTS FROM THE ANALYSIS

In the Institute of Earthquake Engineering and Engineering Seismology in Skopje has been developed a standard procedure for strong motion data processing, taking as base the standard procedure developed at CALTECH - Pasadena, aimed to obtain more exact information. Some changes have been made due to use of different equipment for digitalization and calculation.

Applying this procedure several records of the Friuli earthquakes obtained in Yugoslavia, which are of interest for the engineering practice, have been analysed. The seismological characteristics of these records are presented in Table 3.

Fig.10 through Fig.13 illustrate the response spectra of the Friuli Earthquakes of September 15, 1976, taken at Breginj, Kobarid and Robic.

All these investigations add to the fact that more studious investigations of the mechanism of these earthquakes, of the radioation pattern of the seismic waves, of the acceleration attenuation depending on the epicentral distance, as well as of the effect of the local soil conditions on the acceleration amplification, is necessary.

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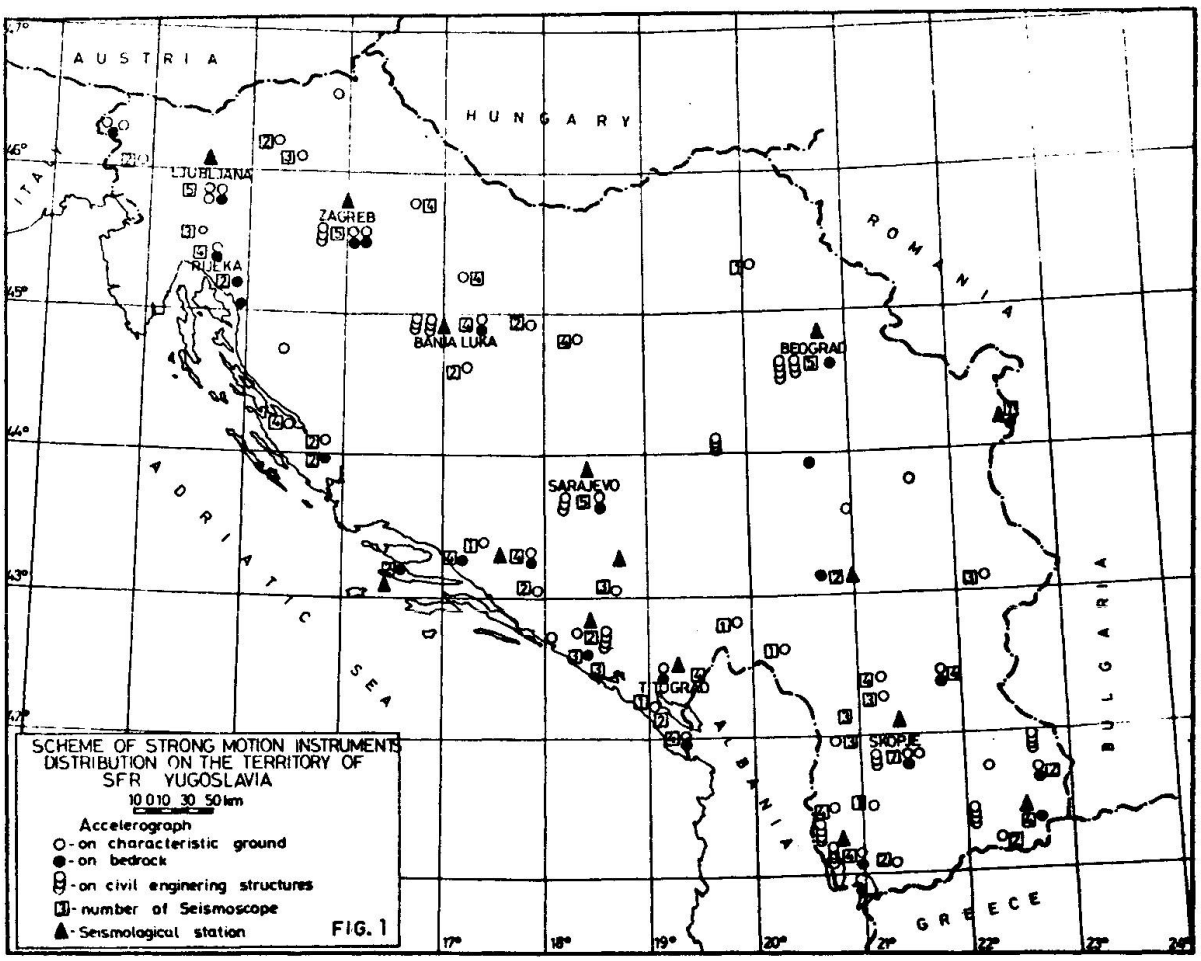
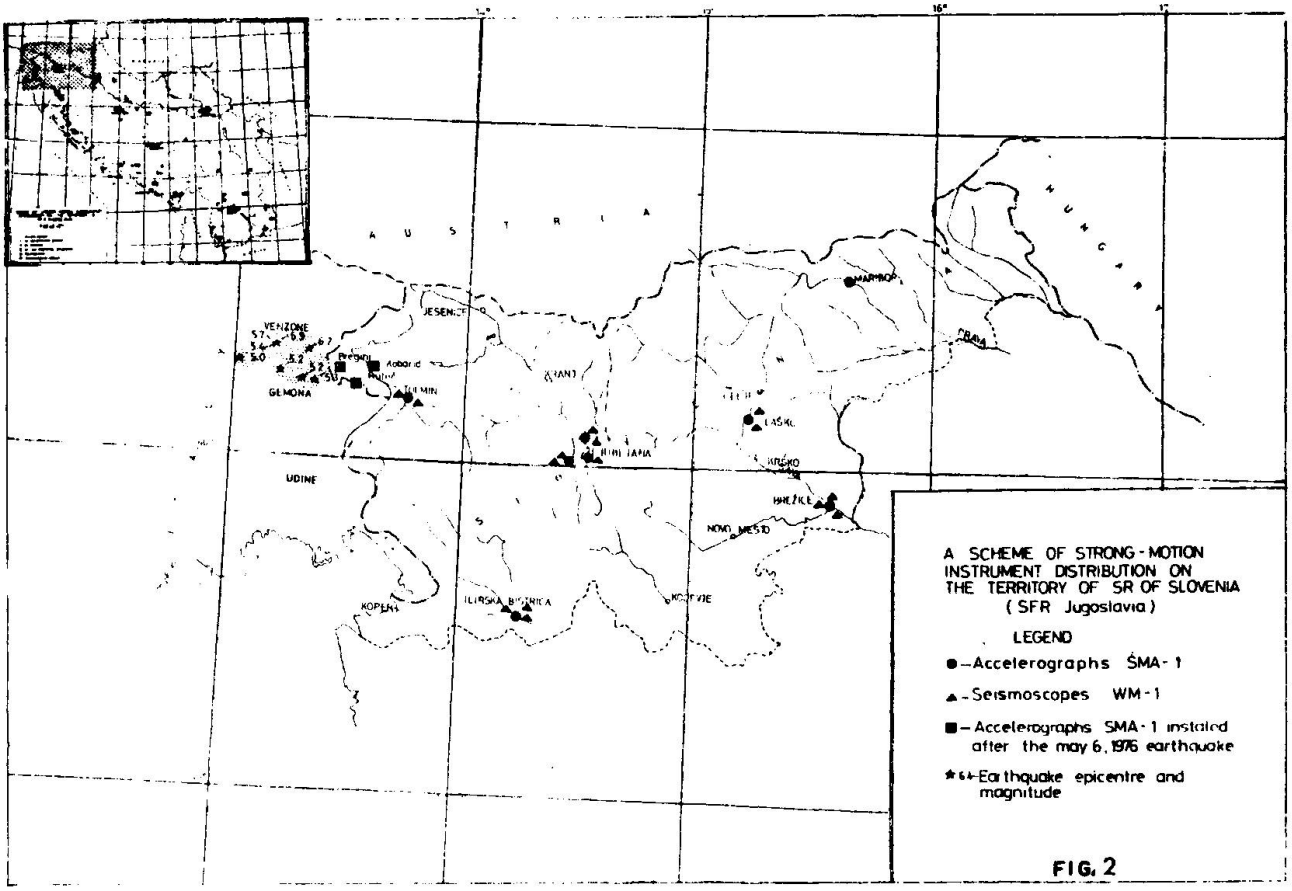

AUSTRIA
HUNGARY
ROMANIA
BULGARIA
GREECE
ADRIATIC SEA
LJUBLJANA
ZAGREB
RIJEKA
BANJA LUKA
BEDGRAD
SARAJEVO
TITOGRAD
SKOPJE
SCHEME OF STRONG MOTION INSTRUMENTS DISTRIBUTION ON THE TERRITORY OF SFR YUGOSLAVIA
10 0 10 30 50 km
Accelerograph
O-on characteristic ground
●-on bedrock
-on civil enginering structures
-number of Seismoscope
▲-Seismological station
FIG. 1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HUNGARY
VENZONE
GEMONA
UDINE
JESENICE
LJUBLJANA
MARIBOR
CELJE
LAŠKO
KRŠKO
KRŠKE
NOVO MESTO
KOPER
ILIRSKA BISTRICA
A SCHEME OF STRONG-MOTION INSTRUMENT DISTRIBUTION ON THE TERRITORY OF SR OF SLOVENIA (SFR Jugoslavia)
LEGEND
●-Accelerographs SMA-1
▲-Seismoscopes WM-1
■-Accelerographs SMA-1 instaled after the may 6, 1976 earthquake
★6.4-Earthquake epicentre and magnitude
FIG. 2

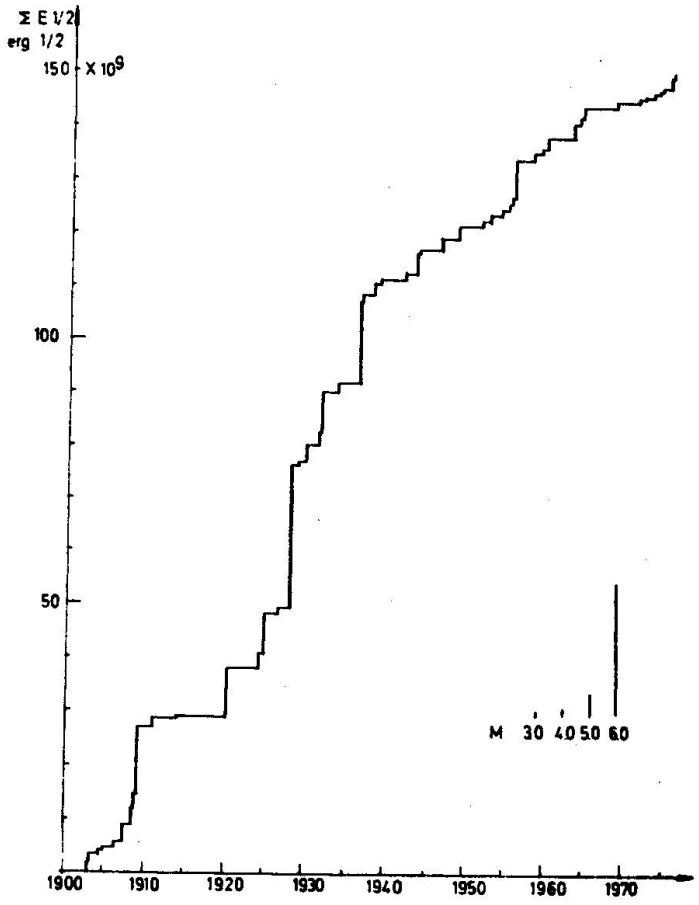

Fig. 3 STRAIN RELEASE CURVE (1900 - 1976)
(After D.Cvijanovic)

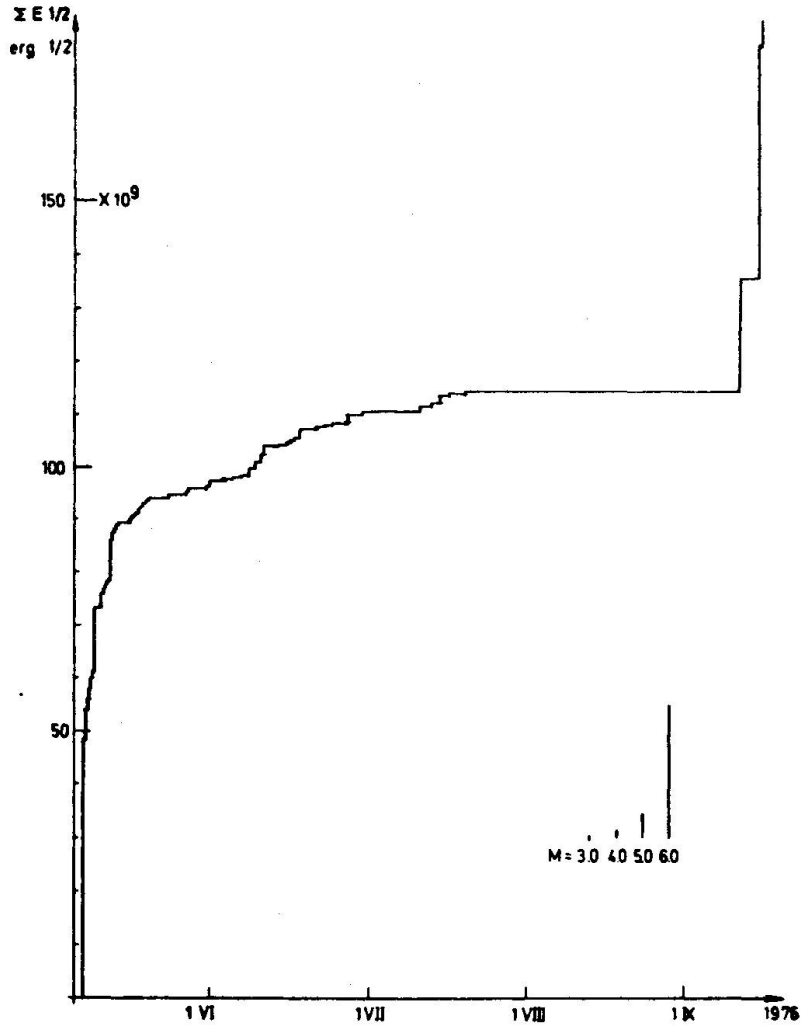

Fig. 4 STRAIN RELEASE CURVE (May 1st to Sept. 15, 1976)
(After D. Cvijanovic)

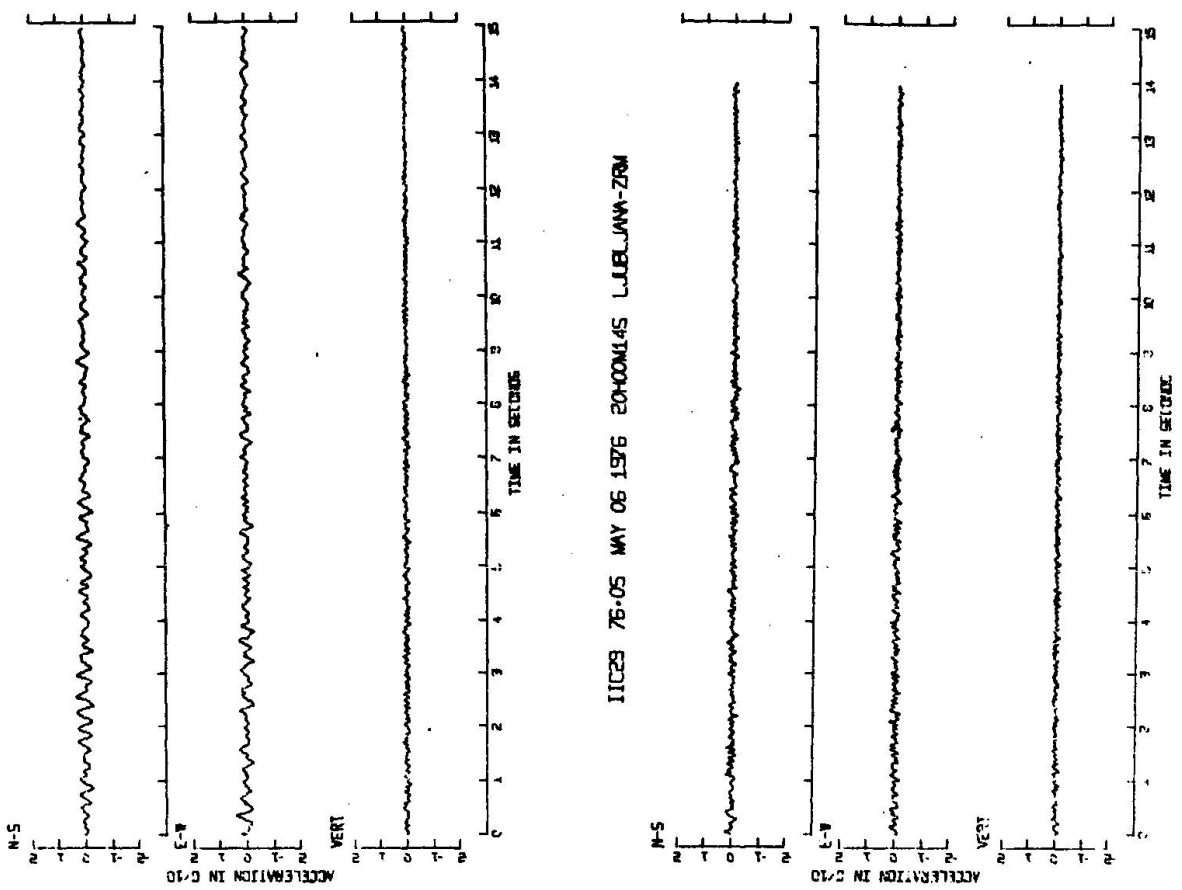
IIC28 76-04 MAY 06 1976 20H00M14S LJUBLJANA-INFIN
N-S
E-W
VERT
ACCELERATION IN G/10
TIME IN SECONDS
IIC29 76-05 MAY 06 1976 20H00M14S LJUBLJANA-ZRM
N-S
E-W
VERT
ACCELERATION IN G/10
TIME IN SECONDS

FIG-6

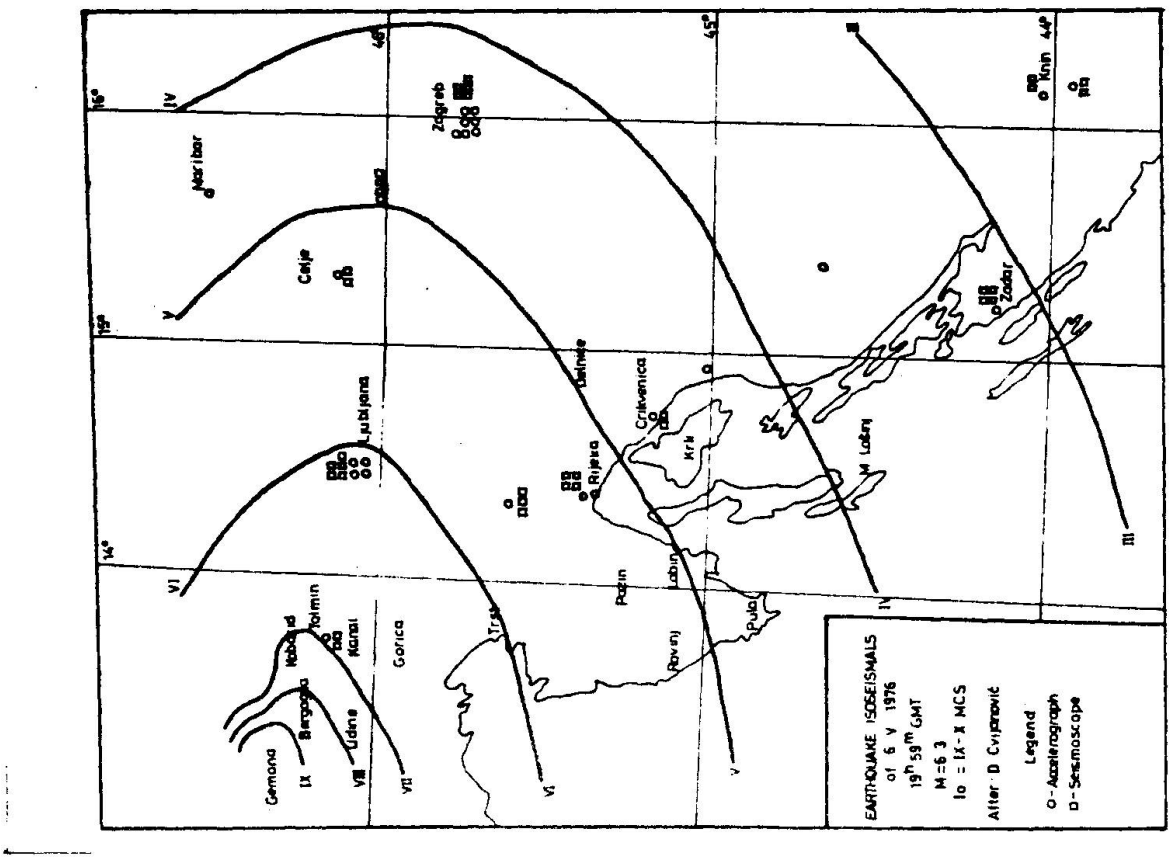
Maribor
Celje
Ljubljana
Zagreb
Delnice
Crikvenica
Rijeka
Krk
M. Lošinj
Zadar
Knin
Pazin
Labin
Pula
Rovinj
Trst
Gorica
Tolmin
Kobarid
Gemona
Barcola
Udine
Kanal
EARTHQUAKE ISOSEISMALS
of 6 V 1976
19h 59m GMT
M=6.3
Io = IX - X MCS
After D Cvijanović
Legend
o - Accelerograph
□ - Seismoscope

FIG 5

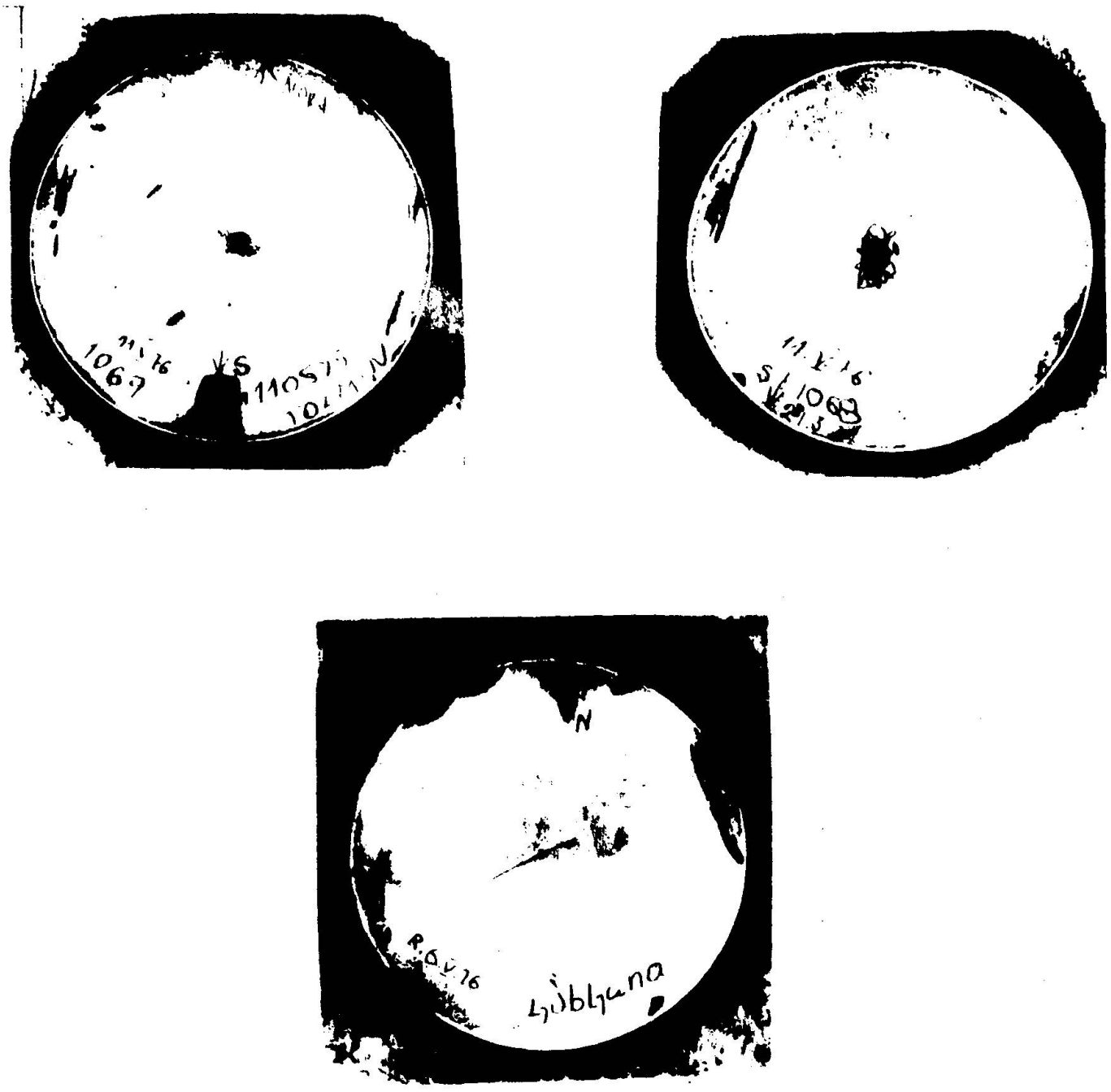

Fig. 7 FRIULI EARTHQUAKE, May 6, 1976
Recordings of Seismoscopes
(1) Tolmin - Town Council
(2) Tolmin - Fire House
(3) Ljubljana - 88 Tokljukarjeva Street

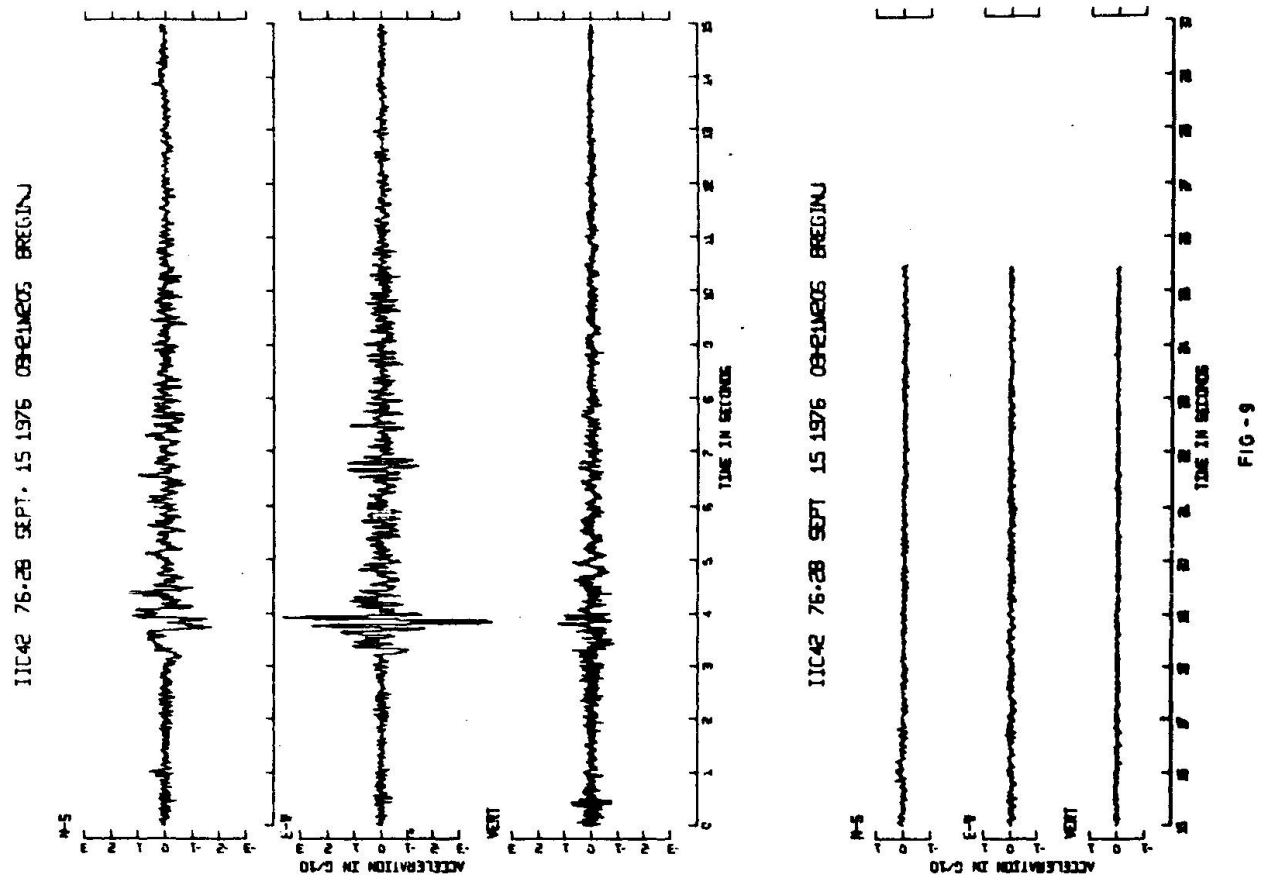
IIC42 76-28 SEPT. 15 1976 08H19M00S BRGINJ
N-S
E-W
VERT
ACCELERATION IN G/10
TIME IN SECONDS

FIG - 9

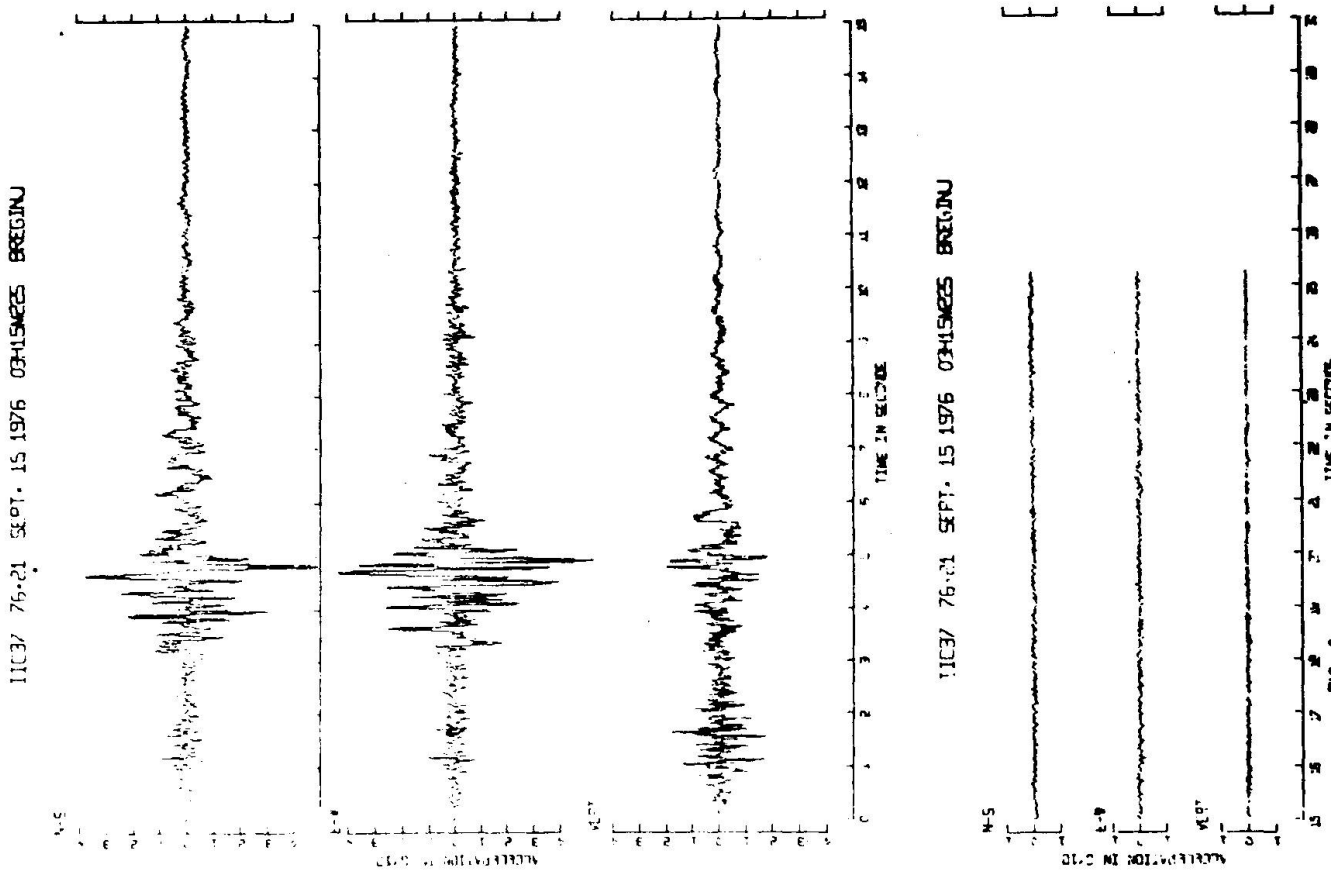
IIC37 76-21 SEPT. 15 1976 03H15M22S BRGINJ
N-S
E-W
VERT
ACCELERATION IN G/10
TIME IN SECONDS

FIG - 8

FRIULI EARTHQUAKE, ITALY, SEPT. 15, 1976, 03h 15m, RECORDED IN BREGINJ - YUGOSLAVIA
RELATIVE DISPLACEMENT AND PSEUDO ACCELERATION RESPONSE SPECTRA
Damping 2, 5 and 10 percent of critical

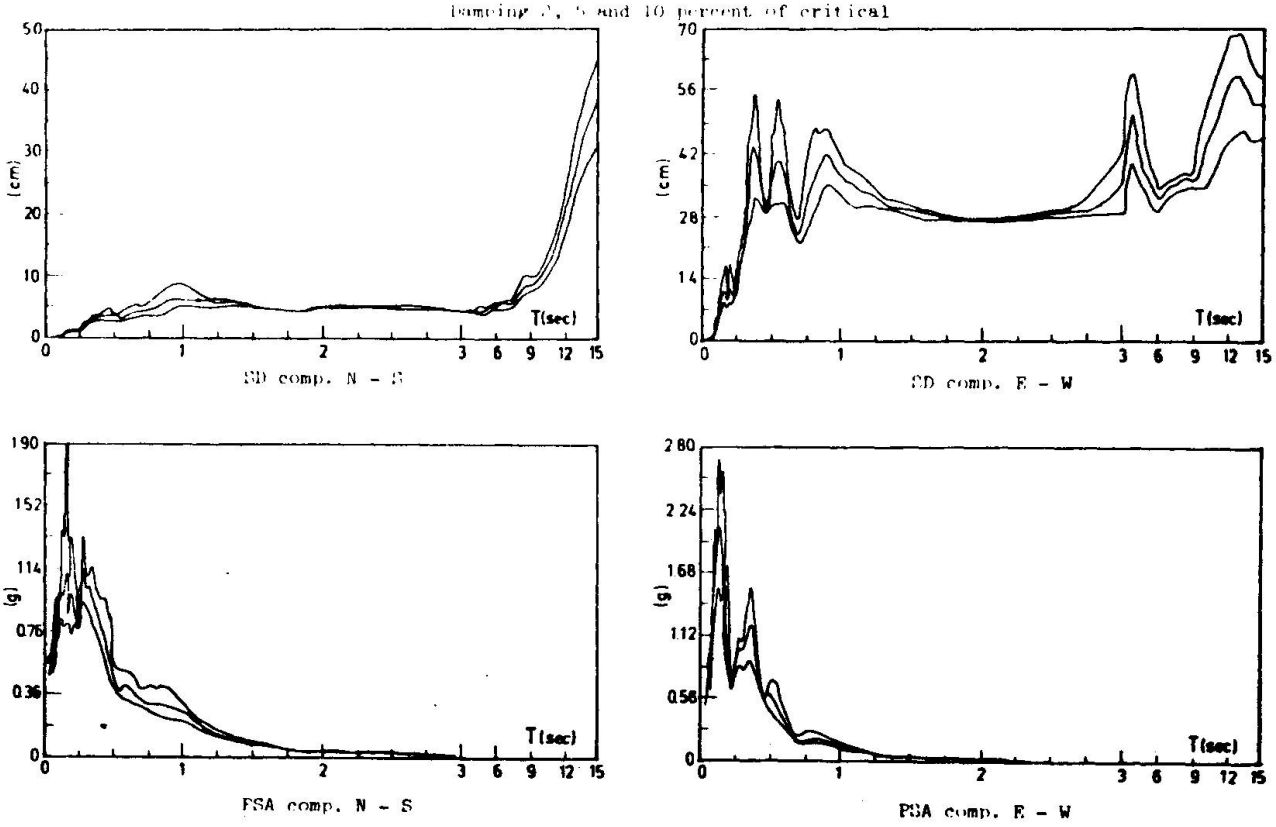

Fig. 10

FRIULI EARTHQUAKE, ITALY, SEPT. 4 1976, 00h 21m, RECORDED IN BREGINJ - YUGOSLAVIA
RELATIVE DISPLACEMENT AND PSEUDO ACCELERATION RESPONSE SPECTRA
Damping 2, 5 and 10 percent of critical

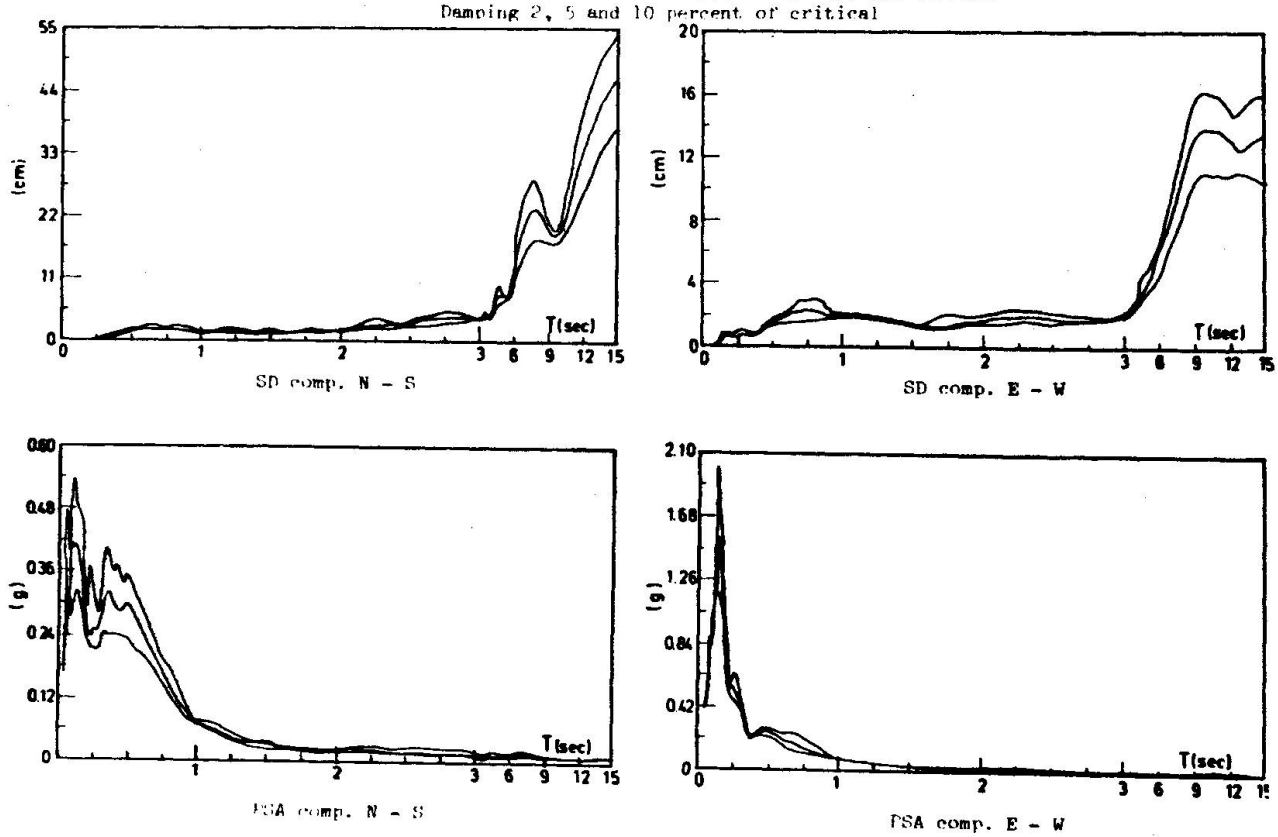

Fig. 11

FRIULI EARTHQUAKE, ITALY, SEPT. 15, 1976, 09h 21m, RECORDED IN KOBARID - YUGOSLAVIA
RELATIVE DISPLACEMENT AND PSEUDO ACCELERATION RESPONSE SPECTRA
Damping 2, 5 and 10 percent from critical

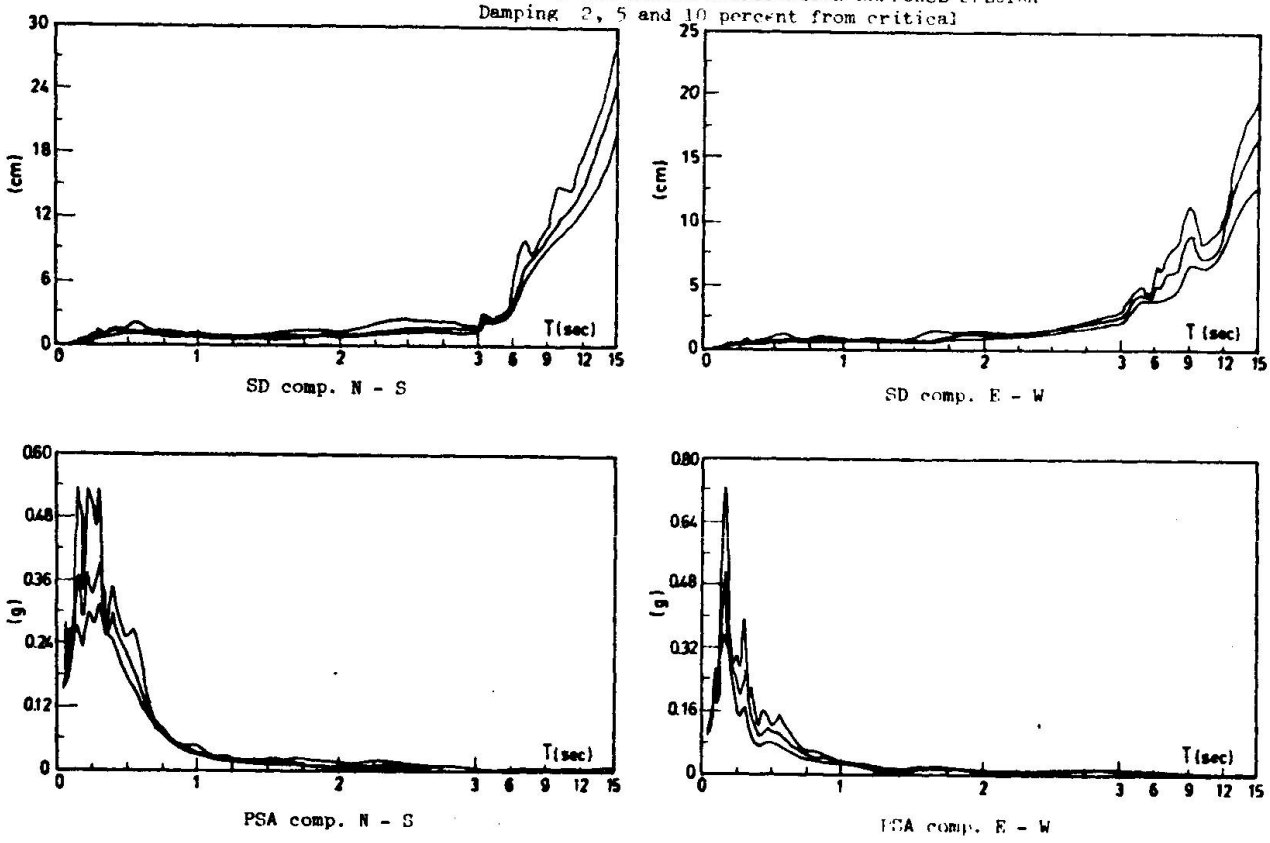

Fig. 12

FRIULI EARTHQUAKE, ITALY, SEPT. 15, 1976, 03 h 15m, RECORDED IN ROBIC - YUGOSLAVIA
RELATIVE DISPLACEMENT AND PSEUDO ACCELERATION RESPONSE SPECTRA
Damping 2, 5 and 10 percent of critical

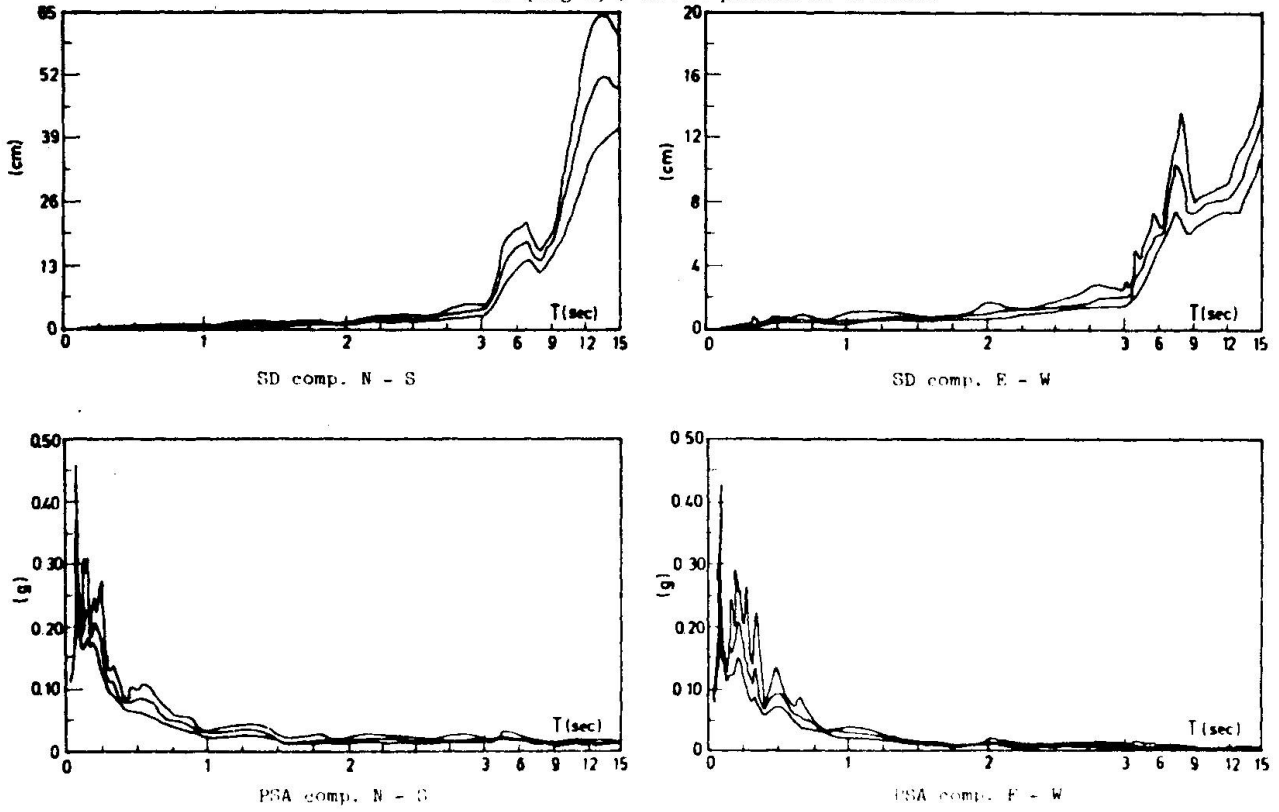

Fig. 13