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EVALUATION OF THE RELIABILITY OF A SEISMIC NETWORK: THE HSSN (ISRAEL) AS AN EXAMPLE

Abstract. Under the assumption that an earthquake can be analyzed if it is detected and recorded by at least four stations, we propose to describe various scenarios leading to the total loss of ability to acquire sufficient data for seismological analysis. These scenarios are presented by constructed fault-trees, to each branch of which is assigned the empirical annual probability of occurrence (equipment malfunction or external disturbance). For each branch of the fault-tree, the probability of occurrence is computed and, eventually, the overall reliability of the seismic network is estimated in terms of annual probability of failure to detect and locate seismic events. This approach, often used by engineers in safety analysis, has been applied to a seven station local network (HSSN) which operates in parallel with the Israel national seismic network. In this example it is estimated that there is an annual probability of $3 \cdot 10^{-4}$ that an earthquake of magnitude 3.0 or higher would not be detected and analyzed.

INTRODUCTION

The need to evaluate the reliability with which a seismic network performs according to its designed characteristics covers a wide range of scientific, technical and economical considerations. This important issue is mentioned in the seismological literature, mainly in association with detectability estimates. Techniques and examples are discussed by, for example, Ringdal et al. (1977), Shapira et al. (1979, 1981), Harjas (1984) and Shapira (1992). In the present study it is proposed that the reliability estimates are obtained by means of a fault-tree analysis. This approach is commonly used by engineers in safety analysis. As an example of the application of this technique in seismic monitoring, it is applied to a local seismic network (HSSN) operating in the Negev, Israel, in parallel with the national seismic network, the ISSN (Israel Seismograph Station Network).

THE HSSN

A seven station seismic network operates in the Halutza area of the Negev, Israel. The Halutza Seismograph Station Network (HSSN) is owned by the Israel Electric Corporation Ltd. (IEC) and, since 1981, has been operated by the Seismological Division of the Institute for Petroleum Research and Geophysics (IPRG). The ultimate purpose of the HSSN is to facilitate continuous monitoring of micro-earthquake activity, if it exists, in the Halutza area, which is considered a candidate site for a nuclear power plant. Thus, the Halutza area is monitored by both the HSSN and the ISSN as shown in the map of Fig. 1.

The seismograph station, powered by solar panel system, continuously transmits ground

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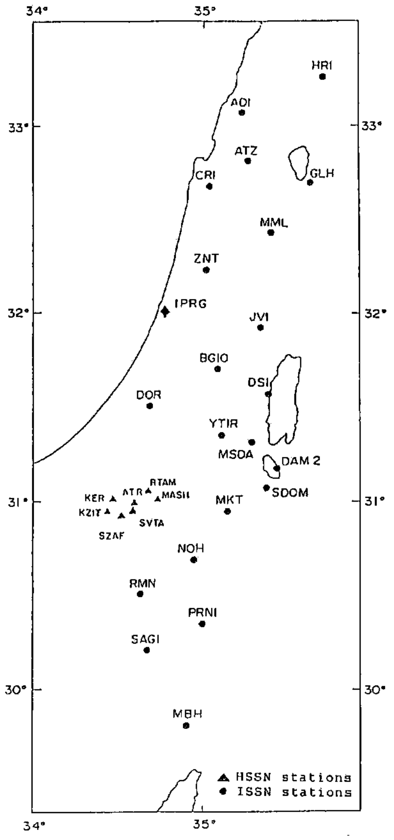


Fig. 1 - Locations of the ISSN and HSSN stations.

motions to the recording center, where they are recorded both digitally and on analog paper recorders. Only triggered events are then digitally recorded with a computerized system. The technical scheme of the HSSN network is described in Fig. 2.

An uninterupted power supply (UPS) is ensured by a UPS system and a diesel generator. The batteries of the UPS system ensures about 1 hour of electrical power supply to the recording equipment, following total loss of the offsite power and of the diesel generator.

THE ISSN

The Israel Seismograph Station Network (ISSN) comprises twenty-one stations geographically distributed throughout the territory of Israel (see Fig. 1). All seismometers are short period (0.2-12.5 Hz) suitable for local and regional seismic monitoring. The data are transmitted via radio (FM telemetry) to the IPRG recording center at Holon.

A computerized data acquisition system is used to digitize the data and records events triggered by at least five (5) stations. Continuous analog recording on helicorders is performed as a backup. An uninterupted power supply (UPS) is ensured by two UPS systems (one for the computer terminals and a smaller for the computer CP Unit) and by a diesel generator (Fig. 2 gives a detailed description of ISSN equipment and instrumentation).

BASIC ASSUMPTIONS

Following the results of Shapira (1992), it is assumed that any seismic event of magnitude

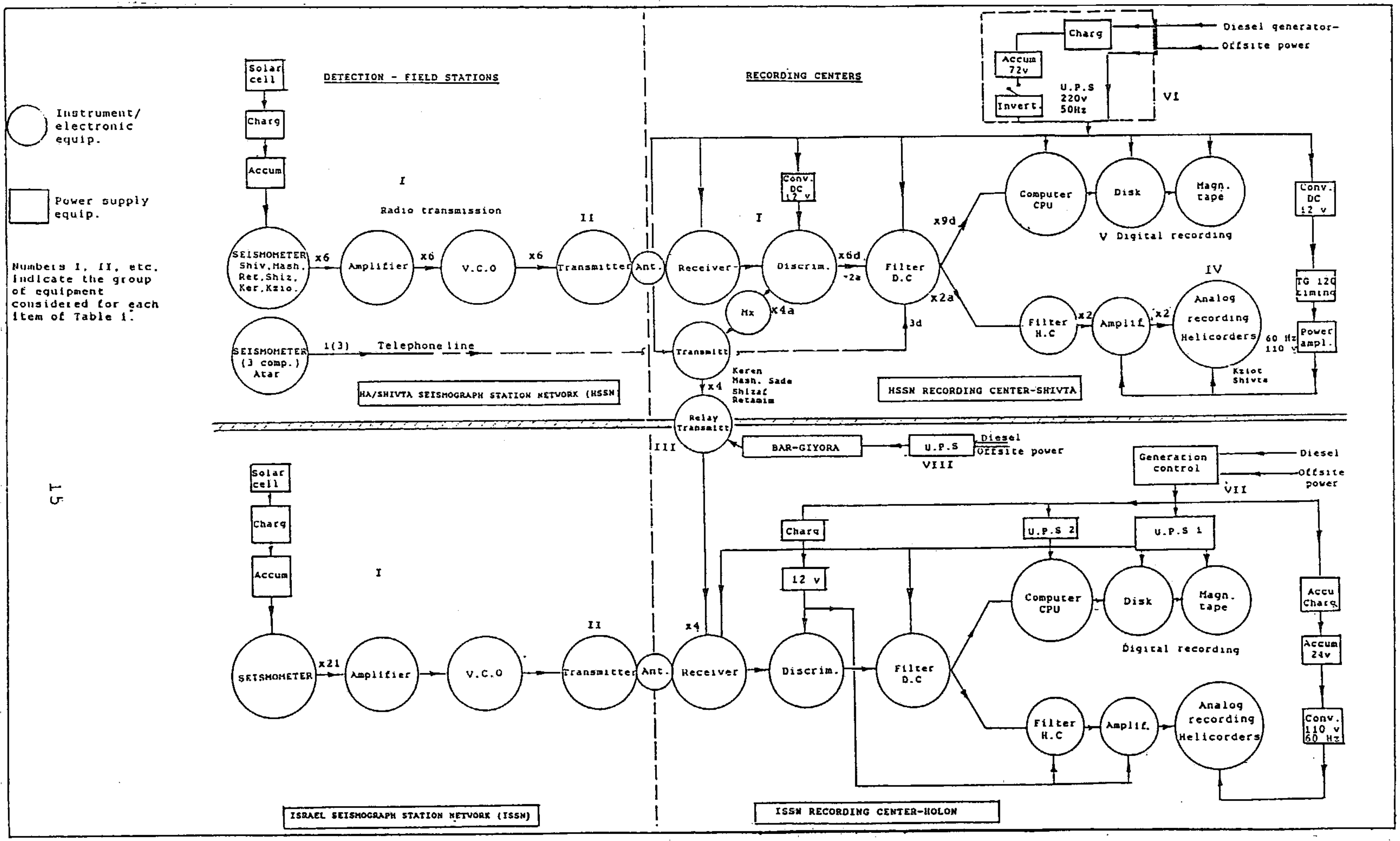


Fig. 2 - Schematic description of the HSSN technical configuration.

$M_L \geqslant 2.0$ which occurs in the Halutza area can be detected and located by the seismicity monitoring systems, provided that these are fully operational. Malfunction of equipment, communication problems with radio telemetry, high background noise, etc. will reduce the capability to monitor earthquakes in the Halutza area. The following scenarios have been selected as the main cases for loss of information regarding the occurrence and location of an earthquake in the Halutza area:

Case A: Earthquakes of magnitude $M_L \leqslant 2$ will be lost if data from at least four out of seven of the HSSN stations are not measurable.

Case B: Earthquakes of magnitude $M_L \leqslant 2.5$ will be lost should Case A occur, and if data from at least four of the eight ISSN stations, DOR, RMN, NOH, YTIR, PRNI, SAGI, MSDA and MKT, are not measurable.

Case C: If four of the seven HSSN stations become non measurable and, in addition, eight ISSN stations of the following 12 stations: DOR, RMN, NOH, YTIR, PRNI, SAGI, MSDA, MKT, BGIO, DSI, MBH, and SDOM are not measurable, then an earthquake of magnitude $M_L \leqslant 3.0$ will be lost.

Case D: Should Case A occur and 18 of the 21 ISSN stations become non measurable, then events of $M_L \leqslant 4.5$ will be lost. Stronger earthquakes will probably be detected and located by seismic stations outside Israel.

FAULT-TREE CONSTRUCTION AND PROBABILITY EVALUATION

Fault-tree construction

The selected scenarios (the top events in the fault-tree) of loss of detection or recording of seismic events occurring at the shivta zone, are developed as combinations of secondary and basic events.

The secondary events consist either in a combination of non-measurable seismograph stations, or in the total loss of power at the recording center, or in the simultaneous loss of analog and digital recording at the recording center.

The basic events which make a station non-measurable are either a malfunction of field station instrumentation and equipment or a malfunction of pre-recording equipment at the recording center (see Fig. 2). Field station malfunctions also include malfunctions caused by human activities in the proximity of the station (earthworks, theft of batteries or solar panel systems, etc.).

High background noise (magnitude dependent) and communication noise (station dependent), which could affect transmission or reception of the seismic signals from the seismograph station, were also considered as basic events which make a station non-measurable. Due to the presence of communication industries in the vicinity of the Holon IPRG recording center, strong radio noise was also included as a basic event for the loss of recording at the Holon IPRG center.

The basic events leading to loss of digital recording include mainly computer (disk, circuit, terminal) and magnetic tape malfunctions. Loss of analog recording equipment at the HSSN center includes mainly helicorder malfunctions (drum, stylus, wiring), failure to change paper for helicorder, and failure of other equipment (filter, amplifier, etc.) necessary for the recording.

The basic event leading to total loss of power at the HSSN and IPRG recording centers are either a malfunction in the UPS system or a simultaneous loss of the electrical grid and of the emergency diesel generator.

The fault-trees of Cases A, B and C, and D as defied in the preceding chapter are presented in Fig. 3, Fig. 4 and Fig. 5, respectively.

Probability evaluation

The fault-trees of Figs. 3 to 5, are represented mathematically using Boolean algebra for

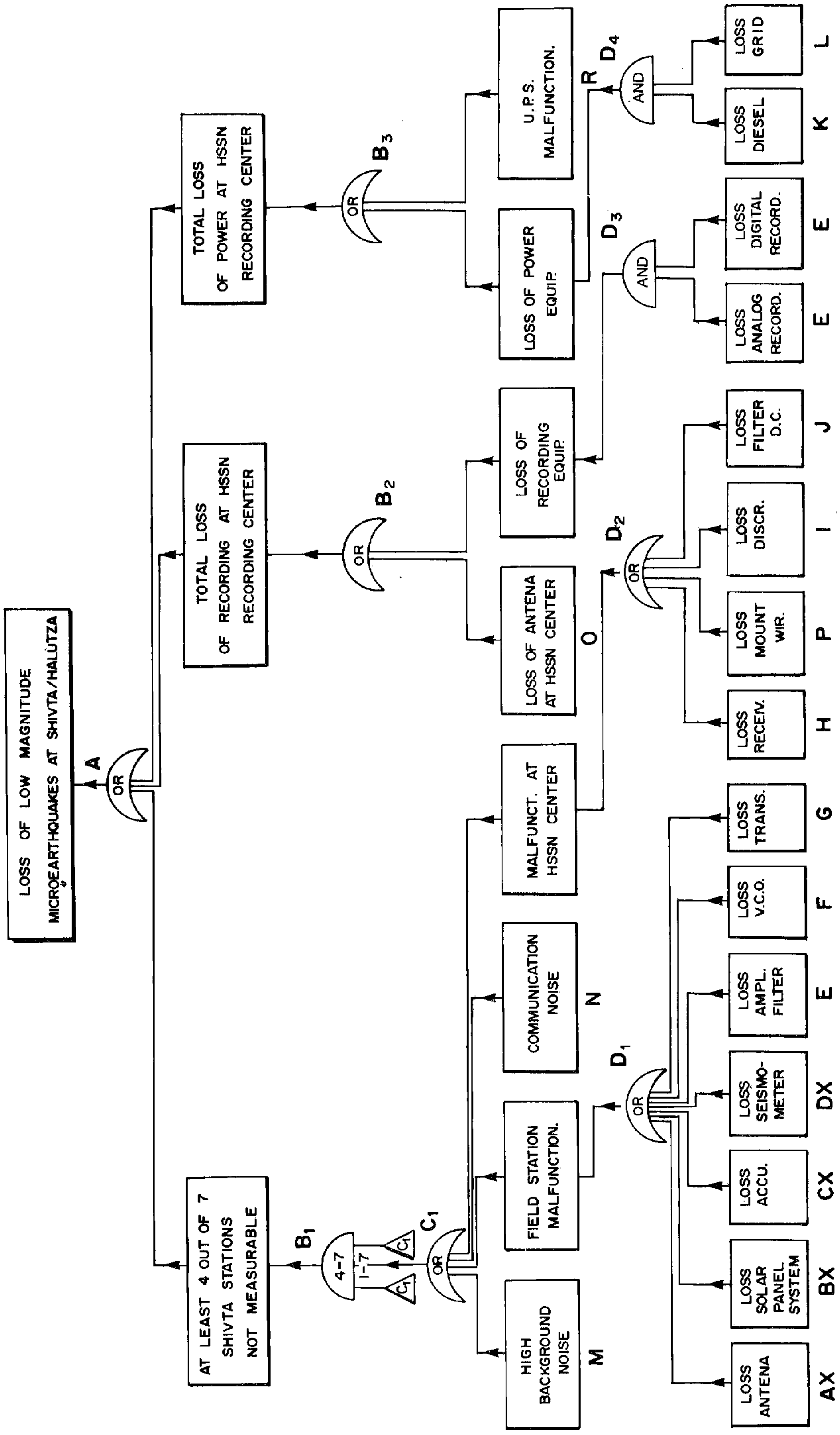
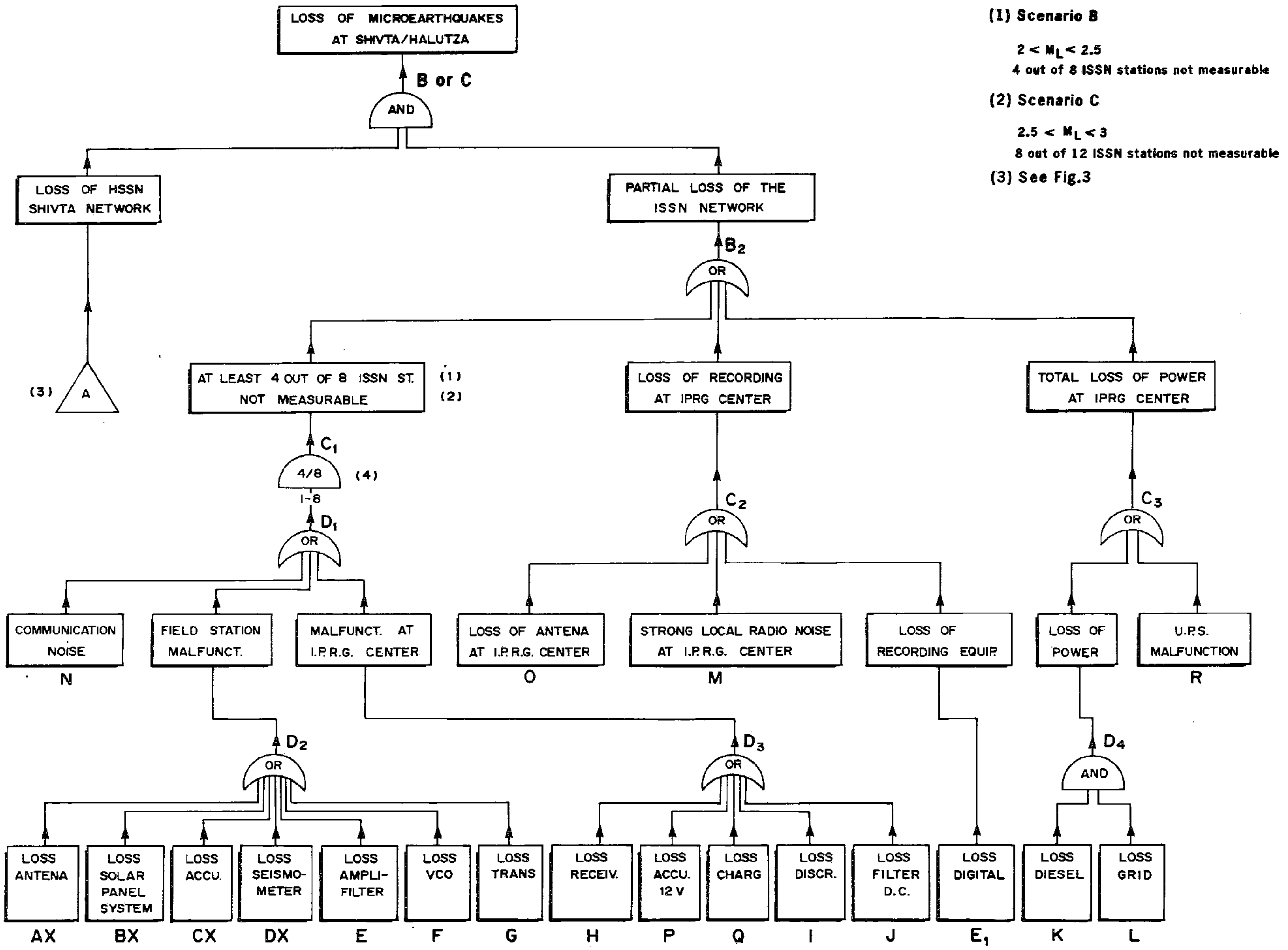


Fig. 3 - Fault-tree for the occurrence of Case A (see text).



(1) Scenario B

$2 < M_L < 2.5$

4 out of 8 ISSN stations not measurable

(2) Scenario C

$2.5 < M_L < 3$

8 out of 12 ISSN stations not measurable

(3) See Fig.3

Fig. 4 - Fault-tree for the occurrence of Cases B and C (see text).

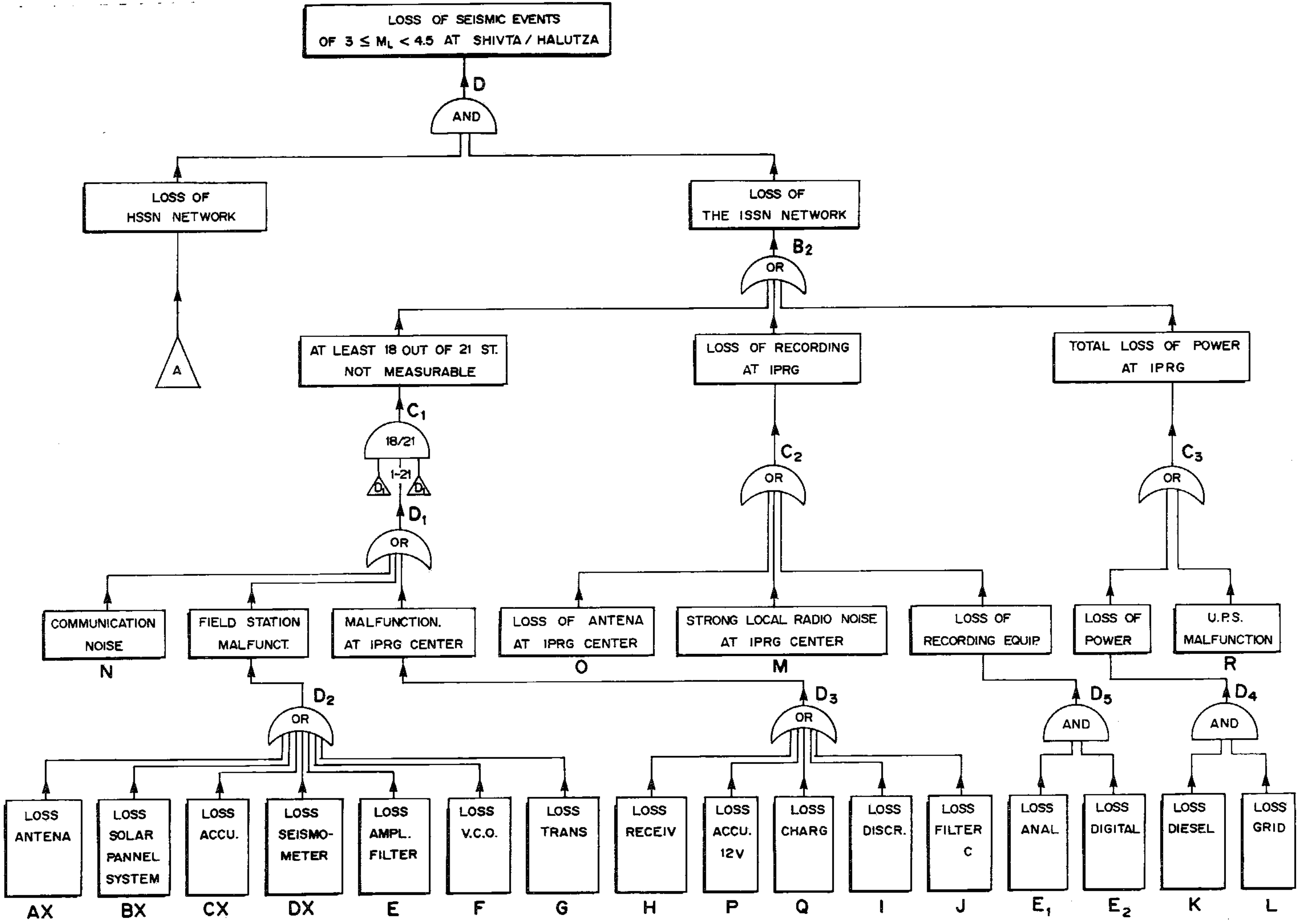


Fig. 5 - Fault-tree for the occurrence of Case D (see text).

each gate, which allows expression of the top-events in terms of basic events (see an example of calculation of scenario D probability as a function of basic event probabilities in the Appendix).

The top-event probabilities are then calculated as a function of the empirical failure probabilities of the basic equipment (see Appendix), and of the likelihood of occurence of communication, high background or strong radio noises.

Experimental data on basic instrumentation or equipment forming the HSSN and ISSN networks was taken from IPRG quarterly seismological bulletins. The basic equipment failure probabilites considered are average values over a period of four years from 1986 to 1989 (see the Table in the Appendix).

RESULTS AND DISCUSSIONS

In spite of back-up systems and some redundancy in instrumentation, there may always be cases where seismic data are lost. This analysis for the HSSN serves as a test case and example for demonstrating the use of the fault-tree technique to obtain and estimate of the probability that data are lost. This is termed as "reliability assessment". The reliability of the HSSN can be summarized as follows:

1. There is an annual probability of $3 \cdot 10^{-4}$ that an event of magnitude $M_L < 4.5$ in the Halutza area would not be measured and located by the Israeli seismographs. The strong radio noise at the IPRG recording center due to the presence of communication industries in the vicinity of the center has been found to be the main contributor to the loss of such seismic events.

2. The annual probability that micro-earthquakes of $M_L < 3$ will be missed is in the order of $2 \cdot 10^{-3}$. In this case, computer malfunction at the IPRG center appeared to be an important contributor to the loss.

3. The likelihood of a detection or recording loss of low magnitude micro-earthquakes (magnitude $M_L < 2$) in the Halutza area was also found to be low: ($6 \cdot 10^{-3}$) per year. Total loss of electrical power supply at the HSSN recording center was found to be an important contributor to the loss of such low magnitude micro-earthquakes occurring in the Halutza area.

4. The fault-tree analysis reveals that, due to the great redundancy of seismograph stations, loss of detection does not appear to have been an important contributor to loss of network capabilities.

The above critical reasons for the loss of important seismic data have been identified through this analysis. Although some of them are beyond our controls, others could easily be eliminated once they have been recognized. It should be realized, however, that such an analysis requires a good statistical sample of the failure rates of the different systems, sub-systems and components. The more detailed the fault-tree, the more difficult and time consuming it is to obtain this type of information.

Obviously such information may only be available when a quality assurance program is designed and operational throughout all the technical operations associated with the seismic monitoring. Seismic monitoring in Israel is fully controlled and technically documented, thus facilitating the assessment of reliability of the Israeli seismic networks.

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APPENDIX

Example of Calculation of the scenario probabilites as a function of basic event probabilites for Scenario D

(Loss of detection or recording of seismic events of magnitude $3 \leqslant ML \leqslant 4.5$)

$$D=A.B2,$$

where

A is the loss of the HSSN network,

B2 = C1 + C2 + C3

C1 = f(D1) where f is a 18 out of 21 logical gate,

D1 = N + D2 + D3

D2 = AX + BX + CX + DX + E + F + G,

D3 = H + P + Q + I + J,

C2 = O + M + D5,

D5 = E1 . E2,

C3 = D4 + R,

D4 = K.L,

Thus

$$D=A.\{f\ (N+AX+BX+CX+DX+E+F+G+H+P+Q+I+J)+O+M+E1.E2+K.L+R\},$$

where,

E1 = f (F1) where f is a 18 out of 21 logical gate,

F1 = G1 + G2 + G3 + G4 + G5 + G6 + G7 + G8,

E2 = F2 + G15 + F3 = G9 + G10 + G11 + G12 + G13 + G14 + G15.

The scenario D probability as function of basic event probabilites is given by

$$P\ (D)=P\ (A).\ \{P\ [f\ (N+AX+BX+CX+DX+E+F+G+H+P+Q+I+J)]\ +P\ (O)+P\ (M)+ P\ (E1).P\ (E2)+P\ (K).P\ (L)+P\ (R)\}. \qquad (1)$$

The probability that at least 18 out 21 ISSN stations are not measurable is given by

$$P\ [f\ (N+AX+BX+CX+DX+E+F+G+H+P+O+I+J)]=c_{18}\ ,\ _{21}\ p_1^{18}\ (1-p_1)^3+C_{19}\ ,\ _{21}\ p_1^{19}\ (1-p_1\ )^2+C_{20}\ ,\ _{21}\ p_1^{20}\ (1-p1)+C_{21}\ ,\ _{21}\ p_1^{21} \approx 1330\ p_1^{18}\ ,$$

where $p_1 = P\ (N) + P\ (AX) + P\ (BX) + P\ (CX) + P\ (DX) + P\ (E) + P\ (F) + P\ (G) + P\ (H) + P\ (P) + P\ (Q) + P(I) + P\ (J)$.
Using the Table values,

$$p_1=P\ (N)+P\ (DX)+P\ (G),$$

where

P (N) = Communication noise,

P (DX) = Loss of seismometer,

P (G) = loss of transmitter.

Now,

$$p_1=0.011+0.049+8.10^{-3}=0.068 \text{ per year}$$

P (M) = strong radio noise at IPRG = 0.055 per year,

$P\ (K).P\ (L)+P\ (R)$ = total loss of power at IPRG $= 1.8\cdot 10^{-3}$/year,

$P\ (E2)$ = loss of digital recording at IPRG $= 0.25$ per year,

$P\ (E1)=1330\ p_2^{18}$,

$p_2=P\ (G1\text{–}G8)$ = loss of analog recording of ISSN stations at IPRG $= 0.029$ per year

Replacing the above values in eqn. (1) gives

$$P\ (D)=6\cdot 10^{-3}\ [1330x\ (0.068)^{18}+0.055+1.8\cdot 10^{-3}+0.25x1330$$

$$\times(0.029)^{18}]=6\cdot 10^{-3}\ (0.055+1.8\cdot 10^{-3}).$$

The probability of occurrence of scenario D is

$$P\ (D)=3\cdot 10^{-4}\ \text{per year}$$

Table - Average empirical probabilities (1986 to 1989) calculated with data from IPRG quarterly seismological bulletins.

Malfunction/ Perturbation	1989	1988	1987	1986	Average per year
Seismometer (I)	0.018	0.023	0.055	0.102	0.049
Transmitter (II)	-	0.0125	0.014	5.0 10^{-3}	8. 10^{-3}
High background noise	0.28	-	0.021	0.012	0.015
Communication noise	7.0 10^{-3}	2.7 10^{-3}	0.012	0.022	0.011
Strong radio noise at IPRG	-	-	-	-	0.055 (2)
Bar-Giyora (BG) relay station (III)	0.036	0.049	0.085	-	0.057 (1)
Analog recording equipment (IV)	0.068	0.125	0.078	4.10 $^{-3}$	0.069
Digital recording at HSSN center (V)	0.15	0.28	0.31	-	0.25 (1)
Total loss of power at HSSN center (VI)	5.5 10^{-3}	2.7 10^{-3}	-	2.7 10^{-3}	2.7 10^{-3}
Total loss of power at IPRG center (VII)	-	-	-	-	1.8 10^{-3} (2)
Total loss of power at BG relay station (VIII)	-	-	-	-	1.8 10^{-3} (2)

(1) Average value over 3 years

(2) From discussions with IPRG staff

The numbers I, II, III, etc., indicate in Fig. 2 the group of equipment considered for each item.

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