COMPUTER PROGRAMS FOR SEISMIC HAZARD ANALYSIS

A USER MANUAL

(STANFORD SEISMIC HAZARD ANALYSIS--STASHA)

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16. Abstract (Limit: 200 words)

A set of computer programs organized in a consistent manner are described and implemented. The programs are based on probabilistic seismic risk models which have been utilized for hazard mapping of areas throughout the world. Constituting a complementary set sufficient for analysis, they are written in FORTRAN IV and have been tested on the Stanford IBM 370/168 computer. Program titles are: REPLACE.LETTER. MAGNITUDE; INTENSITY. MAGNITUDE; GENER.MAGNITUDE; PLOT. EPI; REGRESSION.ANALYSIS; ACC.LINE.AREA; SORT.MAGNITUDE; SEISMIC.HAZARD; CONST.PROB; and PLOT.ISO. For each program, the purpose and description, input data, macro flow chart, sample problem, presentation, and comments on the output are included. Sample problems are presented to illustrate and test the programs. The data used corresponds to a hypothetical though a realistic situation. A flow diagram schematically shows the three stages of the present form of seismic hazard analysis used at Stanford University.

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CHAPTER I

1.0 Introduction

When planning the design of a structure or a facility in a region of potential seismic activity, it becomes necessary to estimate the ground motion intensity to which the structure will be exposed during its economic life. The required information on the site intensity has to be derived using the seismic information available for the region, such as frequency of occurrence of earthquakes, Richter magnitude levels, etc.

Seismic Hazard Models are utilized to obtain the probabilities of the different ground intensity levels at a site. Therefore, the use of an established methodology to perform seismic hazard analysis and hence to synthesize the available seismological information for the purpose of obtaining a reliable estimate of future seismic loading at a site is necessary.

The principal objective of the current work is that of describing a set of computer programs organized in a consistent way in order to be used to perform seismic hazard analysis at a specified geographic location.

The programs have been developed at Stanford University. They are based on probabilistic seismic risk models discussed in detail by Shah, Mortgat, and Kiremidjian (1975), and Mortgat (1978). They have been utilized for hazard mapping of Nicaragua, Costa Rica, Guatemala, Algeria, offshore Alaska, California, and Honduras (currently in progress) (1, 2, 3, 4, 7).*

The programs constitute a complementary set and are sufficient for the analysis. They are written in FORTRAN IV and have been tested on the Stanford IBM 370/168 computer. Certain programs, such as plotting and mapping routines, are system oriented and can be used only at the Stanford Computer Center.

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*Numbers correspond to items in Reference List (see Appendix A).

1.1 Scope

The subsequent chapters of this work will be devoted to the description and implementation of each of the (ten) programs constituting the set, namely:

1.) Program REPLACE.LETTER.MAGNITUDE
2.) Program INTENSITY.MAGNITUDE
3.) Program GENER.MAGNITUDE
4.) Program PLOT.EPI
5.) Program REGRESSION.ANALYSIS
6.) Program ACC.LINE.AREA
7.) Program SORT.MAGNITUDE
8.) Program SEISMIC.HAZARD
9.) Program CONST.PROB
10.) Program PLOT.ISO

The items listed below will be included in each chapter in order to properly describe each computer program.

- Purpose and description of the program
- Description of input data
- Macro flow chart*
- Sample problem(s)
- Presentation and comments on the output

The sample problems will be presented with the purpose of illustrating the method and testing of the programs. They will be independent from one another and the data used will correspond to a hypothetical though a realistic situation.

Figure (1-1) shows schematically the three stages of the present form of seismic hazard analysis used at Stanford. Each of the three stages and

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*Macro flow charts have been included for each program in order to show the overall logic. The statements and symbols used in the current work are shown in Figures (1-4) and (1-5).

their related programs are summarized in the general flow chart shown in Figure (1-2). Each item presented in the chart will be discussed briefly in the remaining sections of this chapter. The reader is advised to consult references (1) and (6) for a detailed explanation of the theoretical development of the problem.

1.2 Remarks on the Flow Chart for Seismic Hazard Analysis (Figure 1-2)

Item (0)

There are various parameters used in the literature to represent the seismic loading. They are:

- Richter Magnitude (RM)
- Modified Mercalli Intensity (MMI)
- Peak Ground Acceleration or Velocity (PGA, PGV)
- Spectral Intensity
- Root Mean Square (RMS) acceleration, velocity or displacement

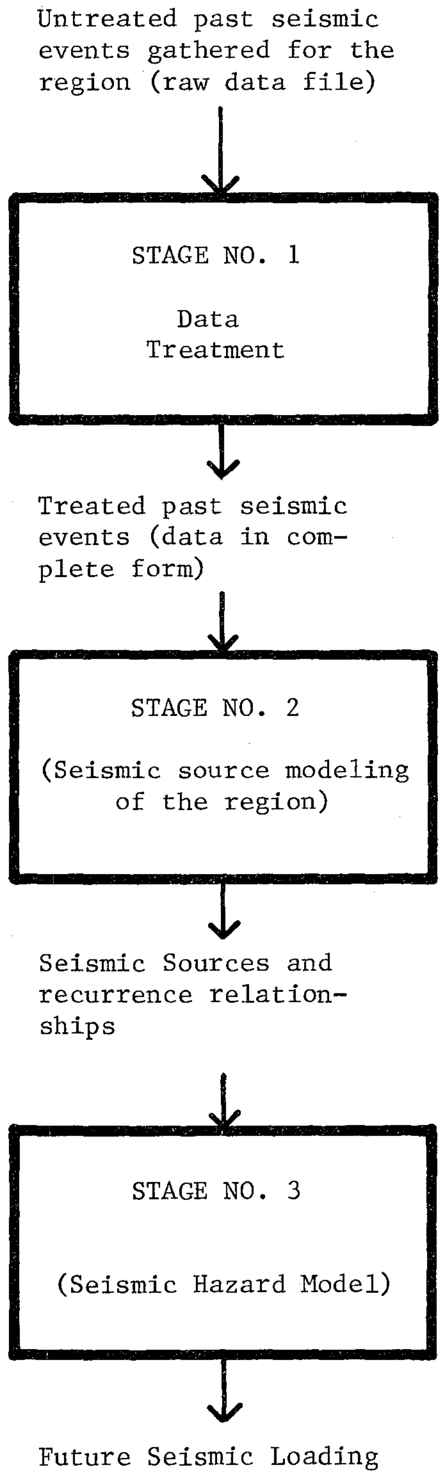
However, for structural engineering and design purposes, the most commonly and conveniently used parameter is the Peak Ground Acceleration (PGA).

To estimate probabilistically the Peak Ground Acceleration levels throughout a geographical location, one needs to get information regarding past seismic events. In particular, the following information is needed:

- Epicentral locations of past seismic events
- Time of occurrence
- Magnitude associated with each occurrence
- Depth of hypocenter
- Acceleration records associated with the above occurrences at different sites
- If possible, information on how energy (or Peak Ground Acceleration) attenuates from source of energy release to any site away from the source

Figure 1-1

SCHEME OF PRESENT SEISMIC HAZARD METHODOLOGY*



*Each of the above three stages are explained further in the following sections.

1.1 GENERAL FLOW CHART FOR SEISMIC HAZARD ANALYSIS

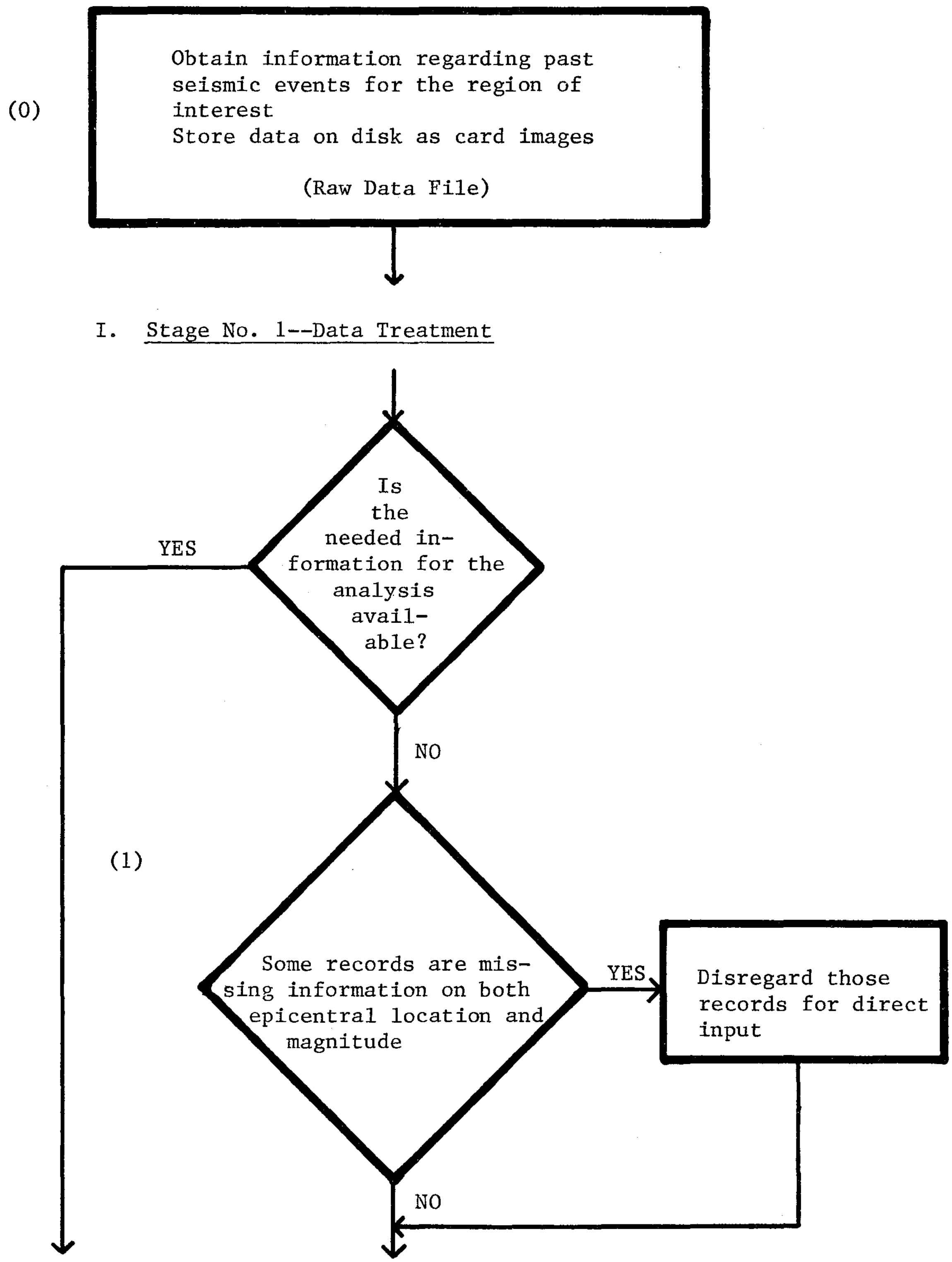


Figure 1-2

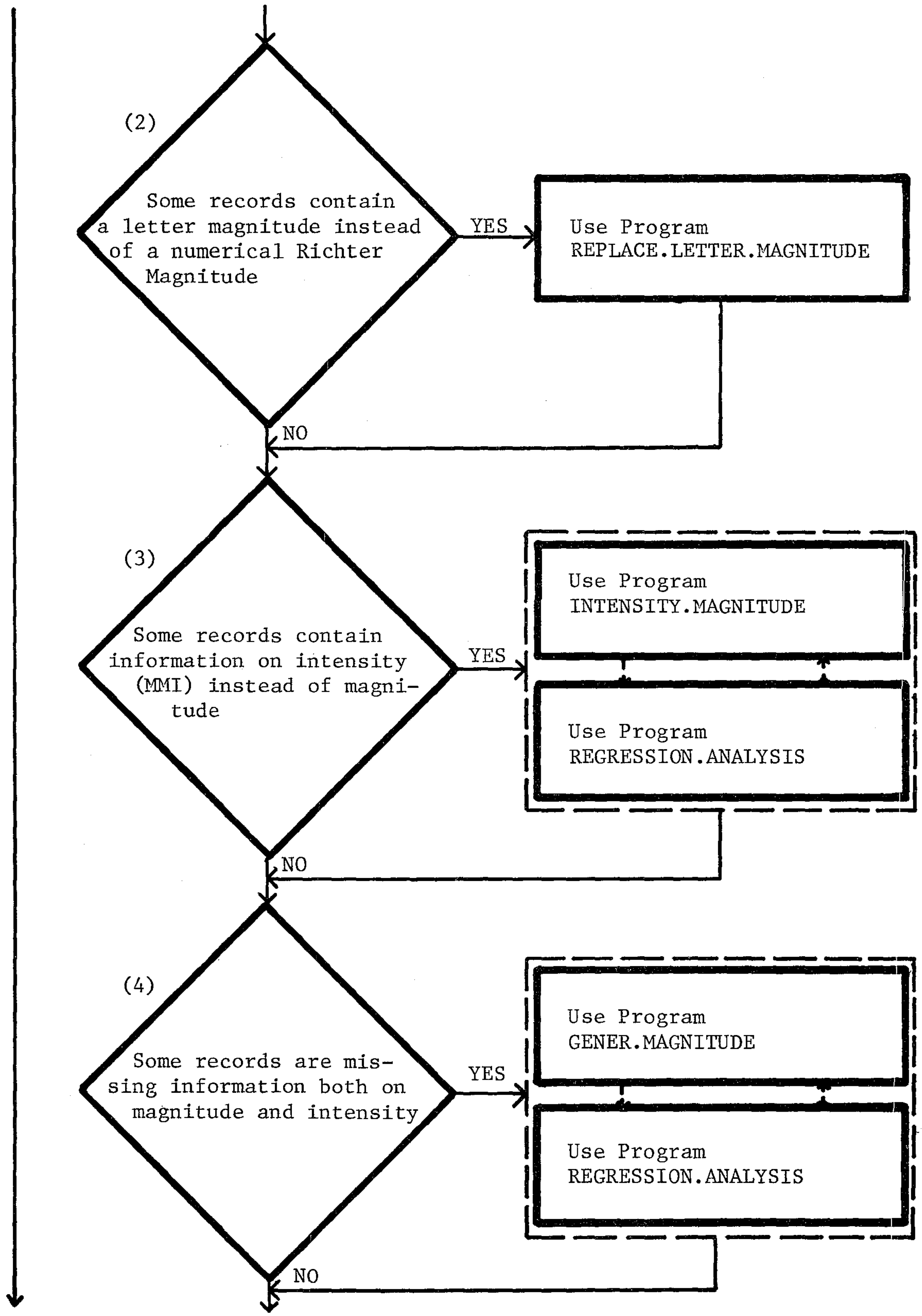
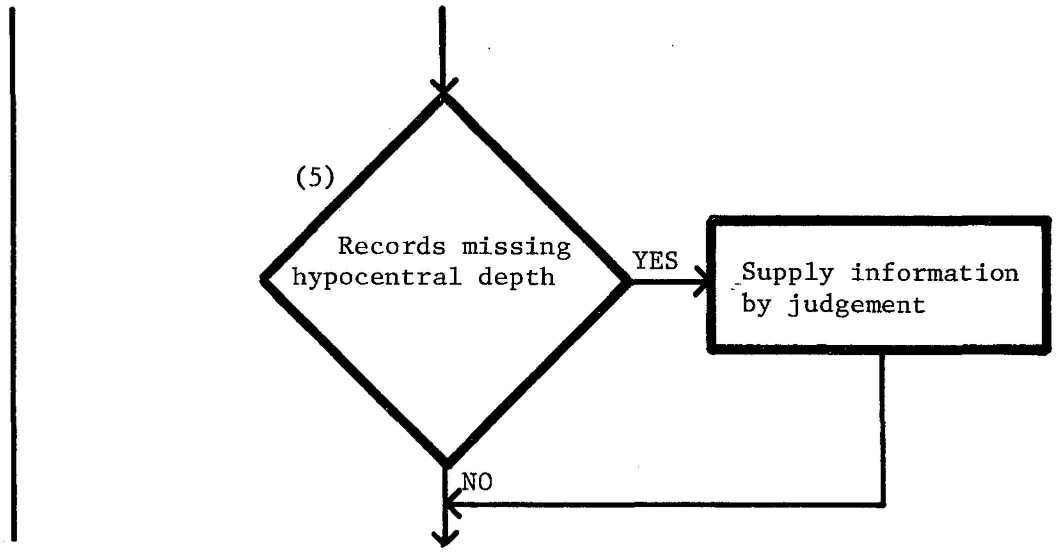
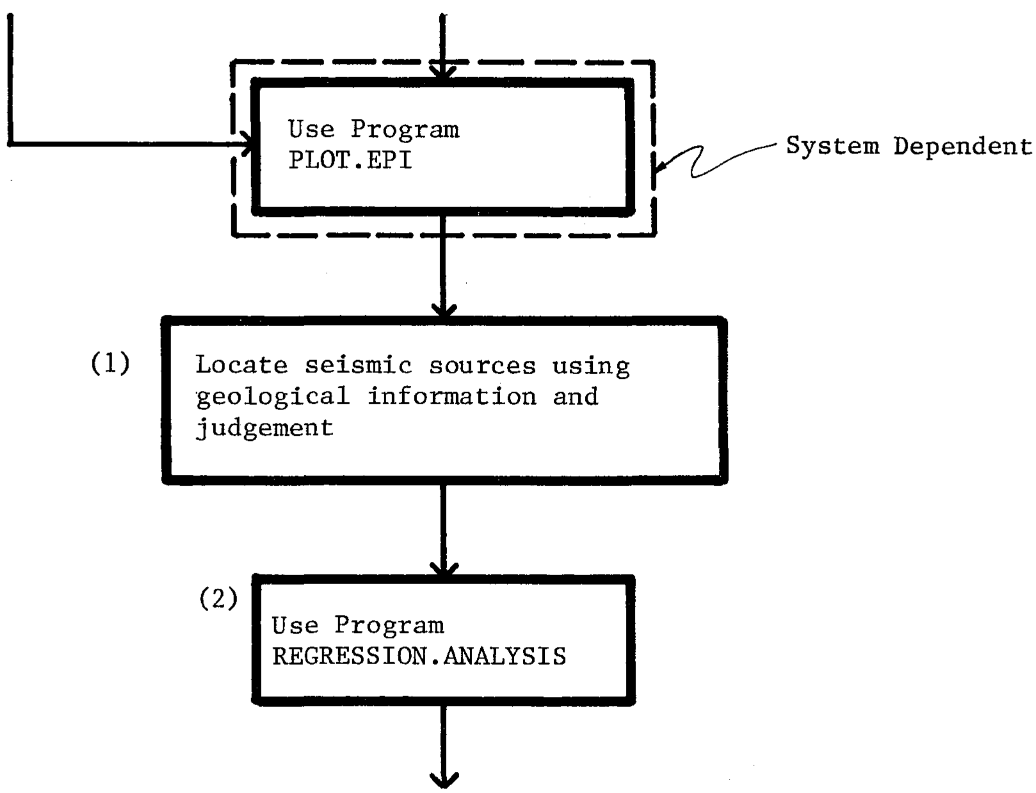


Figure 1-2 (Con't.)

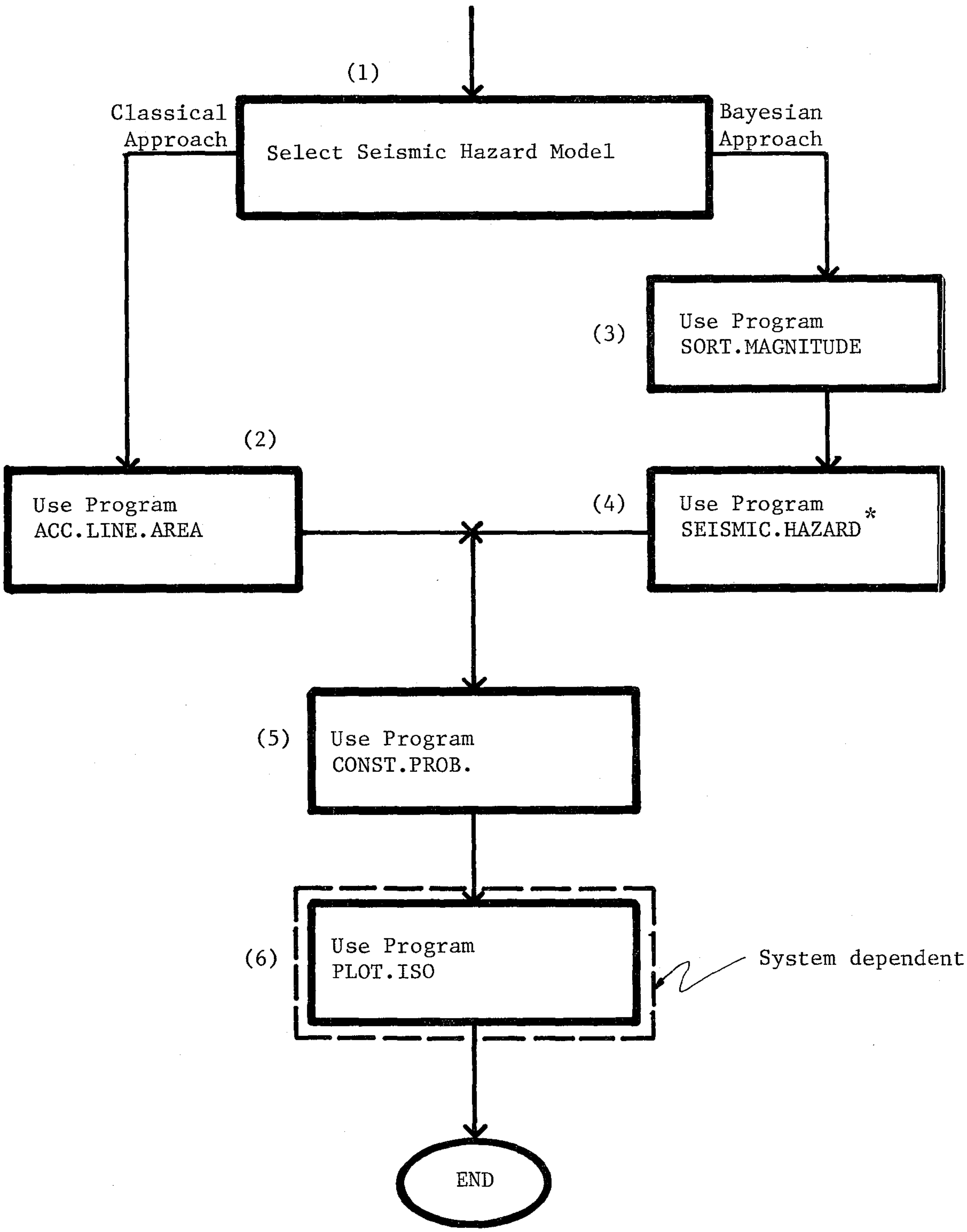


II. Stage No. 2--Seismic Modeling of the Region



III. Stage No. 3--Seismic Hazard Model

Figure 1-2 (Con't.)



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*See Appendix B for auxiliary program which is used to check the Input Data for program SEISMIC.HAZARD.

• Any other pertinent geological and seismological information about the region considered.

Unfortunately, it is seldom possible to have all the available data with complete information. In view of the problem, there are several techniques available by which the data can be treated to achieve a reasonably complete form. The techniques* currently used will be briefly discussed in the following paragraphs and dealt with in more detail in the next chapters.

The first step of the analysis consists of storing in the computer the information on past seismic events (RAW DATA FILE). An example of the format for data storage and record presentation is shown in Figure (1-3).

Item (I-1)--Check if the information regarding past seismic events is complete

If earthquake records belonging to the RAW DATA FILE are missing epicentral location and magnitude information, these will be disregarded and hence excluded as direct input in the analysis. However, the analyst must be aware of the existence of these events in order to complement his subjective information on the seismicity of the region.

Item (I-2)--Some records contain a letter magnitude instead of a numerical Richter Magnitude

Frequently, events are recorded and assigned a letter symbol or class instead of a numerical Richter-Magnitude. In general, the class or letter associated with the particular event covers a specific range on the magnitude scale. For example, CLASS C ($6 \leq M \leq 6.9$) stands for an earthquake with a Richter Magnitude between 6.0 and 6.9. Since it is more practical to work with numerical quantities rather than ranges, PROGRAM.REPLACE.

*The presented methodology applies to correcting the available data only. It does not check the validity of the data, such as incompleteness, biases in time, population, etc.

EARTHQUAKE DATA IN CHRONOLOGICAL ORDER

SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	LATITUDE	LONGITUDE	CLASS	MMI	RADIUS	DEPTH	MS	MB	MR1	MR2
A.GRAN	09	10	1790	01	00	35.700N	-00.700W		10.						
A.GRAN		03	1819			35.400N	00.100E		10.						
A.GRAN	02	03	1825	07	00	36.400N	02.800E		10.5						
A.GRAN		12	1846			36.600N	02.200E		6.5						
A.GRAN	18	06	1847	05	00	36.700N	02.900E		6.5						
A.GRAN	09	02	1850			36.300N	04.800E		9.						
A.GRAN	17	12	1850	12	30	36.500N	07.400E		6.5						
A.GRAN	22	11	1851	09	30	35.400N	00.100E		8.						
A.GRAN	15	05	1854			36.400N	02.700E		6.						
A.GRAN	21	08	1856	21	00	37.100N	05.700E	C	9.						6.90
A.GRAN	04	08	1908	02	11	36.400N	06.600E	D	8.					5.10	5.10
GUTE	16	06	1910	04	16	36.500N	-4.000W							6.10PAS	6.10
A.GRAN	24	06	1910	13	26	36.167N	03.400E	C	10.					6.40	6.40
GUTE	24	06	1910	13	27	36.000N	04.000E							6.40PAS	6.40
GUTE	01	08	1910	10	40	39.000N	15.000E				200			6.50PAS	6.50
A.GRAN	07	01	1911	01	33	36.100N	03.400E	E	5.5						4.20
A.GRAN	24	07	1912	18	06	35.700N	-00.400W	E	7.						4.05
A.GRAN	06	08	1912	18	44	36.600N	05.200E	D	6.					5.30	5.30
A.GRAN	08	01	1913	20	38	35.300N	01.100E	E	6.						4.05
GUTE	25	02	1920	17	56	35.000N	09.500E							5.60PAS	5.60
A.GRAN	25	08	1922	11	47	36.283N	01.267E	D	10.					5.10	5.10
A.GRAN	19	11	1922	17	04	36.300N	01.300E	E	8.						4.10
A.GRAN	19	02	1923	16	33	36.100N	03.700E	E	6.						4.20
GUTE	09	07	1923	15	31	35.500N	-4.000W							5.60PAS	5.60

where: SOURCE: refers to the person, institution, etc., recording the data.

CLASS: letter symbol representing Richter Magnitude.

RADIUS: radius of felt area.

DEPTH: hypocentral depth (kms).

MS: Average surface wave magnitude.

MB: Average body wave magnitude.

MR1: Richter Magnitude (originally supplied with raw data).

MR2: Richter Magnitude (as obtained after treatment of records missing magnitude information).

FIGURE 1-3

LETTER. MAGNITUDE (Chapter II) will be used for the purpose of replacing the letter symbols by an appropriate numerical Richter Magnitude level.

Item (I-3)--Some records contain information on intensity (MMI) instead of magnitude

It is very common to find earthquake records in the data set (RAW DATA file) described in terms of intensity (MMI) only. As such information is not directly usable in the analysis, an intensity vs. magnitude relationship is needed to express the magnitude in terms of intensity.

Several attempts have been made in the past to correlate magnitude to intensity using regression analysis to fit to the data a straight line relationship of the form:

$$M = B.I + A \tag{1.1}$$

where: M = Richter magnitude

I = Intensity (MMI)

A, B = regression coefficients

Such relations are only valid on a regional basis. Therefore, it is good practice to obtain a specific intensity vs. magnitude relation for the region of interest using the information contained in the records considered to be complete (specifically those records having both an MMI and Richter magnitude value).

With the purpose of obtaining the regression coefficients (A and B), and the magnitude value for the incomplete records in the RAW DATA FILE, programs REGRESSION.ANALYSIS and INTENSITY.MAGNITUDE will be used in conjunction (Chapters III and VI).

Item (I-4)--Some records are missing information both on magnitude and intensity

In case there are earthquake records in the RAW DATA FILE missing both magnitude and intensity information, rather than disregarding the events, a Monte Carlo simulation process is used to generate the missing parameters.

From the earthquake records containing complete information, that is, all events containing information on time of occurrence, epicentral location, hypocentral depth, Richter Magnitude, etc., a probability distribution function (normalized histogram) on magnitude is constructed. For this purpose, program REGRESSION.ANALYSIS with one of its optional capabilities will be used (Chapter VI). Once the distribution on magnitude is known, program GENER.MAGNITUDE is implemented in order to generate the missing information (Chapter IV).

Item (I-5)--Records missing hypocentral depth

Rather than disregarding these events, information on hypocentral depth is supplied by judgement. Normally, the analyst is able to assign hypocentral depths basing his judgement on seismological and geologic information available for the region of interest.

Item (II-1)--Epicentral maps and location of seismic sources

Stage No. 2 (seismic modeling of the region) is initiated with this step. At this point of the analysis, the untreated earthquake data (RAW DATA FILE) should be in complete form, that is, information on time of occurrence, epicentral location, depth of hypocenter, Richter Magnitude, etc., is known for each record. Program PLOT.EPICENTERS will incorporate such information (specifically epicentral locations) to obtain maps displaying epicenters for the region of interest.

Having the epicentral map will enable the analyst to model the region into seismic sources. Geological and seismological information together with judgement is used to model the seismic sources.

Item (II-2)--Program Regression Analysis

Once the epicenters have been associated to the various seismic sources within the region, the present step requires the development of recurrence relationships for each individual source. These are obtained by fitting to the data (for each source) a regression line of the form:

$$Ln_e N(M) = \alpha + \beta M \qquad (1.2)$$

where: N(M) = number of events above Richter Magnitude (M)

M = Richter Magnitude

α and β = regression coefficients

The constant α being a measure of the number of events above magnitude zero for a given source and β, a measure of the sources' seismic severity.

For the purpose of obtaining Eq. (1.2), program REGRESSION.ANALYSIS will be used (Chapter VI).

Item (III-1)--Seismic Hazard Model Selection

Stage No. 3 is initiated with this step. The analyst can choose between the two available seismic hazard models, namely:

1.) Classical Model

2.) Bayesian Model

A brief discussion on the differences between both models (based on the key elements associated to seismic hazard models, reference 9) will be presented in the following paragraphs. The key elements are:

- Source geometry
- Earthquake recurrence model
- Tectonic model and travel path
- Attenuation uncertainty

Table 1 summarizes the main characteristics of each model.

TABLE 1

	Classical Model	Bayesian Model
Source Geometry	Line Area	Line Area Dipping Planes
Tectonic Model	No rupture	Rupture
Earthquake Recurrence Model	Poisson	Poisson + Bernoulli + Bayesian
Attenuation Uncertainty	None	Log-Normal

Source Geometry

The Classical Model (Reference 1) represents the seismic sources either by straight lines (Line Sources) or circular area sources.

The Bayesian Model (Reference 6) permits the use of more general source geometry by introducing trapezoid area sources and dipping plane sources.

Earthquake Recurrence Model

Both models use a Poisson process for earthquake occurrence. In the Classical Model, the distribution on the different magnitude occurrences is introduced directly in the Poisson model through the use of a constant mean rate of occurrence for each Richter Magnitude level.

The Bayesian model treats the mean rate of occurrence as a random variable and the information on magnitude is modeled by a Bernoulli trial in which the probability of success is also treated as a random variable. The input to the model is obtained from two sources, namely:

1.) Subjective information (obtained from expert's past experience)

2.) Recorded data (e.g., RAW DATA FILE).

Both are combined with different weights (depending on the expert) through the use of Bayesian Statistics.

Tectonic Model

The Classical model assumes that the total energy released during an earthquake is radiated from the hypocenter (point model). The maximum intensity at a given site is governed by its distance from the hypocenter.

The Bayesian Model associates fault rupture with energy release and the intensity of ground shaking is determined by the fault slip that is closest to the site (significant distance).

Attenuation Uncertainty

The Classical model treats the energy attenuation deterministically. No probability distribution with respect to the mean value of attenuation is associated.

The Bayesian Model treats the scatter of the data about the attenuation relationship in a probabilistic manner. It considers a log-normal distribution with respect to the mean value.

Judging from the differences (key elements) mentioned for both models, it is evident that the Bayesian approach is a more consistent and advanced method of assessing seismic exposure. However, rather than disregarding the Classical approach, it has been included in the current work as a matter of completeness and comparison.

Item (III-2)--PROGRAM ACC.LINE. AREA

In the event of selecting the Classical Approach for seismic hazard analysis, program ACC.LINE.AREA, (which incorporates the theory behind the Classical model), will be used to compute the probabilities of exceedance for a given ground parameter (e.g., PGA, PGV, etc.) and a given time period of interest, at a specified site or sites due to line or circular seismic sources.

Item (III-3) Program SORT.MAGNITUDE and Item (III-4) Program SEISMIC.HAZARD

In the event of selecting the Bayesian Approach for seismic hazard analysis, program SORT.MAGNITUDE (Chapter VIII) will be used to sort the treated earthquake records as a function of their magnitude, the output will be used to obtain the sample likelihood function in the Bernoulli trial of program SEISMIC.HAZARD (which incorporates the theory behind the Bayesian model), and is used to compute the probabilities of exceedance for a given ground parameter and a given time period of interest, at a specified site or sites due to line, area, and dipping plane sources (see Ref. 6 for details).

Item (III-5)--PROGRAM CONST. PROB

The output of either program ACC.LINE.AREA or program SEISMIC.HAZARD, in the form of cumulative or complementary cumulative distribution functions (e.g., $P\{A \leq a\}$ or $P\{A > a\}$) for a given period of interest, ground parameter, and at a site or at the nodes of a grid, provides the necessary information for the implementation of program CONST.PROB. This program will allow the analyst to obtain the value of the ground parameter at a site for a specific probability of exceedance (1 - P{non-exceedance}).

Item (III-6)--Program PLOT.ISO

The use of program PLOT.ISO for the purpose of developing regional seismic hazard maps (e.g., in the form of iso-acceleration contours, iso-velocity contours, etc.), will conclude with the present form of seismic hazard methodology. This program is system dependent.

FIGURE 1-4

FLOW CHART CONVENTION

Operator	Symbol
Arithmetic Operators	
• Addition	+
• Subtraction	-
• Multiplication	*
• Division	/
• Exponentiation	**
Relational Operators	
• Less	<
• Less than or equal	≤
• Equal	=
• Greater than or equal	≥
• Greater	>
• Not equal	≠

Figure 1-5 Flow Chart Convention

Type of Statement

a) Assignment

b) Input

c) Output

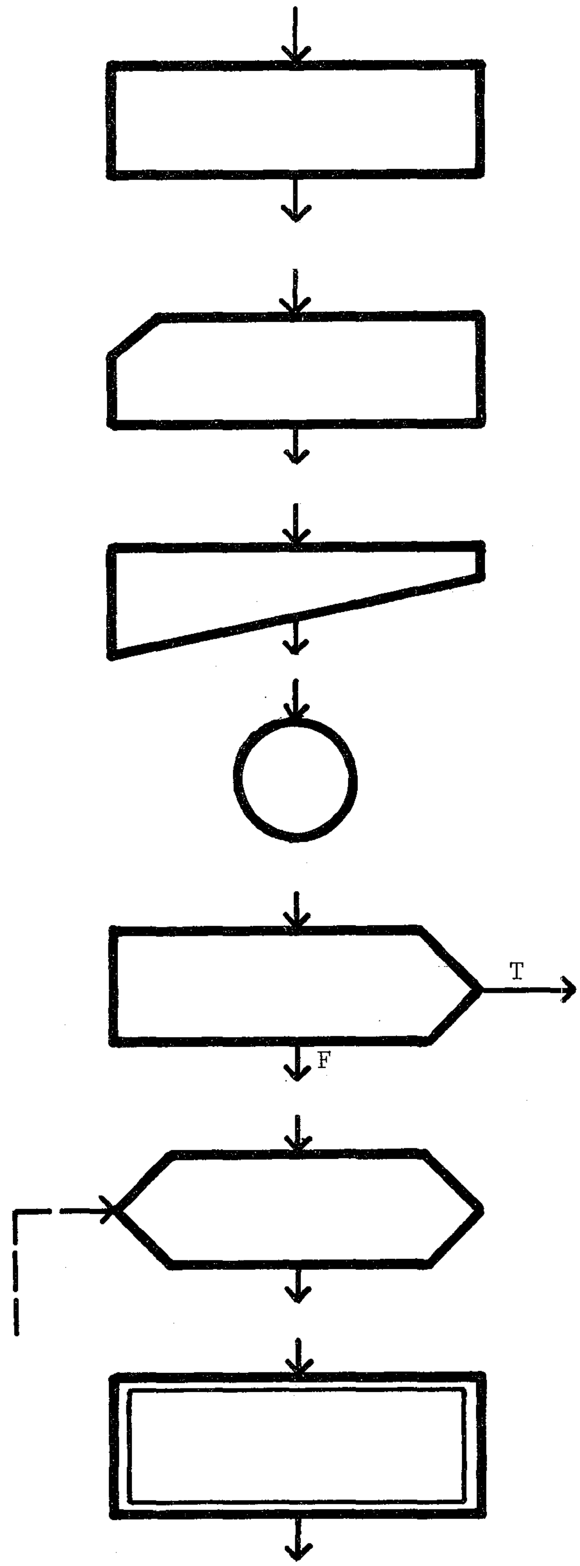
d) Unconditional Control

e) Conditional Control

f) Iterative Control

g) Call Subroutine

Flow Chart Symbol



CHAPTER II

PROGRAM REPLACE.LETTER.MAGNITUDE

2.1 Purpose and Description of the Program

Frequently, when dealing with past earthquake records, the analyst is faced with events having a Richter Magnitude expressed by a letter symbol instead of a numerical value. The common classification encountered in practice is shown below:

Symbol	Magnitude Range
B	$7.0 \leq M \leq 7.7$
C	$6.0 \leq M \leq 6.9$
D	$5.3 \leq M \leq 5.9$
E	$4.0 \leq M \leq 5.2$
F	$M < 4.0$

Since working with ranges is not practical, the present program, through a simulation process, replaces the letter symbol by a numerical Richter Magnitude. A random number generator is used for this purpose and a uniform distribution is assumed over the magnitude range corresponding to each letter symbol.

In its present form, program REPLACE.LETTER.MAGNITUDE has practically no limitations regarding the number of earthquake records to be processed. The actual iteration control statement for the number of records has been set arbitrarily to one thousand.

The present version has been divided into a main routine and one subroutine. It contains 40 executable Fortran statements and the space requirements is approximately 1952 bytes.

2.2 Description of Input Data

Input data for program REPLACE.LETTER.MAGNITUDE will consist of one set of cards (or card images). Standard Fortran formats have been used and are identified by A, or F specifications. It must be pointed out that for this and the rest of the computer programs included under Stage I (Data Treatment, Figs. 1-1 and 1-2), the input and output formats are based on the earthquake record organization shown in Fig. 1-3.*

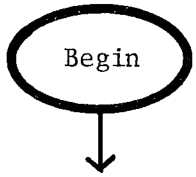
The organization of data on each card, along with a description of the items, is given in the following paragraph.

I. Earthquake Record--(5A8, A1, A8, A6, F4.0, A5, F4.0, A4)
--(number of cards as required)

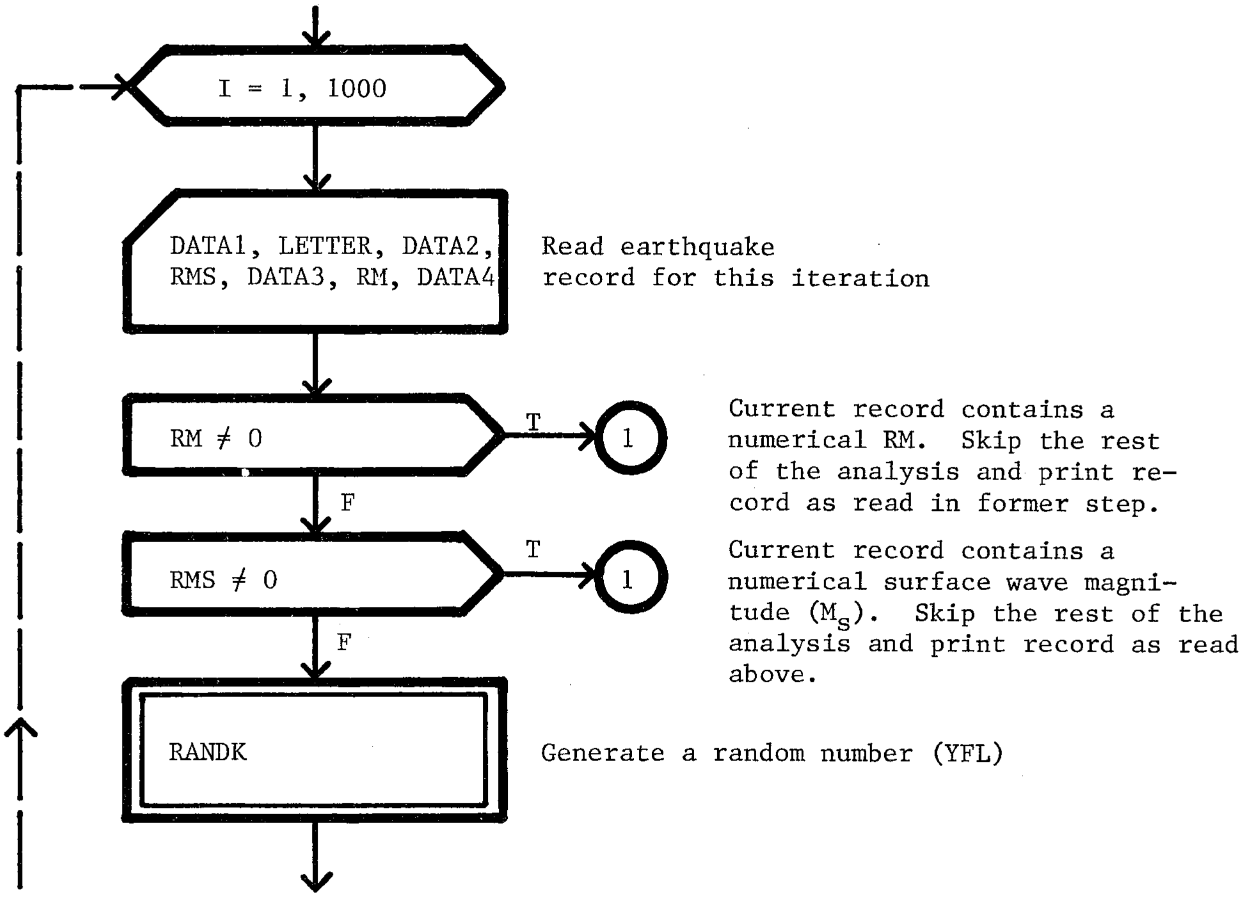
Col.	1-40	Data1	(Dummy variable)
	41-41	Letter	(Letter symbol for Richter Magnitude)
	42-55	Data2	(Dummy variable)
	56-59	RMS	(Surface wave magnitude)
	60-64	Data3	(Dummy variable)
	65-68	RM	(Richter Magnitude)
	69-72	Data4	(Dummy variable)

*If the analyst decides to use a different earthquake record organization from the ones shown in Fig. 1-3, the input and output formats for the programs included under Stage I will have to vary accordingly.

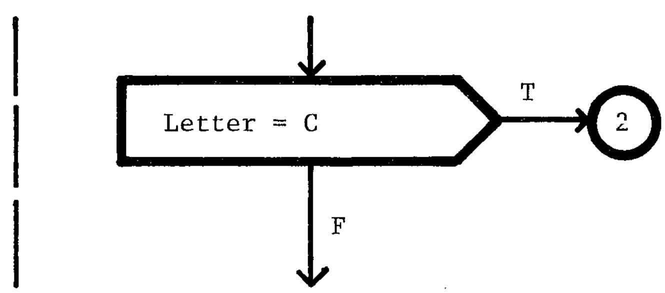
2.3 Macro Flow Chart for Program REPLACE.LETTER.MAGNITUDE

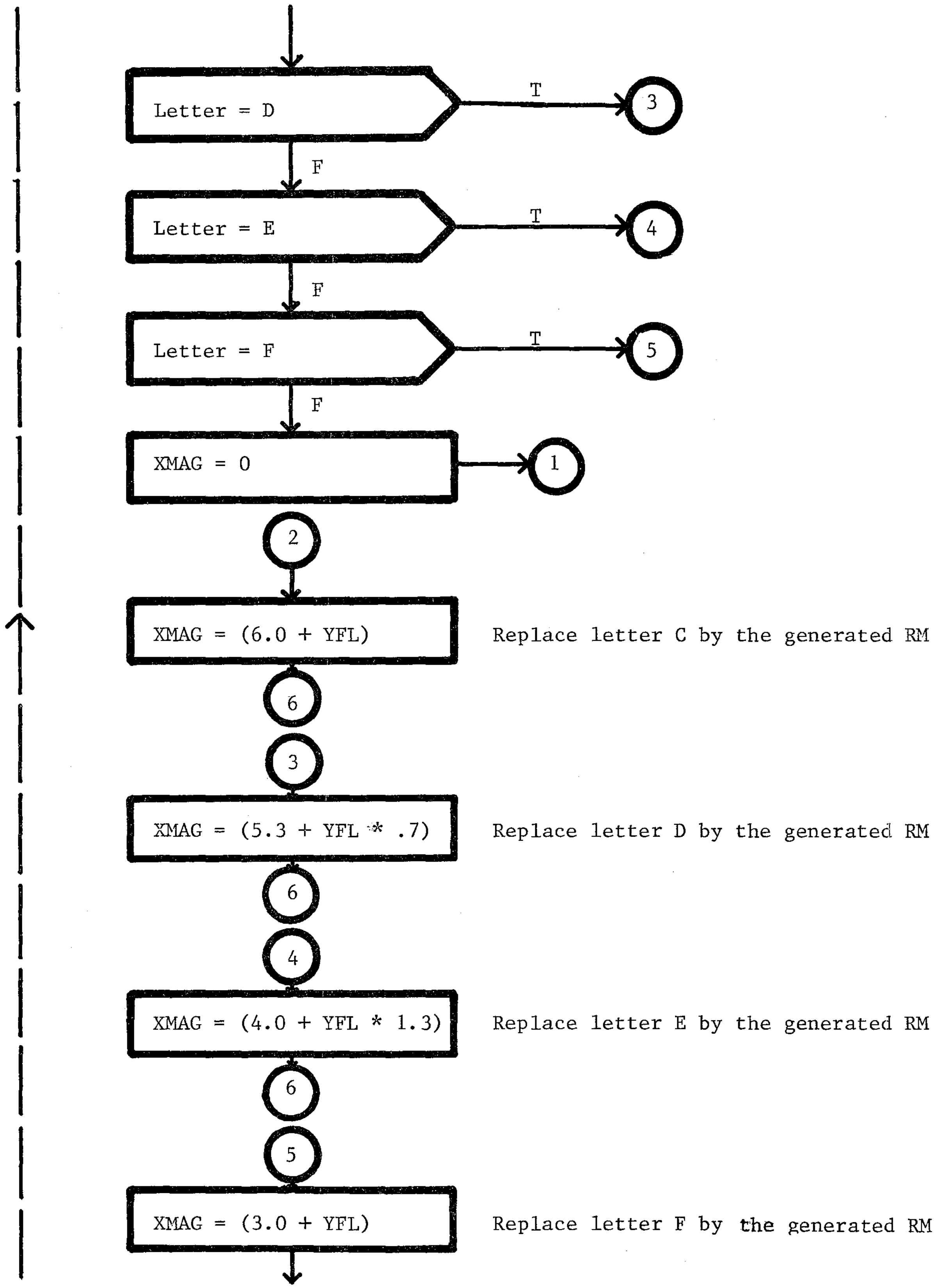


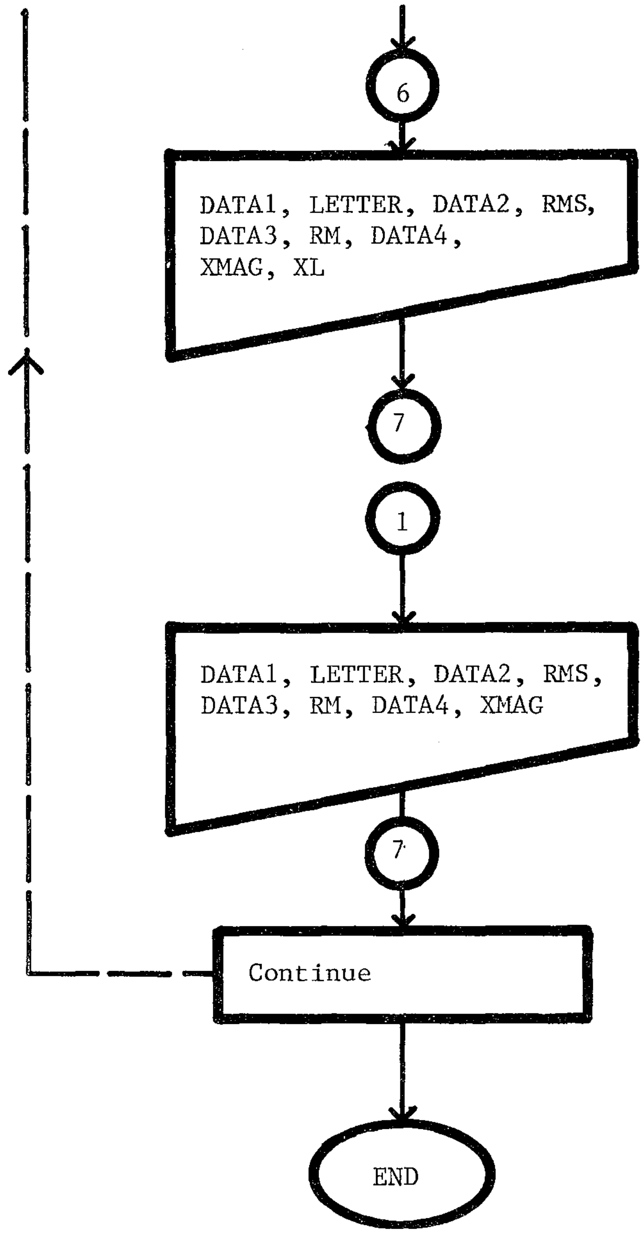
I. Iteration on the number of records in this run



II. Check letter symbol and replace it by a numerical RM




Letter = D
T
3
F
Letter = E
T
4
F
Letter = F
T
5
F
XMAG = 0
1
2
XMAG = (6.0 + YFL)
Replace letter C by the generated RM
6
3
XMAG = (5.3 + YFL * .7)
Replace letter D by the generated RM
6
4
XMAG = (4.0 + YFL * 1.3)
Replace letter E by the generated RM
6
5
XMAG = (3.0 + YFL)
Replace letter F by the generated RM



Print current record containing the generated RM. A flag (in this case the letter L) is printed next to the RM-level in order to identify the records for which a letter has been replaced by the generated RM.

2.4 Sample Problem

The earthquake records shown below constitute the input for program REPLACE.LETTER.MAGNITUDE. It can be observed that all the records are missing magnitude information. (In columns 56-59, RMS = 0 and in columns 65-68, RM = 0.) It can also be observed that in column 41 all the events contain a letter symbol from which a numerical Richter Magnitude can be generated.

INPUT DATA FOR PROGRAM REPLACE.LETTER.MAGNITUDE (SAMPLE PROBLEM)

A.GRAN	19	06	1925	14	44	35.800N	-0.400W	E	6.		0.00	0.00	0.00
A.GRAN	20	06	1925	12	33	35.800N	-0.400W	E	6.		0.00	0.00	0.00
A.GRAN	21	06	1925	03	01	35.800N	-0.400W	E	6.		0.00	0.00	0.00
A.GRAN	04	11	1949	12	36	35.700N	-0.700W	F	5.	50	0.00	0.00	0.00
A.GRAN	20	06	1952	16	42	35.800N	-0.200W	F	5.		0.00	0.00	0.00
A.GRAN	01	01	1956	07	22	35.800N	-0.300W	F	5.5	20	0.00	0.00	0.00
A.GRAN	14	02	1957	06	12	35.800N	-0.400W	F	5.	30	0.00	0.00	0.00
H.BENH	08	06	1957	18	19	35.700N	-0.500W	E	5.		0.00	0.00	0.00
H.BENH	02	10	1957	02	45	35.700N	-0.700W	F	4.5		0.00	0.00	0.00

2.5 Output for Program REPLACE.LETTER.MAGNITUDE

The computer output for program REPLACE.LETTER.MAGNITUDE is shown below. Note that the generated magnitude appears between columns 73 and 76. Also, whenever a letter symbol is replaced by a numerical Richter Magnitude, a symbol (the letter "L") is printed next to the value generated in order to indicate which records have been treated.

OUTPUT FOR PROGRAM REPLACE.LETTER.MAGNITUDE (SAMPLE PROBLEM)

A.GRAN	19	06	1925	14	44	35.800N	-0.400W	E	6.		0.00	0.00	5.25	L
A.GRAN	20	06	1925	12	33	35.800N	-0.400W	E	6.		0.00	0.00	4.95	L
A.GRAN	21	06	1925	03	01	35.800N	-0.400W	E	6.		0.00	0.00	4.40	L
A.GRAN	04	11	1949	12	36	35.700N	-0.700W	F	5.	50	0.00	0.00	3.45	L
A.GRAN	20	06	1952	16	42	35.800N	-0.200W	F	5.		0.00	0.00	3.90	L
A.GRAN	01	01	1956	07	22	35.800N	-0.300W	F	5.5	20	0.90	0.00	3.50	L
A.GRAN	14	02	1957	06	12	35.800N	-0.400W	F	5.	30	0.00	0.00	3.65	L
H.BENH	08	06	1957	18	19	35.700N	-0.500W	E	5.		0.00	0.00	4.75	L
H.BENH	02	10	1957	02	45	35.700N	-0.700W	F	4.5		0.00	0.00	3.25	L

CHAPTER III

PROGRAM INTENSITY.MAGNITUDE

3.1 Introduction

When past earthquake records contain information on intensity (MMI), instead of Richter Magnitude, the current methodology (as shown in Figure 1-2, item I-3) indicates the use of two programs in conjunction, namely:

1.) Program REGRESSION.ANALYSIS

2.) Program INTENSITY.MAGNITUDE

Program REGRESSION.ANALYSIS will assist the user in developing an intensity vs. magnitude relationship of the form: (See Fig. 3-1):

$$M = BI + A \tag{3.1}$$

where M = Richter Magnitude

I = Epicentral intensity

A, B = regression coefficients

The use of program REGRESSION.ANALYSIS for this purpose will be deferred until Chapter VI (Sample Problem #3). It will be assumed at this time that the analyst knows the numerical values of the coefficients A and B and the standard deviation (SIGMA) of the Gaussian distribution associated to the mean value of magnitude estimated by Eq. 3.1 (Figure 3-1).

3.2 Description of Program INTENSITY.MAGNITUDE

Program INTENSITY.MAGNITUDE has been designed for the purpose of supplying a Richter Magnitude value to those events in the Raw Data File containing information only on intensity (MMI). The values supplied by the program are obtained using simulation techniques. A probabilistic relationship between the RM and the MMI is implied.

Information on the parameters A and B in Eq. 3.1 and on the parameter SIGMA (standard deviation) are provided by the analyst as input data together with any number of earthquake records requiring treatment (the use of data format as presented in Fig. 1-3 is understood).

The present version has been divided into a main routine and two subroutines. It contains 100 executable FORTRAN statements, and the space requirements are approximately 4520 bytes. There is practically no limitation regarding the number of earthquake records to be processed. The actual iteration control statement for the number of events has been set arbitrarily to 500. The number of standard deviations (SIGMA) on each side of the mean has been set equal to 3.

3.3 Description of Input Data

Input data for program INTENSITY.MAGNITUDE will consist of two sets of cards (or card images). The first contains information on the Regression parameters (A, B, and SIGMA). The second set contains information on past seismic events. The organization of data on each card, along with a description of the items, is given in the following paragraphs.

I. Regression parameters--(3F10.7) One card required

Col.	1-10	BETA	(coefficient B in Eq. 3.1)
	11-20	CONST	(coefficient A in Eq. 3.1)
	21-30	SIG	(standard deviation on magnitude SIGMA)

II. Earthquake Record--(42A1, F4.1, 26A1, F4.2, A4)
--(number of cards as required)

Col.	1-42	DUM1	(dummy variable)
	43-46	XINT	(MMI--Modified Mercalli Intensity)
	47-72	DUM2	(dummy variable)
	73-76	XMG	(Richter Magnitude)
	77-80	CHECK	(dummy variable)

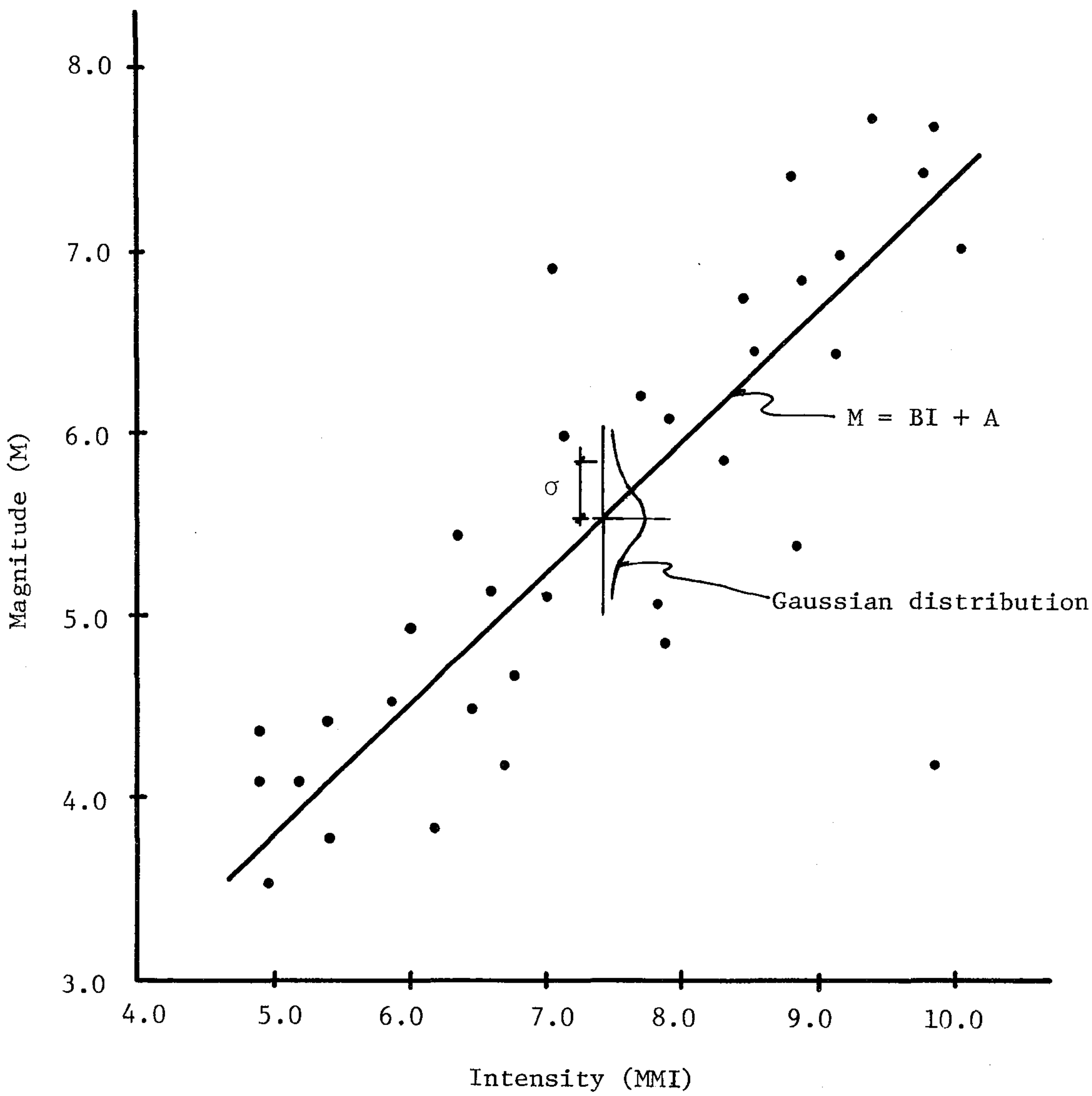
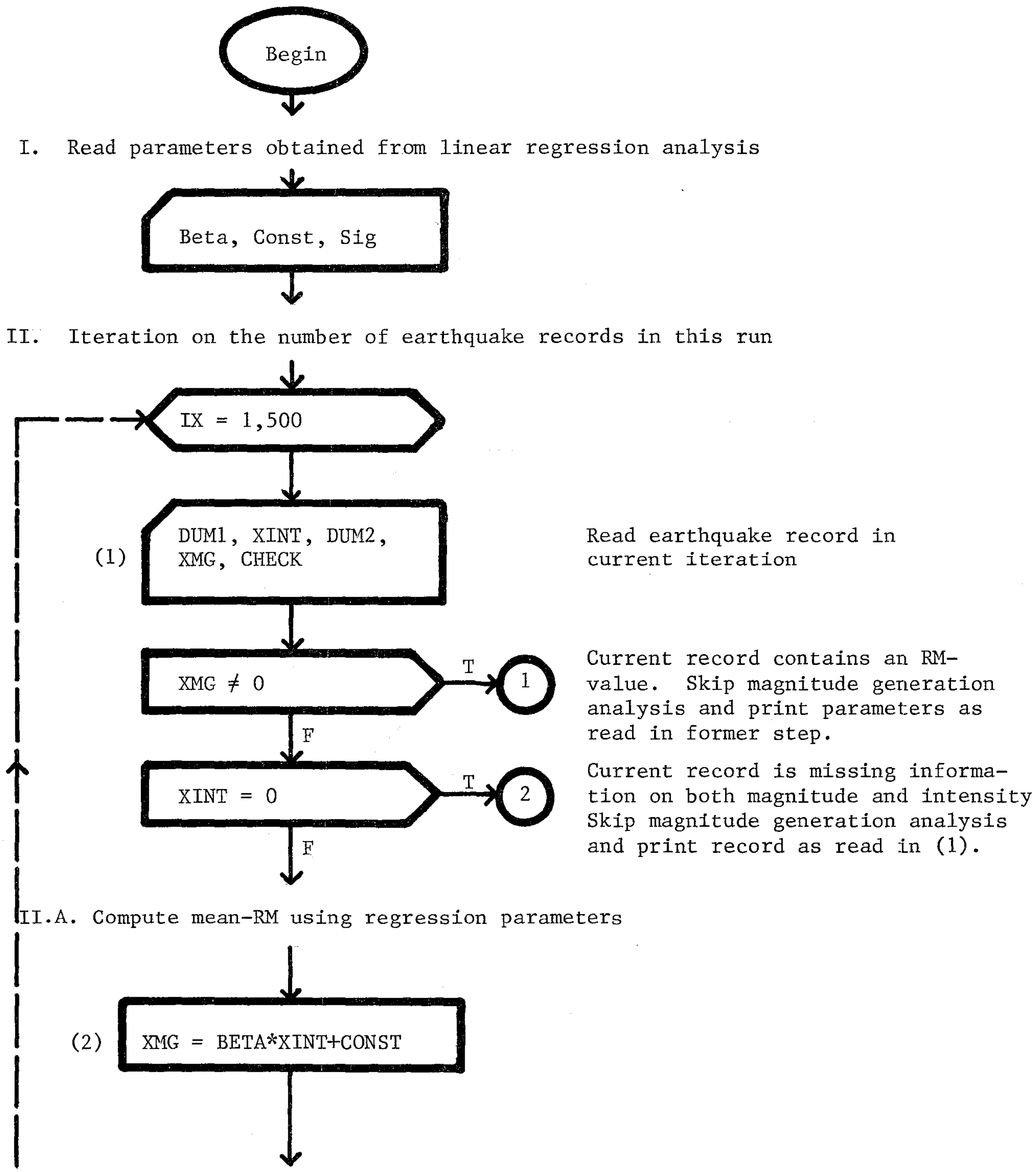
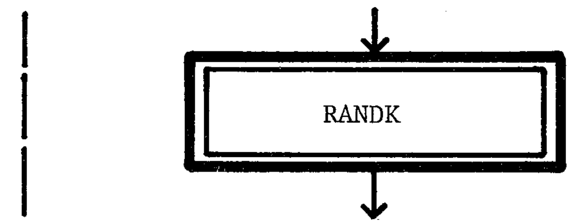


Figure 3-1. Intensity versus Magnitude relationship.

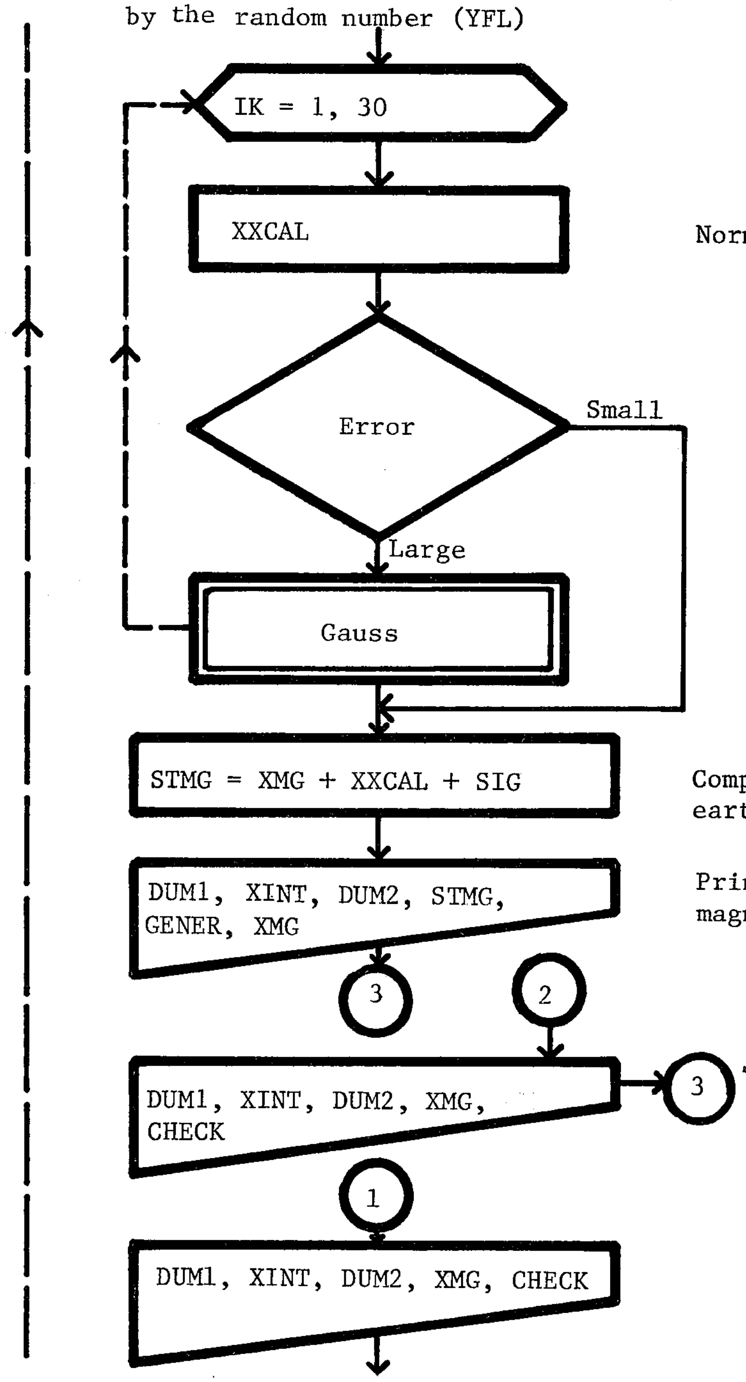
3.4 Macro Flow Chart for Program INTENSITY.MAGNITUDE





Generate a random number (YFL)

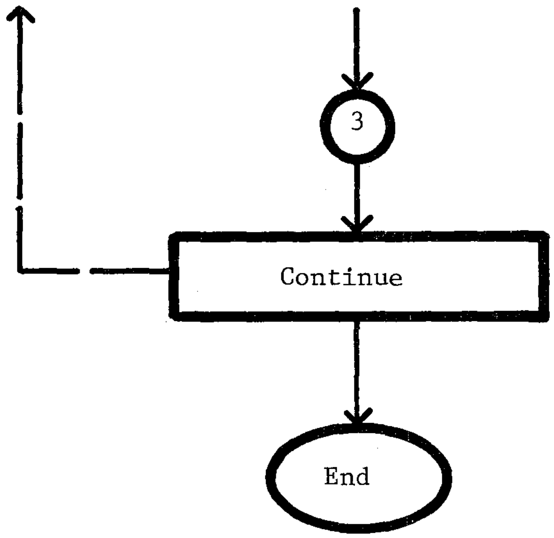
II-B Determine by iteration the normalized deviation (XXCAL) from the RM-mean value (XMG) as specified by the random number (YFL)



Normalized deviation

Compute magnitude for current earthquake record

Print record with generated magnitude


3
Continue
End

3.5 Sample Problem

Assume that the regression coefficients A and B in Eq. 3.1 and the parameter SIGMA (standard deviation) are known to the analyst and have the following numerical values:

$$B = 0.436$$

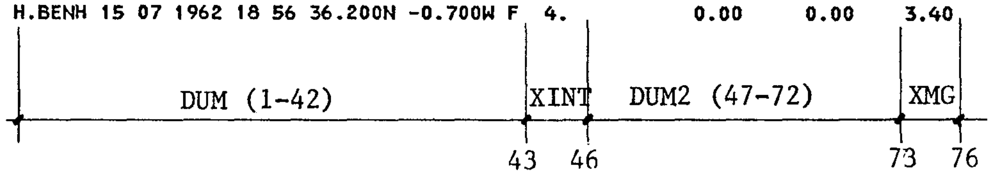
$$A = 1.439$$

$$SIGMA = 0.498$$

Further, assume that the raw data file for a particular region consists of the earthquake records shown below. Note that three of the records (marked with a star) are missing magnitude information completely. The rest of the events contain RM values in columns 73-76. The treatment of the data in order to achieve a complete form is required.

INPUT FOR PROGRAM INTENS.MAG (SAMPLE PROBLEM)

```
1.439      0.436      0.498
A.GRAN 09 10 1790 01 00 35.700N -0.700W   10.        0.00    0.00    0.00 *
A.GRAN 21 05 1889 04 15 35.700N -0.800W    7.5       0.00    0.00    0.00 *
A.GRAN 24 07 1912 18 06 35.700N -0.400W E  7.        0.00    0.00    0.00 *
A.GRAN 19 06 1925 14 44 35.800N -0.400W E  6.        0.00    0.00    4.05
A.GRAN 20 06 1925 12 33 35.800N -0.400W E  6.        0.00    0.00    4.10
A.GRAN 21 06 1925 03 01 35.800N -0.400W E  6.        0.00    0.00    4.05
A.GRAN 04 11 1949 12 36 35.700N -0.700W F  5.   50   0.00    0.00    3.35
A.GRAN 20 06 1952 16 42 35.800N -0.200W F  5.        0.00    0.00    3.80
A.GRAN 01 01 1956 07 22 35.800N -0.300W F  5.5  20   0.00    0.00    3.70
A.GRAN 14 02 1957 06 12 35.800N -0.400W F  5.   30   0.00    0.00    3.15
H.BENH 08 06 1957 18 19 35.700N -0.500W E  5.        0.00    0.00    4.05
H.BENH 02 10 1957 02 45 35.700N -0.700W F  4.5       0.00    0.00    3.20
H.BENH 12 12 1959 20 00 35.800N -0.600W E  7.   75   0.00    0.00    4.25
H.BENH 01 06 1960 11 40 35.700N -0.600W F  5.   20   0.00    0.00    3.50
H.BENH 23 01 1961 02 46 35.800N -0.300W F  4.   25   0.00    0.00    3.25
H.BENH 15 07 1962 18 56 36.200N -0.700W F  4.        0.00    0.00    3.40
```



3.6 Output for Program INTENSITY.MAGNITUDE

The computer output for program INTENSITY.MAGNITUDE (sample problem) is shown below. Observe that the Richter Magnitude values generated by the program are listed between columns 73 and 76, together with a letter symbol (I) in order to identify which earthquake records have been treated. In addition, the mean values for magnitude as estimated by Eq. 3.1 are printed next the the symbol (I).

The last three lines of the output contain general information on statistics for the run.

```
OUTPUT FOR PROGRAM INTENS.MAG (SAMPLE PROBLEM)

A.GRAN 09 10 1790 01 00 35.700N -0.700W   10.0         0.00     0.00     6.92 I  5.80
A.GRAN 21 05 1889 04 15 35.700N -0.800W    7.5         0.00     0.00     5.04 I  4.71
A.GRAN 24 07 1912 18 06 35.700N -0.400W E  7.0         0.00     0.00     4.24 I  4.49
A.GRAN 19 06 1925 14 44 35.800N -0.400W E  6.0         0.00     0.00     4.05
A.GRAN 20 06 1925 12 33 35.800N -0.400W E  6.0         0.00     0.00     4.10
A.GRAN 21 06 1925 03 01 35.800N -0.400W E  6.0         0.00     0.00     4.05
A.GRAN 04 11 1949 12 36 35.700N -0.700W F  5.0  50     0.00     0.00     3.35
A.GRAN 20 06 1952 16 42 35.800N -0.200W F  5.0         0.00     0.00     3.80
A.GRAN 01 01 1956 07 22 35.800N -0.300W F  5.5  20     0.00     0.00     3.70
A.GRAN 14 02 1957 06 12 35.800N -0.400W F  5.0  30     0.00     0.00     3.15
H.BENH 08 06 1957 18 19 35.700N -0.500W E  5.0         0.00     0.00     4.05
H.BENH 02 10 1957 02 45 35.700N -0.700W F  4.5         0.00     0.00     3.20
H.BENH 12 12 1959 20 00 35.800N -0.600W E  7.0  75     0.00     0.00     4.25
H.BENH 01 06 1960 11 40 35.700N -0.600W F  5.0  20     0.00     0.00     3.50
H.BENH 23 01 1961 02 46 35.800N -0.300W F  4.0  25     0.00     0.00     3.25
H.BENH 15 07 1962 18 56 36.200N -0.700W F  4.0         0.00     0.00     3.40
NUMBER OR RECORDS READ               16                                  |   |
NUMBER OF NO MAGNITUDE                3                                  |   |
NUMBER OF GENERATED MAG FROM INT      3                                  |   |
                                                                         73  76
```

CHAPTER IV

PROGRAM GENER.MAGNITUDE

4.1 Introduction

In dealing with past earthquake records, it is common to find events with no information regarding both the intensity and the magnitude. Rather than disregarding these events, the missing magnitude and intensity can be obtained by using simulation techniques.

It will be necessary for the analyst to construct a histogram relating the number of events (frequency) to a set of magnitude intervals. For this reason, all the earthquake records available for the region and containing complete information are used. Namely, events containing:

- Time of occurrence
- Epicentral location
- Depth of hypocenter
- Richter Magnitude

Normally, an upper limit on Richter Magnitude is selected by the analyst when constructing the histogram (e.g., RM = 4.00, 4.50 or 5.00 maximum), based on the assumption that any large event would be thorougly documented, and implying that only small events may be missing information.

As shown in Figure 1-2, Item I-4, the present data treatment analysis requires the use of two programs in conjunction, namely:

1.) Program REGRESSION.ANALYSIS.

2.) Program GENER.MAGNITUDE

Program REGRESSION.ANALYSIS will assist the user in the derivation of the histogram on magnitude thus simplifying the construction of a CDF (Cumulative Distribution Function) necessary for simulation. The use of program

REGRESSION.ANALYSIS for this purpose will be deferred until Chapter VI (Sample Problem #2, page 80). It will be assumed at this time that the analyst knows the distribution on magnitude and the CDF for the region of interest.

4.2 Description of Program GENER.MAGNITUDE

Program GENER.MAGNITUDE supplies a Richter Magnitude value to those records which belong to the raw data set and which are missing information on both magnitude and intensity. The program uses a random number generator, thus setting a correlation between uniform probability distribution between 0 and 1 and the CDF on magnitude ($P\{M \leq m_i$), as obtained from the records with complete information.

The user supplies any number of earthquake records (using the same format shown in Figure 1-3, page 10) and the program will automatically search columns 73-76 (see Fig. 1-3) for a Richter Magnitude value. If a zero magnitude is associated to any particular record, a random number is generated and an RM level is chosen from the CDF. Figure 4-1 summarizes the procedure.

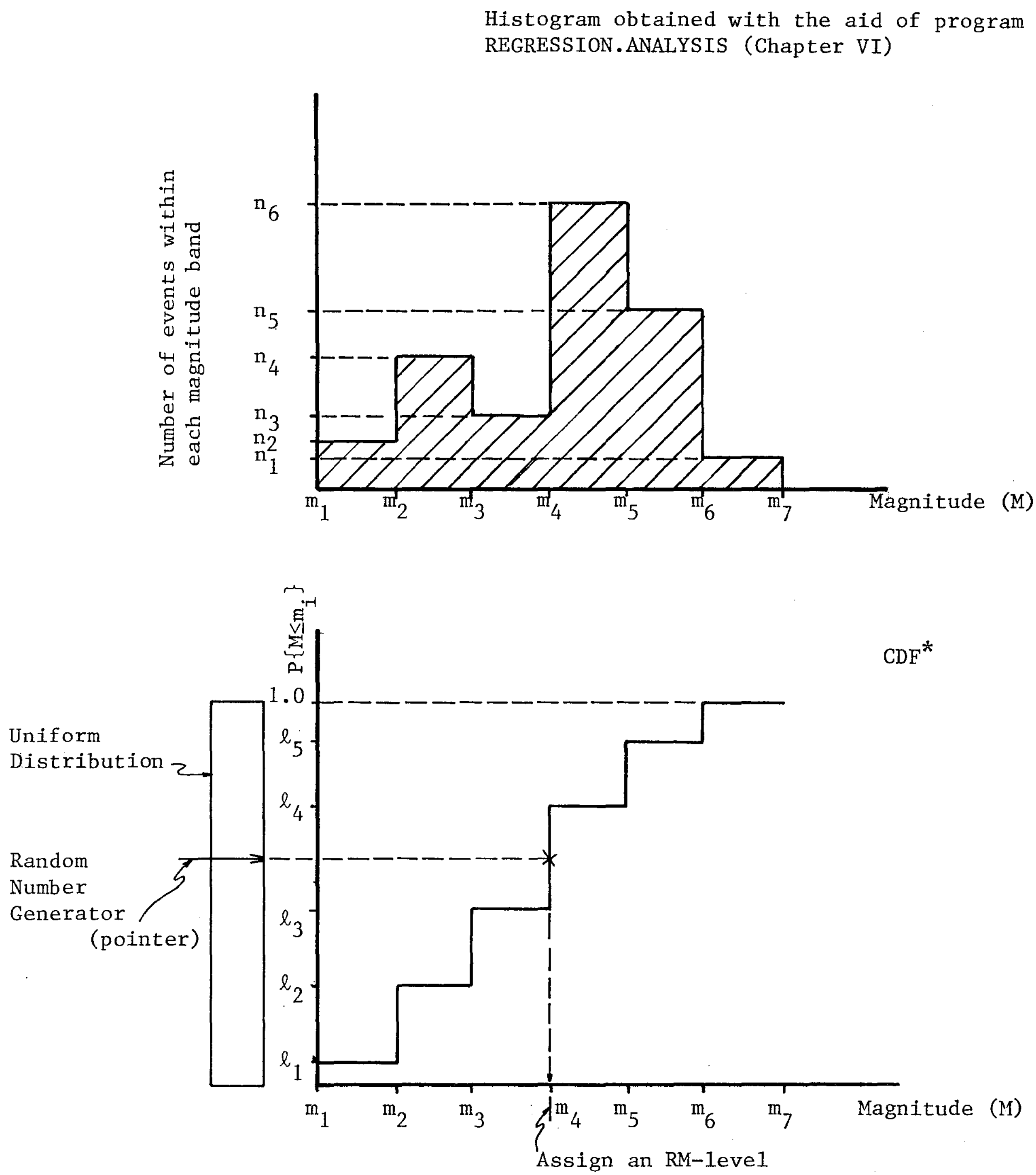
In its present form, program GENER.MAGNITUDE contains 50 executable Fortran statements. There is practically no limitation regarding the number of earthquake records to be processed. The actual iteration control statement for the number of records has been set arbitrarily equal to 800.

4.3 Description of Input Data

Input data for program GENER.MAGNITUDE will consist of any number of cards (or card images) containing information on past earthquakes.

The organization of data on each card, along with a description of the items, is given in the following section.

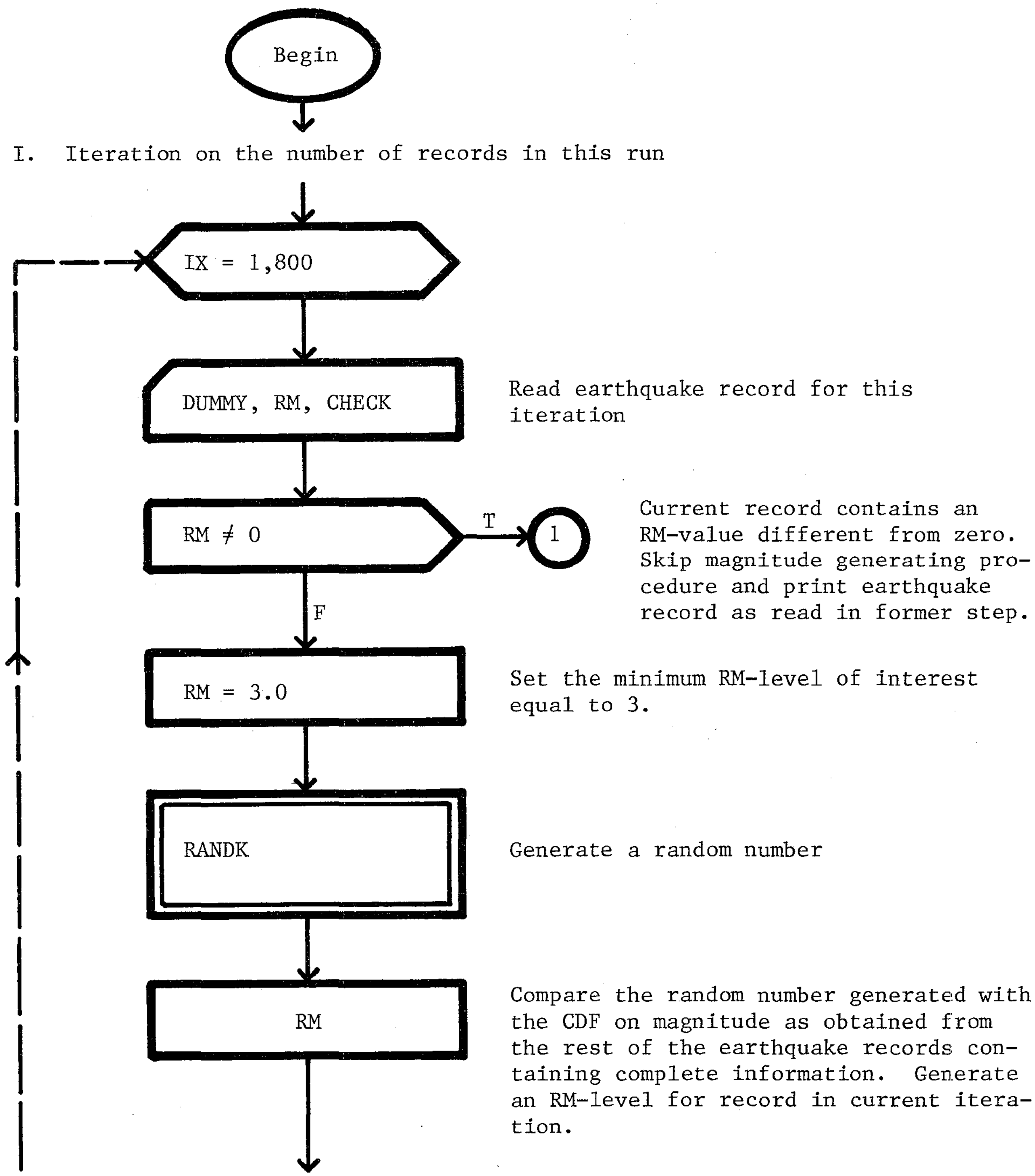
Figure 4-1

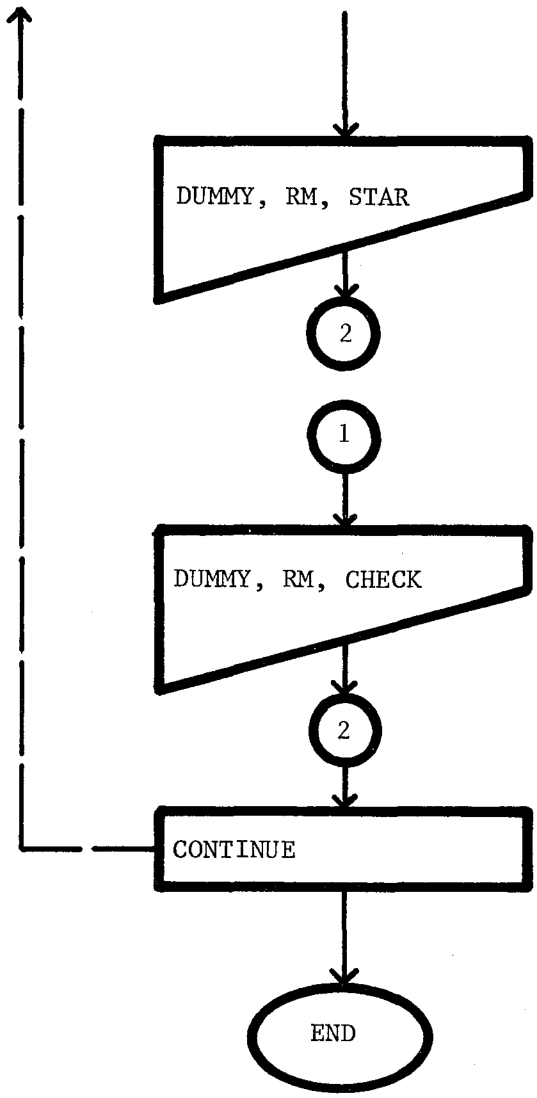


---

*Note: Since the CDF is computed on a regional basis, the values for $P\{M \leq M_i\}$ (Probability of Magnitude (M) less than or equal to a given magnitude level (M_i)) have to be included as part of the main program. (See program's listing, Appendix C, Lines 38-42.)

4.4 Macro Flow Chart for Program GENER.MAGNITUDE





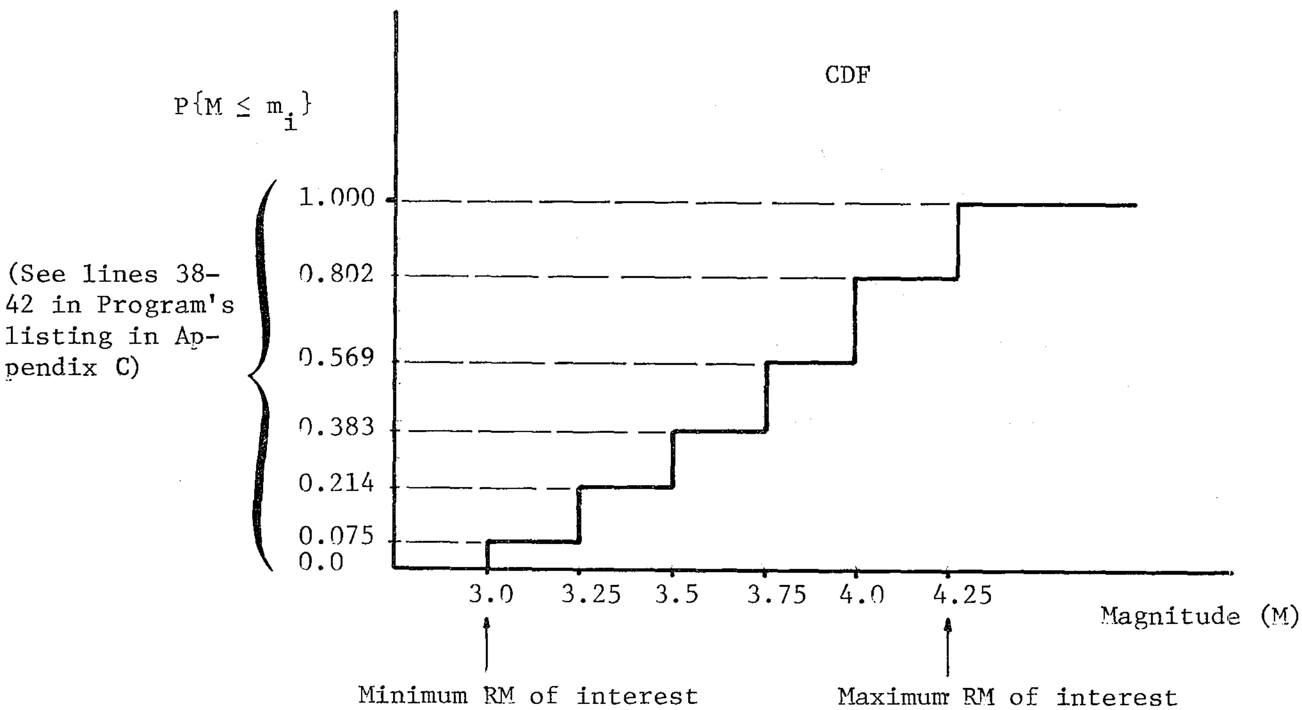
Print current earthquake record containing generated RM-level. A letter symbol (R) is printed next to the RM-level as a means of identifying which records from the raw data file have been treated.

I. Earthquake Record(s)--(9A8, F4.2, A4) Number of cards as required

Col.	1-72	DUMMY	(Data within this column is not used by program)
	73-76	RM*	(Richter Magnitude)
	77-80	CHECK	(Data within this column is not used by program)

4.5 <u>Sample Problem</u>

Assume that for a given region of interest, the following CDF has been obtained using all the available earthquake records containing complete information.



The earthquake records shown below constitute the input data deck for this particular example. Note that "RM" is equal to zero for all the events.

---

*The program checks for an RM-value equal to zero in each record included in the input data deck. If a non-zero value is found, the analysis will be automatically skipped for that particular record; therefore the user does not have to select, prior to the run, the events which need treatment. Instead, he can use the whole raw data file as input.

INPUT FOR PROGRAM GENER.MAGNITUDE (SAMPLE PROBLEM)

```
A.GRAN 09 10 1790 01 00 35.700N -0.700W          0.00     0.00     0.00
A.GRAN 21 05 1889 04 15 35.700N -0.800W          0.00     0.00     0.00
A.GRAN 24 07 1912 18 06 35.700N -0.400W          0.00     0.00     0.00
A.GRAN 19 06 1925 14 44 35.800N -0.400W          0.00     0.00     0.00
                                                                    RM
                                                                  73  76
```

4.6 Output for Program GENER.MAGNITUDE (Sample Problem)

The computer output for program GENER.MAGNITUDE (sample problem) is shown below. Note that the magnitude values generated by the program are listed between columns 73 and 76. A letter symbol (R) has been printed next to each generated magnitude in order to identify which records have been treated.

OUTPUT FOR PROGRAM GENER.MAGNITUDE (SAMPLE PROBLEM)

```
A.GRAN 09 10 1790 01 00 35.700N -0.700W          0.00     0.00     4.25 R
A.GRAN 21 05 1889 04 15 35.700N -0.800W          0.00     0.00     4.00 R
A.GRAN 24 07 1912 18 06 35.700N -0.400W          0.00     0.00     3.50 R
A.GRAN 19 06 1925 14 44 35.800N -0.400W          0.00     0.00     3.75 R
                                                                    RM
                                                                  73  76
```

CHAPTER V

PROGRAM PLOT.EPI

5.1 Introduction

At this point of the analysis (Fig. 1-2), the earthquake data (raw data file) for the region of interest should be in "complete" form. This implies that all the records should contain information on at least the time of occurrence, the epicentral location, the depth of hypocenter, and the Richter Magnitude. Figure 5-1 shows the actual format of earthquake records in complete form (treated earthquake data).

Figure 5-1

EARTHQUAKE DATA IN CHRONOLOGICAL ORDER

SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	LATITUDE	LONGITUDE	CLASS	MMI	RADIUS	DEPTH	MS	MB	MR1	MR2	SYMB
A.GRAN		03	1819			35.400N	00.100E		10.0						5.67	I
A.GRAN	02	03	1825	07	00	36.400N	02.800E		10.5						6.51	I
A.GRAN		12	1846			36.600N	02.200E		6.5						4.07	I
A.GRAN	18	06	1847	05	00	36.700N	02.900E		6.5						4.88	I
A.GRAN	09	02	1850			36.300N	04.800E		9.0						5.71	I
A.GRAN	17	12	1850	12	30	36.500N	07.400E		6.5						4.61	I
A.GRAN	22	11	1851	09	30	35.400N	00.100E		8.0						5.50	I
A.GRAN	15	05	1854			36.400N	02.700E		6.0						4.50	I
A.GRAN	21	08	1856	21	00	37.100N	05.700E	C	9.0						6.25	L
A.GRAN	22	08	1856	22	00	37.100N	05.700E		10.0						5.95	I
A.GRAN	27	09	1860			36.300N	04.500E		7.5						5.11	I
A.GRAN	08	06	1862	12	45	35.700N	00.500E		6.5						4.44	I
A.GRAN	30	11	1862	00	25	36.500N	05.300E		7.0						4.62	I
A.GRAN	02	01	1867	07	13	36.416N	02.663E		10.5						6.17	I
A.GRAN	04	02	1867	13	37	35.000N	04.000E		6.0	200					4.40	I
A.GRAN	17	08	1868	17	00	36.400N	01.200E		6.0						3.95	I
A.GRAN	20	09	1869			36.500N	02.600E		5.5						3.81	I
A.GRAN	16	11	1869	12	45	34.900N	05.900E		9.0						5.73	I
A.GRAN	29	07	1872	08	15	35.900N	09.100E		7.0						4.28	I
A.GRAN	28	03	1874	11	10	36.600N	02.200E		7.0						5.10	I
A.GRAN	23	03	1876	06	34	36.500N	02.600E		7.0						4.73	I
A.GRAN	16	01	1685			35.500N	05.700E		6.0						4.53	I
A.GRAN	03	12	1885	20	30	36.100N	04.600E								3.75	R
A.GRAN	01	07	1886	09	45	36.500N	05.300E		7.0						4.69	I
A.GRAN	09	09	1886	11	15	36.200N	03.600E		7.0						4.93	I
A.GRAN	08	01	1887	20	00	36.100N	04.600E		8.0						5.09	I
A.GRAN	29	11	1887	13	30	35.583N	00.333E		9.5						5.84	I
A.GRAN	06	01	1888	23	40	36.500N	02.600E		8.0						5.12	I
A.GRAN	21	05	1689	04	15	35.700N	-0.800W		7.5						5.08	I
A.GRAN	30	07	1890			35.700N	00.500E		6.5						4.48	I
A.GRAN	15	01	1691	04	00	36.500N	01.800E		10.0	200					6.36	I
A.GRAN	11	03	1908	00	06	36.400N	02.800E		8.0						4.89	I
A.GRAN	17	06	1908	00	24	36.500N	07.500E		7.5						5.25	I
A.GRAN	04	08	1908	02	11	36.400N	06.600E	D	8.0					5.10	5.10	
GUTE	16	06	1910	04	16	36.500N	-4.000W		0.0					6.10	6.10	

A new column (SYMB) has been added in order to indicate which earthquake records have been treated using the programs discussed in Chapters II through IV. Recall that:

I stands for a record treated using Program INTENSITY.MAGNITUDE

L stands for a record treated using Program REPLACE.LETTER.MAGNITUDE

and R stands for a record treated using Program GENER.MAGNITUDE.

The next step in the analysis is to plot the epicenters using the above information for the region of interest. For this, the data under the columns labelled Latitude and Longitude in Figure 5-1 will be used by program PLOT.EPI.

This stage of the seismic hazard methodology will enable the analyst to acquire a good understanding of the spatial distribution of earthquakes throughout the region. Most important, it will help the user to model the seismicity of the region by grouping the events into seismic sources (i.e., line sources and area sources). Hence, the analyst must obtain geological and seismological information for the particular location.

The process of grouping the events into seismic sources is difficult and should be done with great care. The seismic events must be associated with the geotectonic features within the region. This process requires proper communication between the analyst and experts such as seismologists and geologists.

5.2 Program PLOT.EPI

Program PLOT.EPI has been deisgned to plot to scale the epicenters recorded in the given region in a parallelogram area (the present version uses a Conformal Lambert projection, see Ref. 10). The data (as shown in Figure 5-1) will constitute the major part of the input (specifically for each event the magnitude and the latitude and longitude, measured in degrees, with the convention that the quadrant north of the equator and east of Greenwich is positive). The program utilizes a series of symbols (dots, squares, etc.) to differentiate between the Richter Magnitude levels corresponding to each event on the plot (see Figure 5-5).

Program PLOT.EPI has the optional capability of plotting up to 10 cities with their corresponding names. This option can be specified by setting the parameter "NOCITY" different from zero and by including the coordinates of each city as part of the input data deck.

Program PLOT.EPI is system dependent. Its use is limited to Stanford's Computer Center since it uses plotting and mapping routines which are system oriented. The present dimensions allow for a maximum of 500 epicenters and ten cities.

5.3 Description of Input Data

Input data for program PLOT.EPI will consist of ten sets of cards. The organization of data on each card, along with a description of the items, is given in the following sections.

I--Epicenter data format--(20A4)--One card

Col.	1-80	FRMT	(format required to read epicentral coordinates and magnitude. See data set X.)

II--Identification card--(3I5, 16A4)--One card

Col.	1-5	NDTP	(number of plot types or different grids, e.g., plots with different scales or parameters)
	6-10	ICAL	(Plotter size, if 3 = 11 inches, default 4 = 33 inches)
	11-15	NN	(Flag for Lambert projection, if 0 = $1/180^{\circ}$ 1 = $0/360^{\circ}$)
	16-80	HED1	(Run identification)

III--Lambert Projection*--(5F10.0)--One card

Col.	1-10	STLT1	(Standard Latitude° 1)
	11-20	STLT2	(Standard Latitude° 2)
	21-30	STLN	(Standard Longitude°)
	31-40	SCAL	(Scale 1/scal)
	41-50	DTLB	(Distance between grid marks and labels, see Fig. 5-5)

IV--Plot flags--(5I5)--One card

Col.	1-5	NOPL	(Number of plots with the same parameters)
	6-10	NOCITY	(Number of cities to be plotted)
	11-15	PLFR	(Plot frame? If 0 = NO)

V--Grid description--(6F10.0)--One card--(see Fig. 5-5)

Col.	1-10	XXOR	(X-coord.° of origin)
	11-20	YYOR	(Y-coord.° of origin)
	21-30	XXRT	(X-coord.° of right bottom corner)
	31-40	YYRT	(Y-coord.° of right bottom corner)
	41-50	XXUP	(X-coord.° of left top corner)
	51-60	YYUP	(Y-coord.° of left top corner)

VI--Label Description--(7F10.0)--One card--(see Fig. 5-5)

Col.	1-10	DXCR	(X-distance° between marks)
	11-20	DYCR	(Y-distance° between marks)
	21-30	DXLB	(X-distance° between labels)
	31-40	DYLB	(Y-distance° between labels)
	41-50	CRCR	(Marks inside grid? If 0 = NO)

---

*These parameters depend on the maps available for the region (i.e., as obtained from an atlas or any other source).

VII--Flag for magnitudes to be plotted*--(16I5)--One card

Col.	1-5	SKIP2	(No magnitude in data)
	6-10	SKIP3	(Magnitude 3)
	11-15	SKIP4	(Magnitude 4)
	16-20	SKIP5	(Magnitude 5)
	21-25	SKIP6	(Magnitude 6)
	26-30	SKIP7	(Magnitude 7)
	31-35	SKIP8	(Magnitude 8)

VIII--Cities--(2F10.0, 12A1)--NOCITY number of cards

Col.	1-10	XXCITY(IX)	(X-coord.° of city)
	11-20	YYCITY(IX)	(Y-coord.° of city)
	21-32	CITY(IX,1-12)	(Name of city)

IX--Plot identification--(I5, 70A1)--One card

Col.	1-5	NORC	(Number of earthquake records to be read)
	6-75	HED2	(Title for the plot)

X--Coordinates° of epicenters--(FMRT)--NORC number of cards

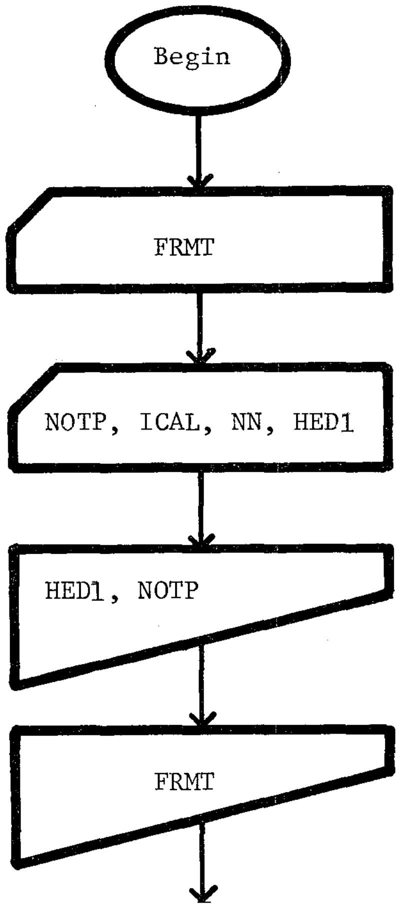
Use format given in data set I	XXCK	(Longitude°)
	YYCK	(Latitude°)
	XMP	(Richter Magnitude)

Note: Do-Loop on NOPL (see data set IV) starts at data set IX.

Do-Loop on NOTP (see data set II) starts at data set II.

If any SKIP (where * can be any number between 2 and 8) is read as 1, the magnitude corresponding to * will not be plotted.

5.4 Macro Flow Chart for Program PLOT.EPI



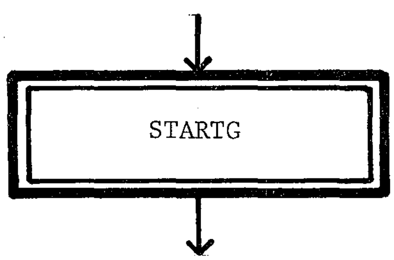
Input format statement to read earthquake epicentral coordinates

Read:
1. Number of plot types (different grids
2. Plotter size
3. Flag for Lambert projection
4. Run identification

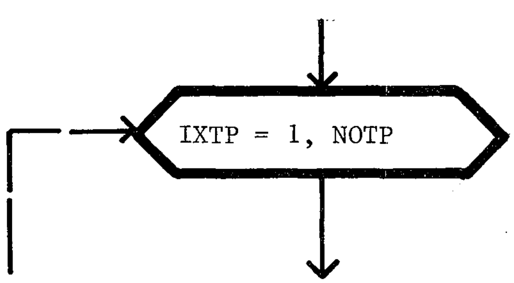
Print run identification and number of plot types

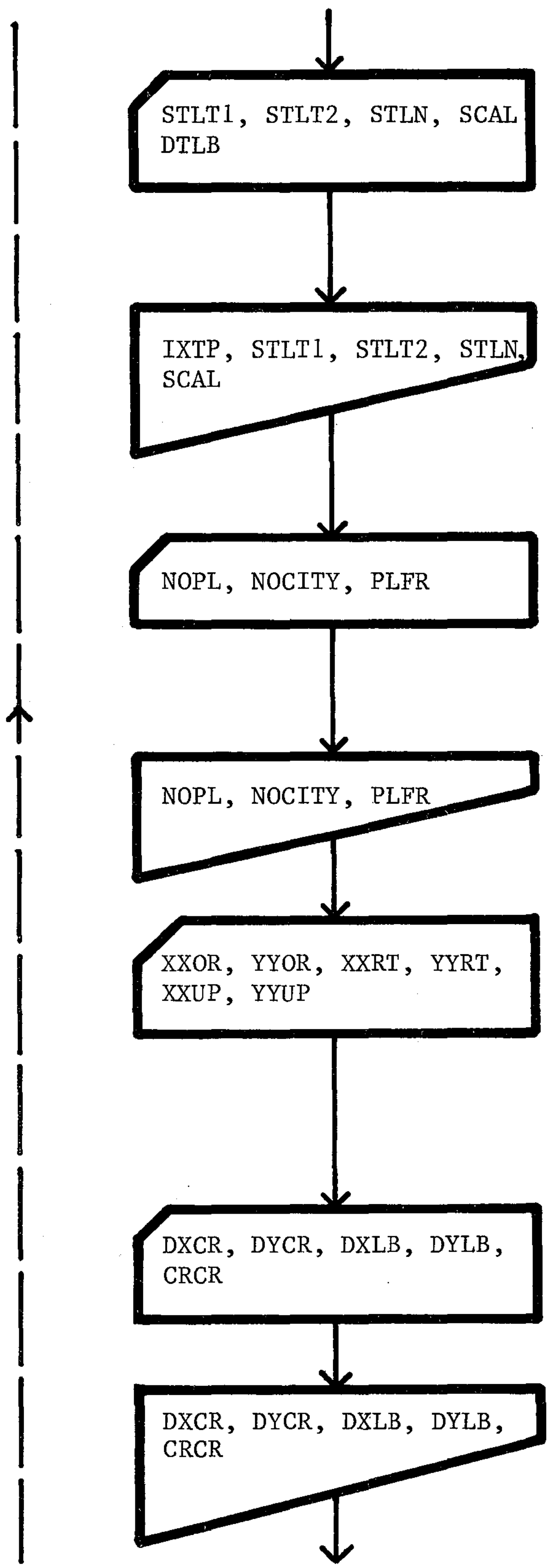
Print format to be used when reading epicentral coordinates

I. Initialize plot



II. Iteration control on the number of plot types in this run





Read:
1. Standard latitude 1
2. Standard latitude 2
3. Standard longitude
4. Map scale
5. Distance between grid marks

Print:
1. Index for plot type in current iteration
2. Lambert projection parameters

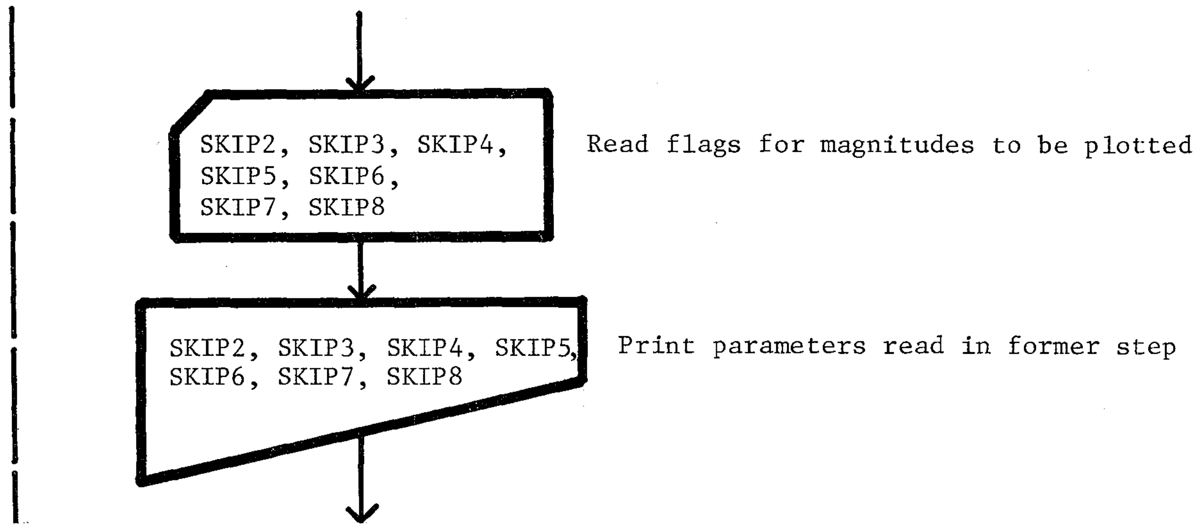
Read:
1. Number of plots with same parameters
2. Number of cities to be plotted
3. Plot frame, 0 = NO.

Print parameters read in former step

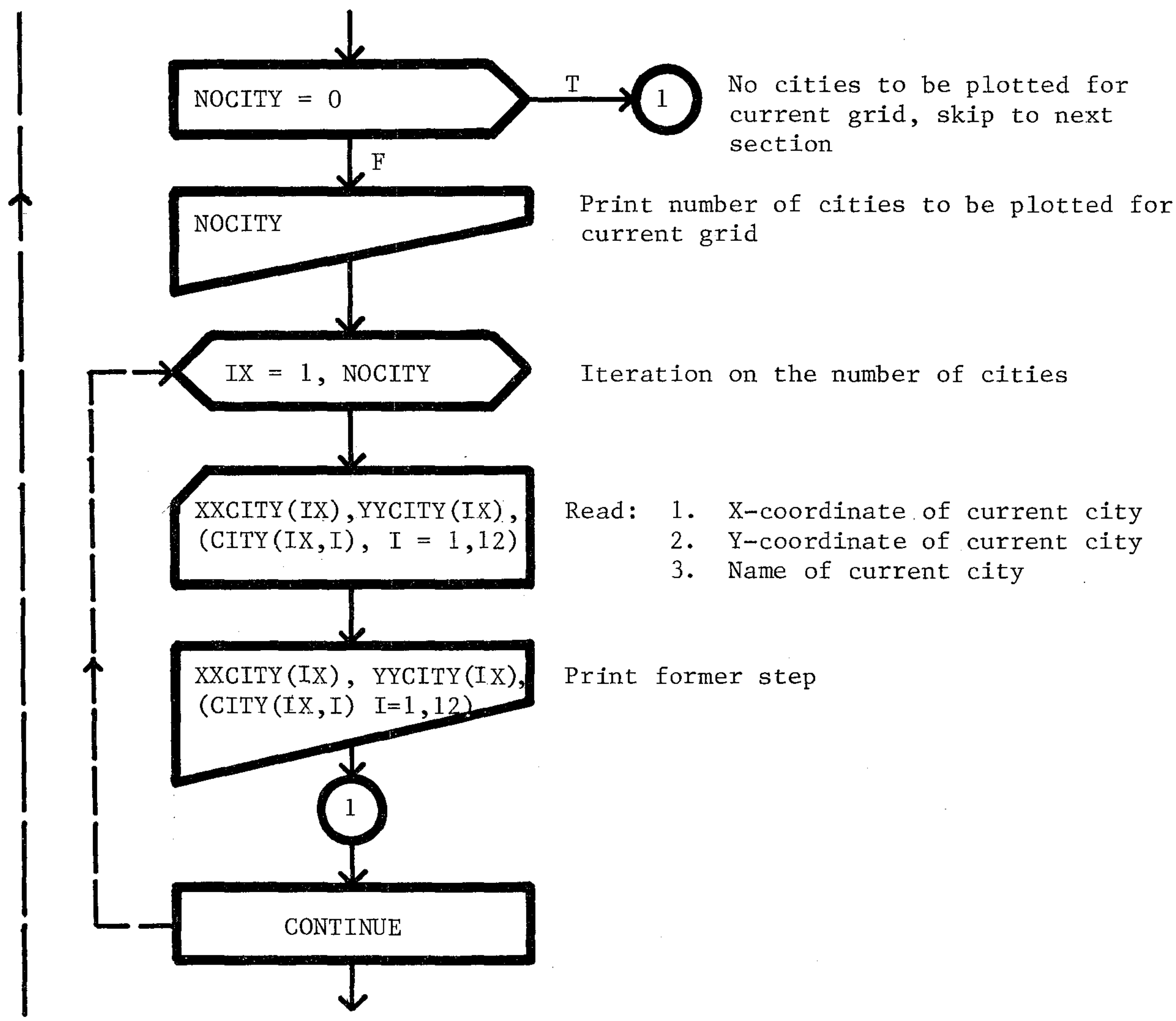
Read:
1. X-coordinate of grid's origin
2. Y-coordinate of grid's origin
3. X-coordinate of right bottom corner
4. Y-coordinate of right bottom corner
5. X-coordinate of left top corner
6. Y-coordinate of left top corner

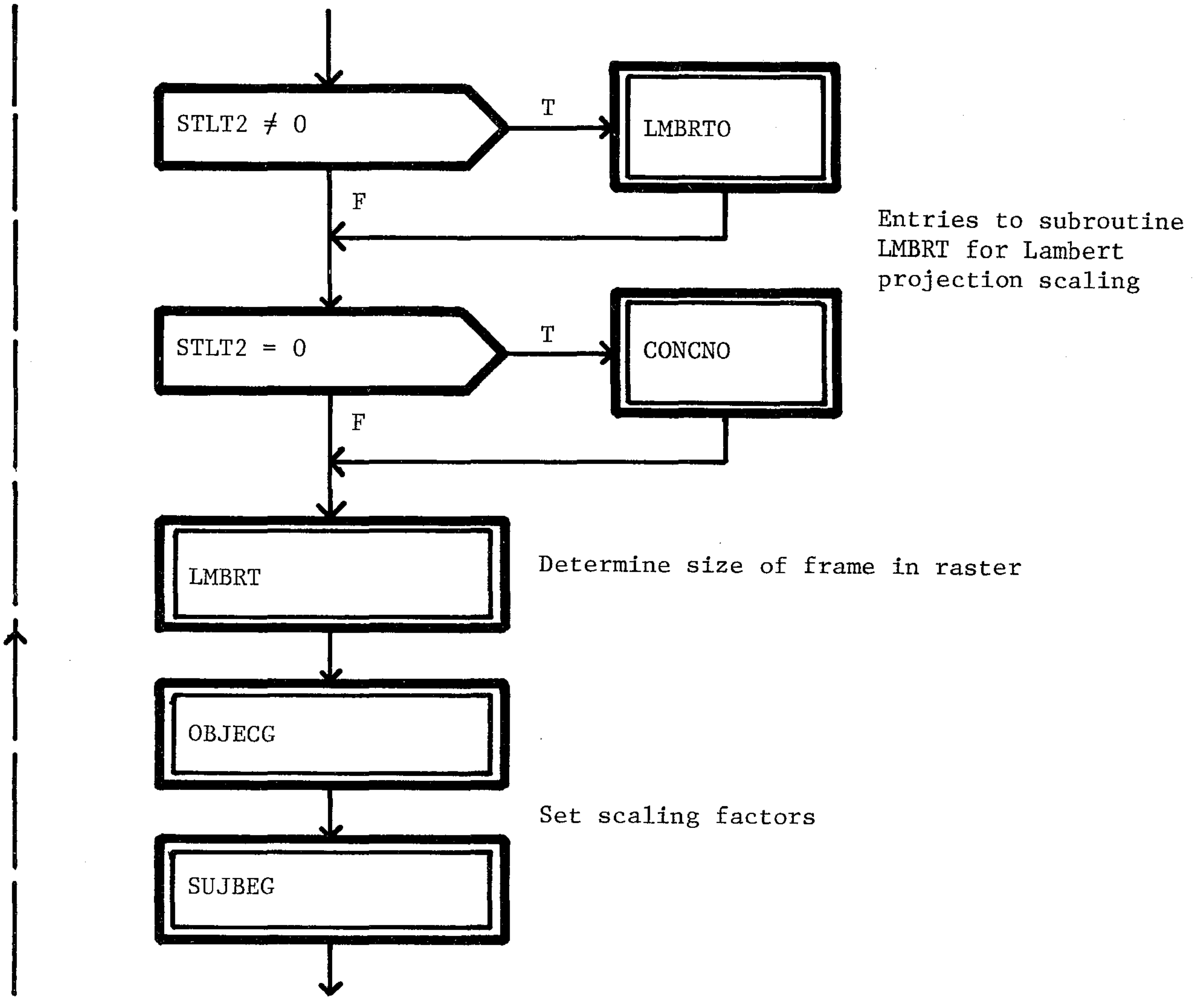
Read label description

Print parameters read in former step

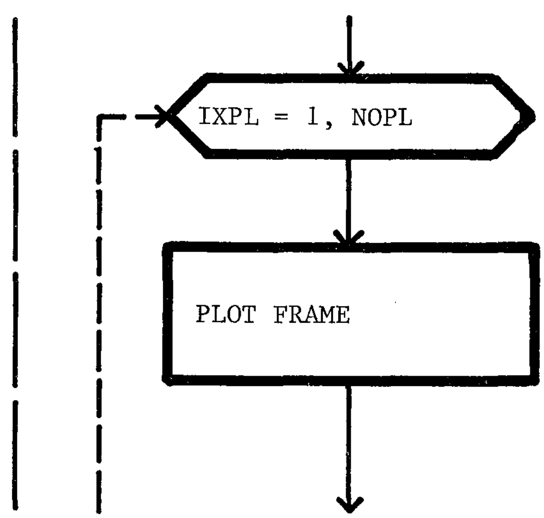


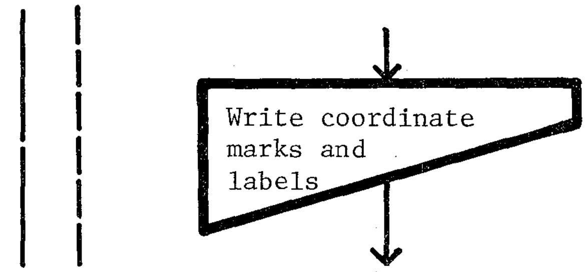
III. Read and store cities



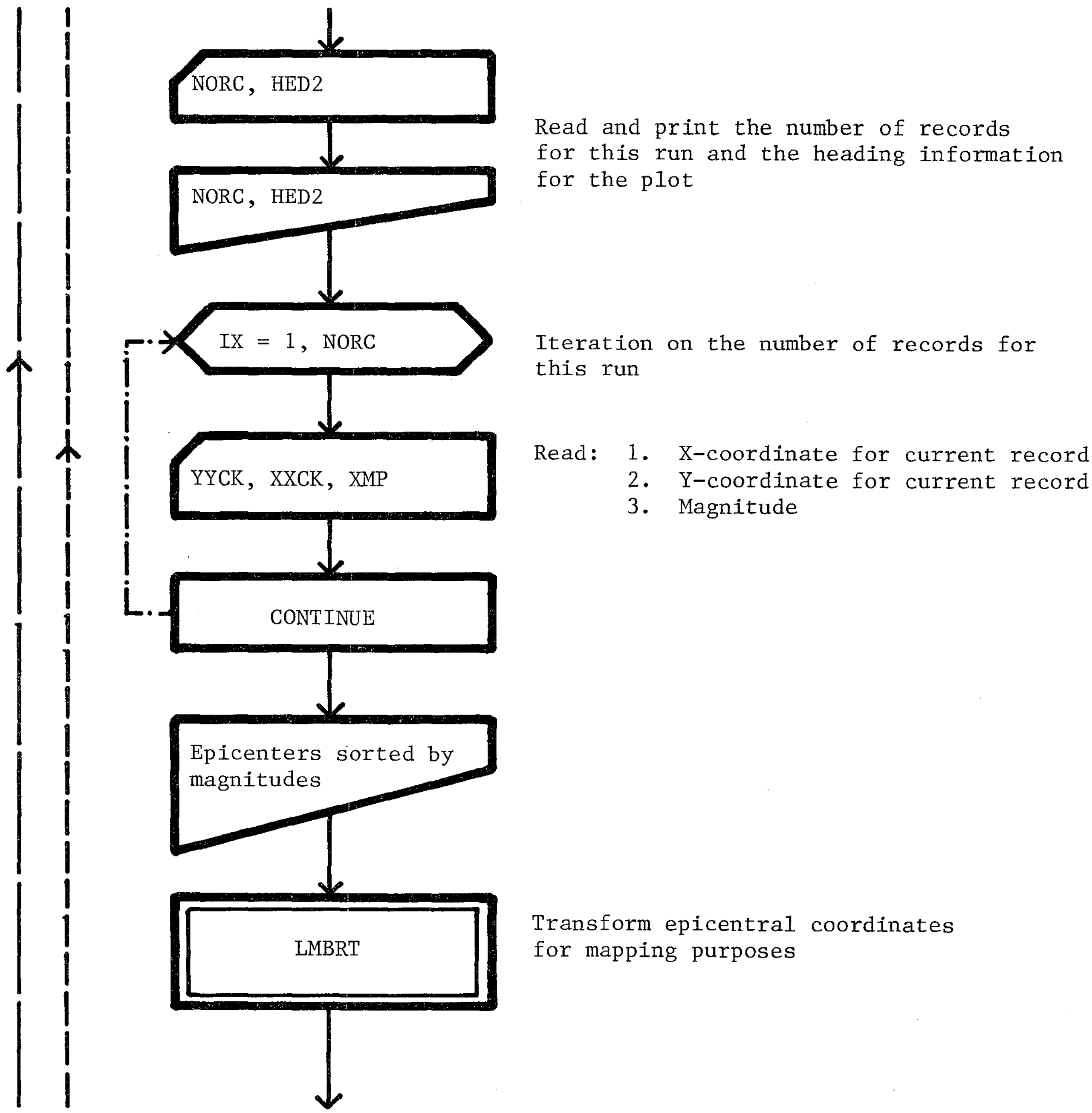


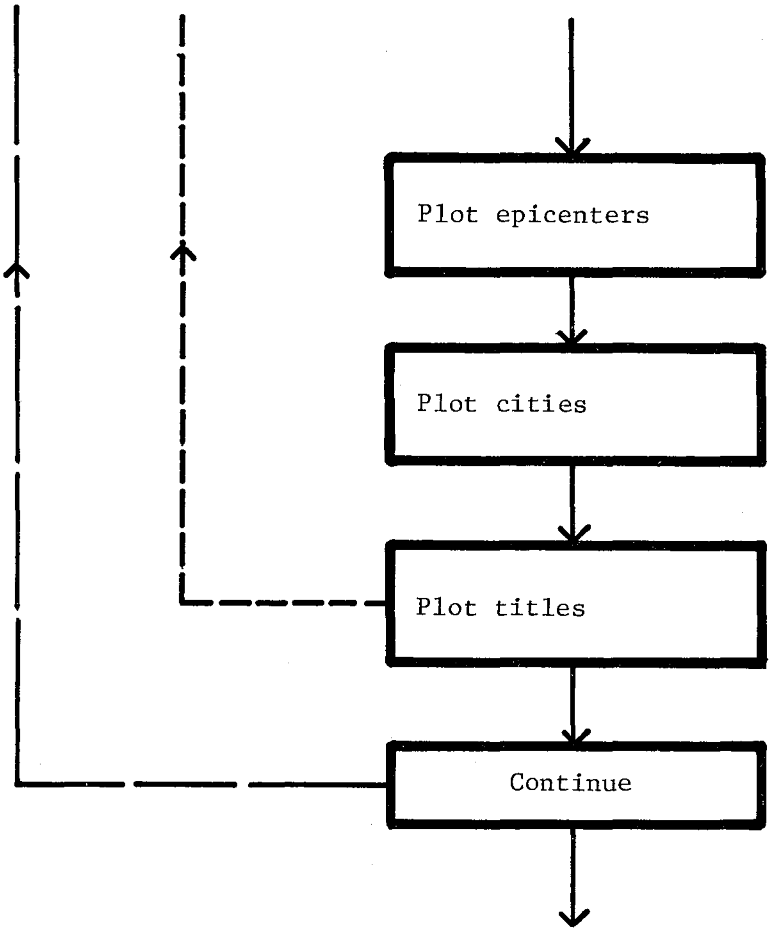
IV. Iteration on the number of grids of the same size (NOPL)



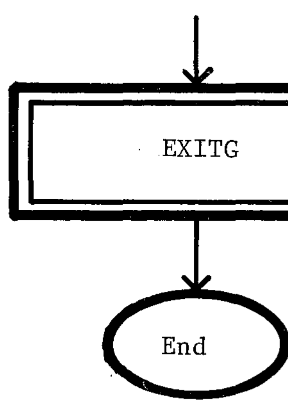


V. Read earthquake records and sort them by magnitudes





VI. End of plot



5.5 Sample Problem

Plot the epicenters for the earthquakes listed in Figure 5-2 below. The grid covering the region of interest is defined by the following parameters (data set V):

XXOR = 30^{o} (east of Greenwich); YYOR = 30^{o} (north of the equator)

XXRT = 33^{o} (east of Greenwich); YYRT = 30^{o} (north of the equator)

XXUP = 30^{o} (east of Greenwich); YYUP = 33^{o} (north of the equator)

Figure 5-2

EARTHQUAKE DATA IN CHRONOLOGICAL ORDER

SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	LATITUDE	LONGITUDE	CLASS	MMI	RADIUS	DEPTH	MS	MB	MR1	MR2	SYMBOL
A.GRAN	02	03	1900	07	00	32.600N	30.750E							3.50	3.50	
A.GRAN	03	05	1902	05	00	32.500N	30.900E							3.75	3.75	
A.GRAN	05	03	1905	01	00	32.350N	30.900E							4.75	4.75	
A.GRAN	05	03	1912	02	00	32.000N	30.500E							3.25	3.25	
A.GRAN	04	09	1916	01	00	31.600N	30.530E							3.50	3.50	
A.GRAN	08	01	1920	02	30	32.200N	30.700E							6.00	6.00	
A.GRAN	06	08	1921	09	10	31.700N	30.650E							4.50	4.50	
A.GRAN	17	02	1923	08	00	31.050N	32.350E							4.35	4.35	
A.GRAN	16	01	1925	14	00	30.700N	32.700E							5.60	5.60	
A.GRAN	30	11	1925	12	15	31.500N	32.400E							3.50	3.50	
A.GRAN	04	01	1935	15	30	31.450N	31.000E							5.55	5.55	
A.GRAN	10	08	1937	01	15	31.200N	30.900E							3.80	3.80	
A.GRAN	04	12	1940	03	00	31.250N	31.200E							4.10	4.10	
A.GRAN	14	02	1948	01	00	31.250N	32.450E							5.60	5.60	
A.GRAN	13	04	1950	13	30	31.150N	32.600E							3.80	3.80	
A.GRAN	18	11	1951	02	15	31.300N	32.150E							7.00	7.00	
A.GRAN	15	06	1954	06	35	31.100N	32.000E							5.60	5.60	
A.GRAN	02	12	1958	06	15	30.900N	31.800E							3.00	3.00	
A.GRAN	18	01	1960	04	18	30.620N	32.250E							4.85	4.85	
A.GRAN	04	08	1965	09	30	32.000N	30.600E							4.65	4.65	
A.GRAN	01	01	1968	13	14	30.550N	32.570E							3.40	3.40	
A.GRAN	04	10	1969	02	00	30.850N	32.150E							3.15	3.15	
A.GRAN	03	12	1970	10	12	30.350N	32.570E							3.00	3.00	
A.GRAN	12	01	1972	11	05	31.750N	30.900E							4.65	4.65	
A.GRAN	17	03	1972	13	05	30.850N	32.460E							4.50	4.50	
A.GRAN	03	08	1973	08	30	32.400N	30.750E							5.00	5.00	
A.GRAN	08	11	1973	15	00	32.600N	32.750E							3.50	3.50	
A.GRAN	11	05	1975	01	15	31.500N	30.750E							6.30	6.30	
A.GRAN	06	04	1976	05	00	32.150N	30.530E							3.25	3.25	
A.GRAN	01	08	1976	08	12	30.500N	31.250E							3.50	3.50	
A.GRAN	16	10	1976	10	00	31.400N	32.650E							3.65	3.65	
A.GRAN	01	07	1978	03	15	30.500N	32.420E							4.25	4.25	

The Lambert Projection parameters (data set III) selected for this example are as follows:

STLT1 = 30^{o} (north of the equator)

STLN = 31^{o} (east of Greenwich)

SCAL = 1 to 2,000,000

(Recall that the parameters given above depend on the available geographic and geologic maps for the region considered.)

In addition to the epicenters, two cities, namely:

CITY1 (31.0^{o}, 30.50^{o})

and CITY2 (32.0^{o}, 30.006^{o})

will be plotted. Figure 5-3 shows a listing of the input data deck for program PLOT.EPI. Each data set as described in Section 5.3 is indicated with the corresponding item number.

5.6 Output for Program PLOT.EPI (Sample Problem)

Figure 5-4 shows the listing of the output for program PLOT.EPI as obtained on the line printer. It contains basically the mapping parameters as given by the analyst (echo printing), plus the events' coordinates sorted by magnitude ranges (i.e., where 3+ indicates events with magnitude between 3 and 4). The output as obtained on the Calcomp Plotter is shown in Figure 5-5.

5.6.1 Source Mechanisms

Several different types of sources can be used to represent the seismicity of any location, namely:

- Point sources
- Line sources
- Area sources
- Dipping plane sources

} References 1 and 5

Figure 5-3

INPUT DATA FOR PROGRAM PLOT.EPI (SAMPLE PROBLEM)

```
(23X,F7.0,1X,F7.0,34X,F4.0)                                        I
   1    3     0 SAMPLE PROBLEM FOR PROGRAM PLOT.EPI                 II
30.0000     0.00       31.000     2000000.                          III
   1    2     1                                                     IV
30.          30.         33.          30.         30.      33.      V
1.             1.          1.           1.                          VI
   0     0     0     0     0     0     0                            VII
31.0         30.50       CITY1                                      VIII
32.00        32.006      CITY2
   32  PLOT OF EPICENTERS (SAMPLE PROBLEM)                          IX
A.GRAN 02 03 1900 07 00 32.600N 30.750E          3.50      3.50
A.GRAN 03 05 1902 05 00 32.500N 30.900E          3.75      3.75
A.GRAN 05 03 1905 01 00 32.350N 30.900E          4.75      4.75
A.GRAN 05 03 1912 02 00 32.000N 30.500E          3.25      3.25
A.GRAN 04 09 1916 01 00 31.600N 30.530E          3.50      3.50
A.GRAN 08 01 1920 02 30 32.200N 30.700E          6.00      6.00
A.GRAN 06 08 1921 09 10 31.700N 30.650E          4.50      4.50
A.GRAN 17 02 1923 08 00 31.050N 32.350E          4.35      4.35
A.GRAN 16 01 1925 14 00 30.700N 32.700E          5.60      5.60
A.GRAN 30 11 1925 12 15 31.500N 32.400E          3.50      3.50
A.GRAN 04 01 1935 15 30 31.450N 31.000E          5.55      5.55
A.GRAN 10 08 1937 01 15 31.200N 30.900E          3.80      3.80   X
A.GRAN 04 12 1940 03 00 31.250N 31.200E          4.10      4.10
A.GRAN 14 02 1948 01 00 31.250N 32.450E          5.60      5.60
A.GRAN 13 04 1950 13 30 31.150N 32.600E          3.80      3.80
A.GRAN 18 11 1951 02 15 31.300N 32.150E          7.00      7.00
A.GRAN 15 06 1954 06 35 31.100N 32.000E          5.60      5.60
A.GRAN 02 12 1958 06 15 30.900N 31.800E          3.00      3.00
A.GRAN 18 01 1960 04 18 30.620N 32.250E          4.85      4.85
A.GRAN 04 08 1965 09 30 32.000N 30.600E          4.65      4.65
A.GRAN 01 01 1968 13 14 30.550N 32.570E          3.40      3.40
A.GRAN 04 10 1969 02 00 30.850N 32.150E          3.15      3.15
A.GRAN 03 12 1970 10 12 30.350N 32.570E          3.00      3.00
A.GRAN 12 01 1972 11 05 31.750N 30.900E          4.65      4.65
A.GRAN 17 03 1972 13 05 30.850N 32.460E          4.50      4.50
A.GRAN 03 08 1973 08 30 32.400N 30.750E          5.00      5.00
A.GRAN 08 11 1973 15 00 32.600N 32.750E          3.50      3.50
A.GRAN 11 05 1975 01 15 31.500N 30.750E          6.30      6.30
A.GRAN 06 04 1976 05 00 32.150N 30.530E          3.25      3.25
A.GRAN 01 08 1976 08 12 30.500N 31.250E          3.50      3.50
A.GRAN 16 10 1976 10 00 31.400N 32.650E          3.65      3.65
A.GRAN 01 07 1978 03 15 30.500N 32.420E          4.25      4.25
```

Figure 5-4

```
OUTPUT FOR PROGRAM PLOT.EPI (SAMPLE PROBLEM)


 SAMPLE PROBLEM FOR PROGRAM PLOT.EPI                                          1  DIFFERENT FRAMES
FORMAT USE TO READ DATA   (23X,F7.0,1X,F7.0,34X,F4.0)
PLOT TYPE                         1
STANDARD LATITUDE 1         30.0000
STANDARD LATITUDE 2          0.0000
STANDARD LONGITUDE          31.0000
SCALE               1  TO  2000000.0
NUMBER OF PLOTS                   1
NUMBER OF CITIES                  2
PLOT FRAME? 0=NO                  1
X MARK  EVERY                1.0000
Y MARK  EVERY                1.0000
X LABEL EVERY                1.0000
Y LABEL EVERY                1.0000
CROSSES INSIDE? 0=NO            0.0
THE MAGNITUDES DIRECTLY ABOVE A 1 WILL NOT BE PLOTTED
      NONE         3         4         5         6         7         8
         0         0         0         0         0         0         0
   2  CITIES WILL BE PLOTTED
 X COORD   Y COORD     NAME
   31.000    30.500     CITY1
   32.000    32.000     CITY2
GRID COORDINATES  X     30.000    33.000    33.000    30.000
                  Y     30.000    30.000    33.000    33.000
  PLOT OF EPICENTERS (SAMPLE PROBLEM)                                            32  RECORDS
NUMBER OF EARTHQUAKES DISREGARDED     0
MAGNITUDE 0 +
MAGNITUDE 3 +
   30.750    32.600    30.900    32.500    30.500    32.000    30.530    31.600    32.400    31.500    30.900    31.200
   32.600    31.150    31.800    30.900    32.570    30.550    32.150    30.850    32.570    30.350    32.750    32.600
   30.530    32.150    31.250    30.500    32.650    31.400
MAGNITUDE 4 +
   30.900    32.350    30.650    31.700    32.350    31.050    31.200    31.250    32.250    30.620    30.600    32.000
   30.900    31.750    32.460    30.850    32.420    30.500
MAGNITUDE 5 +
   32.700    30.700    31.000    31.450    32.450    31.250    32.000    31.100    30.750    32.400
MAGNITUDE 6 +
   30.700    32.200    30.750    31.500
MAGNITUDE 7 +
   32.150    31.300
MAGNITUDE 8 +
```

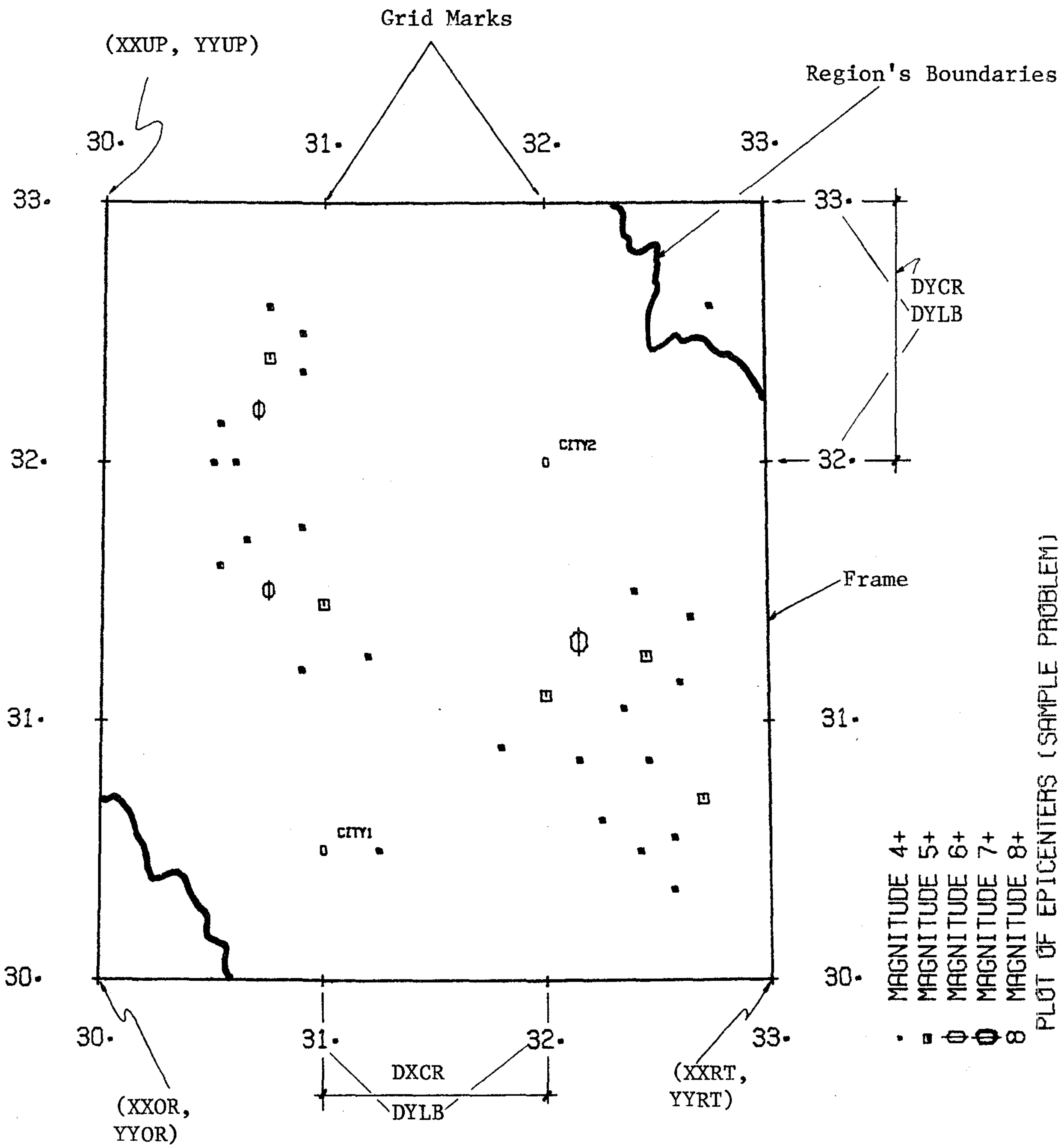


Figure 5-5 Epicentral Map

For the purpose of illustrating the seismic modelling of a given region, it will be assumed in this case that the analyst, after correlating the earthquake epicenters (shown in Fig. 5-5) with tectonic features identified within the region, has grouped the events in three seismic sources (two line sources and one area source). Figure 5-6 shows the location of the seismic sources and the events associated to each one.

In order to increase the organization of earthquake data after the location of seismic sources, it is good practice to sort* the recorded events (as shown in Figure 5-2) by sources. Figure 5-7 shows a listing of the data sorted by sources (as grouped in Figure 5-6).

---

*It must be pointed out that all the manipulation done on past earthquake data to achieve formats shown in Figures 1-3, 5-2, 5-7, etc. is done using the editing capabilities made available to the user by the Computer Center.

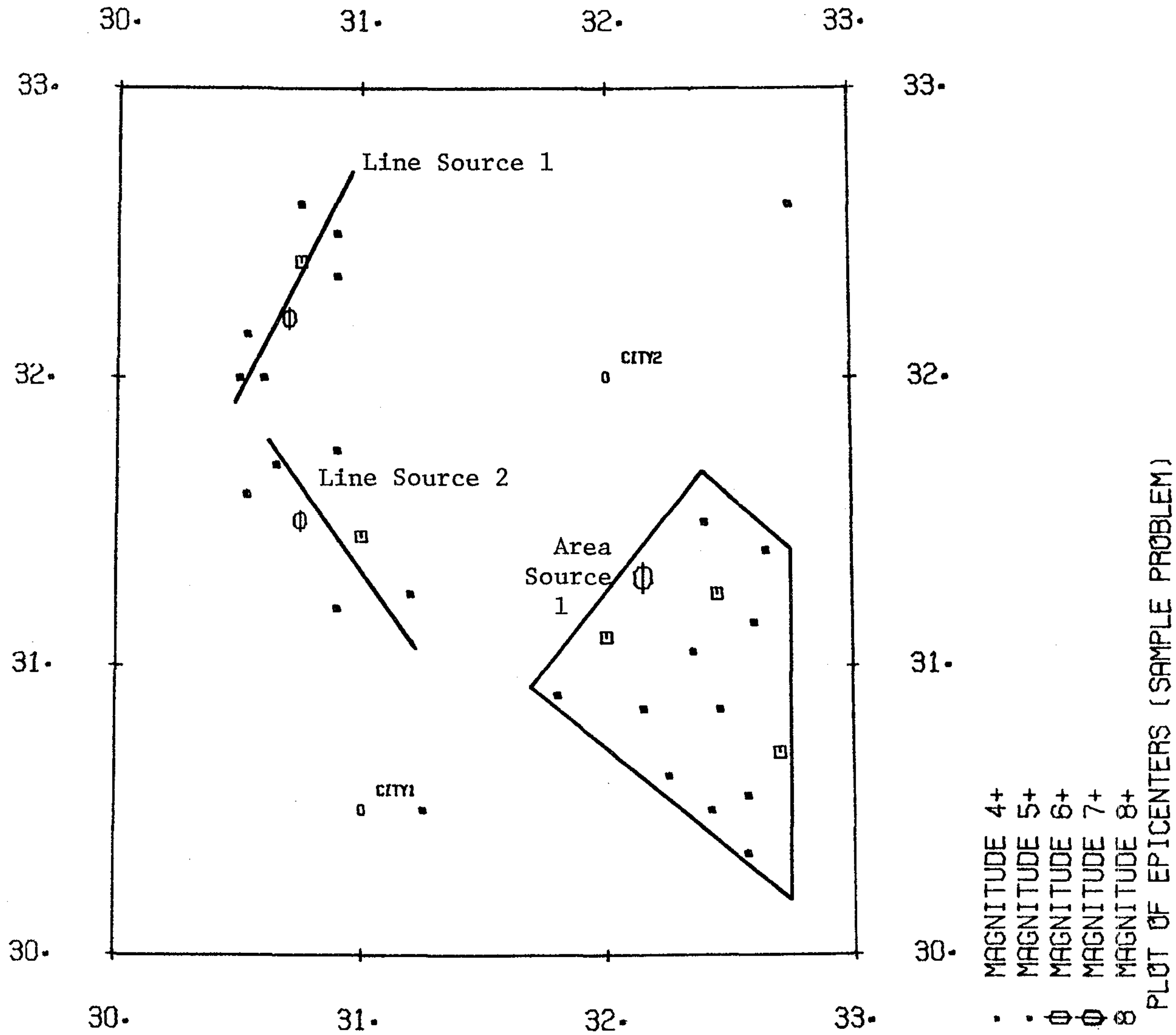


Figure 5-6 Location of Seismic Sources

Figure 5-7

EARTHQUAKE DATA SORTED BY SOURCES

SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	LATITUDE	LONGITUDE	CLASS	MMI	RADIUS	DEPTH	MS	MB	MR1	MR2	SYMBOL
LINE SOURCE 1 (8 RECORDS)																
A.GRAN	02	03	1900	07	00	32.600N	30.750E							3.50	3.50	
A.GRAN	03	05	1902	05	00	32.500N	30.900E							3.75	3.75	
A.GRAN	05	03	1905	01	00	32.350N	30.900E							4.75	4.75	
A.GRAN	05	03	1912	02	00	32.000N	30.500E							3.25	3.25	
A.GRAN	08	01	1920	02	30	32.200N	30.700E							6.00	6.00	
A.GRAN	04	08	1965	09	30	32.000N	30.600E							4.65	4.65	
A.GRAN	03	08	1973	08	30	32.400N	30.750E							5.00	5.00	
A.GRAN	06	04	1976	05	00	32.150N	30.530E							3.25	3.25	
LINE SOURCE 2 (9 RECORDS)																
A.GRAN	04	09	1916	01	00	31.600N	30.530E							3.50	3.50	
A.GRAN	06	08	1921	09	10	31.700N	30.650E							4.50	4.50	
A.GRAN	04	01	1935	15	30	31.450N	31.000E							5.55	5.55	
A.GRAN	10	08	1937	01	15	31.200N	30.900E							3.80	3.80	
A.GRAN	04	12	1940	03	00	31.250N	31.200E							4.10	4.10	
A.GRAN	12	01	1972	11	05	31.750N	30.900E							4.65	4.65	
A.GRAN	11	05	1975	01	15	31.500N	30.750E							6.30	6.30	
A.GRAN	01	08	1976	08	12	30.500N	31.250E							3.50	3.50	
A.GRAN	01	07	1978	03	15	30.500N	32.420E							4.25	4.25	
AREA SOURCE 1 (15 RECORDS)																
A.GRAN	17	02	1923	08	00	31.050N	32.350E							4.35	4.35	
A.GRAN	16	01	1925	14	00	30.700N	32.700E							5.60	5.60	
A.GRAN	30	11	1925	12	15	31.500N	32.400E							3.50	3.50	
A.GRAN	14	02	1948	01	00	31.250N	32.450E							5.60	5.60	
A.GRAN	13	04	1950	13	30	31.150N	32.600E							3.80	3.80	
A.GRAN	18	11	1951	02	15	31.300N	32.150E							7.00	7.00	
A.GRAN	15	06	1954	06	35	31.100N	32.000E							5.60	5.60	
A.GRAN	02	12	1958	06	15	30.900N	31.800E							3.00	3.00	
A.GRAN	18	01	1960	04	18	30.620N	32.250E							4.85	4.85	
A.GRAN	01	01	1968	13	14	30.550N	32.570E							3.40	3.40	
A.GRAN	04	10	1969	02	00	30.850N	32.150E							3.15	3.15	
A.GRAN	03	12	1970	10	12	30.350N	32.570E							3.00	3.00	
A.GRAN	17	03	1972	13	05	30.850N	32.460E							4.50	4.50	
A.GRAN	08	11	1973	15	00	32.600N	32.750E							3.50	3.50	
A.GRAN	16	10	1976	10	00	31.400N	32.650E							3.65	3.65	

CHAPTER VI

PROGRAM REGRESSION.ANALYSIS

6.1 Introduction

At this stage of the analysis (Fig. 1-2, item II-2), all the available data on past seismic events has been grouped into Seismic Sources (Fig. 5-6). The analyst is ready to describe the seismicity of each source using recurrence relationships of the form:

$$Ln_e N(M) = \alpha + \beta M \tag{6.1}$$

where: N(M) = number of events of magnitude greater or equal to M

M = Richter Magnitude

α and β = regression constants

where alpha (α) is a measure of the number of events above magnitude zero for a given source. Beta (β) is the slope of the line and measures the seismic severity of the source.

6.2 Description of the Program REGRESSION.ANALYSIS

The program REGRESSION.ANALYSIS has been designed to determine the two parameters (α and β), given a set of earthquake events corresponding to a specific seismic source.

In order to implement the program, the analyst has to set the value of two parameters, namely:

RMMN = smallest Richter Magnitude of interest

RMIC = Richter Magnitude increment

The parameter (RMMN) in normally taken as 3.0, since it is considered that earthquakes with magnitudes less than three have none or very little effect on structures. Events having magnitudes less than RMMN are automatically disregarded by the program and hence excluded as direct input for the analysis.

The parameter RMIC is normally defined as 0.25, since in practice magnitudes are rounded off to the closest multiple of 1/4. The program will automatically divide the Richter Magnitude scale in bands of width RMIC starting at RMMN and construct a histogram with the number of earthquakes in each Richter Magnitude band. The next step is to obtain a cumulative histogram of the number of events of magnitude greater or equal to any given magnitude band and through linear regression analysis to fit a straight line on the cumulative histogram. The two sets of variables of the regression are thus the Richter Magnitude band and the number of events of magnitude greater or equal to the corresponding band width.

If the data connot be represented by one straight line, the program allows for a bilinear fit. This is done by assigning as an input a breaking point magnitude RMBK. The data is then treated as two separate sets; all the points of magnitude smaller or equal to RMBK on one hand and all the points larger or equal to RMBK on the other. The intersection between the two lines (real breaking point magnitude) is computed by the program.

How to incorporate the results as produced by program REGRESSION.ANALYSIS to the seismic hazard model (Classical or Bayesian) will be presented in a later chapter. However, it is necessary at this stage of the analysis to make a few comments on the parameter alpha (α) (see Eq. 6.1), since its final form depends on the seismic hazard model to be selected by the analyst.

If the Classical model (III-1, Figure 1-2) is to be used, the coefficient α as obtained from the log-linear fit is normalized with respect to time (time period of the data for a given source) and length or area of the source.

If the Bayesian model (III-1, Fig. 1-2) is to be used, normalization of the coefficient α is not necessary.

Program REGRESSION.ANALYSIS possesses other useful optional capabilities. It can be used for regression analysis between any pair of variables (one dependent and one independent). The linear scale is used for the independent variable (X) and the logarithmic scale is used for the dependent variable (Y), the program can also be used to obtain the cumulative distribution function (CDF) for Richter Magnitude, necessary for the implementation of program GENER.MAGNITUDE (Chapter IV). These options can be specified by setting certain parameters to 1 in the input data deck.

If a linear-linear regression analysis is needed, the program may be used after making the following modifications to the present version (see Appendix C for program's listing).

Line	Present Form	Modified Form
222	Y(IX) = ALOG(YY(IX))	Y(IX) = YY(IX)
294	XX1 = EXP(ALPHA(IR) + BETA(IR)*3.)	XX1 = ALPHA(IR) + BETA(IR)*3.
295	XX2 = EXP(ALPHA(IR) + BETA(IR)*5.)	XX2 = ALPHA(IR) + BETA(IR)*5.
296	XX3 = EXP(ALPHA(IR) + BETA(IR)*6.)	XX3 = ALPHA(IR) + BETA(IR)*6.
297	XX4 = EXP(ALPHA(IR) + BETA(IR)*7.)	XX4 = ALPHA(IR) + BETA(IR)*7.

In its present form, the program can handle up to 2500 earthquake records when used to compute the recurrence relationship between Richter Magnitude and cumulative number of events. If used as a general purpose program for regression analysis between any pair of variables, the array dimensions have been set arbitrarily to a maximum number of 50 values of X and Y. If confidence levels are needed, the program can handle up to 5 different intervals at one time.

The present version has been divided into a main routine plus one library subprogram. It contains 217 executable FORTRAN statements. The space requirement is approximately 18180 bytes.

6.3 Description of Input Data

Input data for program REGRESSION.ANALYSIS will consist of six sets of cards. The organization of data on each card, along with a description of the items, is given in the following section.

I--Record data format--(20A4)--One card

Col. 1-80	FMT	(Format enclosed in parentheses to read X and Y variables or Richter Magnitude; see V and VI below)

II--Analysis Parameters--(4F10.0, 6I5)--One card

Col. 1-10	RMMN	(Smallest Richter Magnitude of interest, input as zero if program is to be used for general purpose regression analysis)
11-20	RMIC	(Richter Magnitude increment to be used for histogram computation)
21-30	RMBK	(Breakoff magnitude--if input as zero, only one line will be fitted to the data)
31-40	T	(Time period of the earthquake data--input different from zero only if normalization of alpha (α) is required.)
41-45	INDV	(Logical unit number from where the data will be read, e.g., card reader = 5)
46-50	SKIPCD	If = 1, both X and Y values are read, indicating that the program will be used for general purpose regression analysis.

		If = 0, only X is input (as RM), Y is automatically computed from histogram.
51-55	SKIPRG	If = 0, the regression analysis will be executed. If = 1, the regression analysis will not be executed and only the histogram will be computed.
56-60	SKIPDZ	If = 0, the intervals (as defined by RMIC above) with no event, will not be considered in regression analysis. If = 1, all intervals will be considered--use this for earthquake recurrence relationship.
61-65	NBCNF	Number of confidence intervals to be computed, 5 maximum per recurrence relationship

III--<u>Confidence levels</u>--(8F10.2)--One card (read only if NBCNF ≠ 0)

Col. 1-50	CNF	Confidence levels (5 maximum per recurrence relation)

IV--<u>Run identification</u>--(4A4, I4, 2F10.0)--One card

Col. 1-16	HED2	Heading
17-20	NBRCTT	Number of records to be read
21-30	A	Length or area of seismic source. Input different from zero only if alpha (α) is to be normalized.

V--<u>X and Y values</u>--(FMT)--NBRCTT number of cards

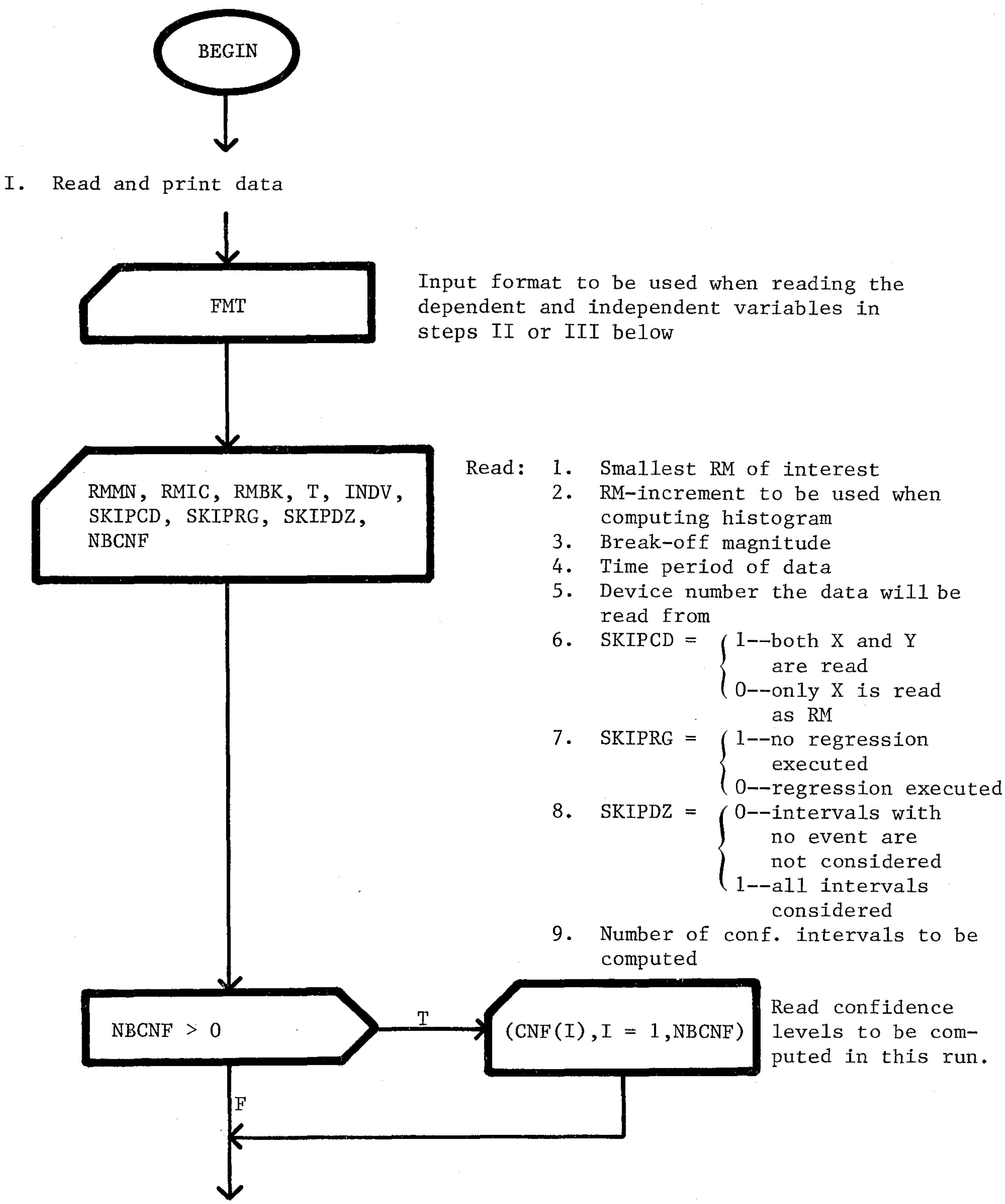
Col. --	X	Independent variable	Only if SKIPCD = 1
--	Y	Dependent variable	

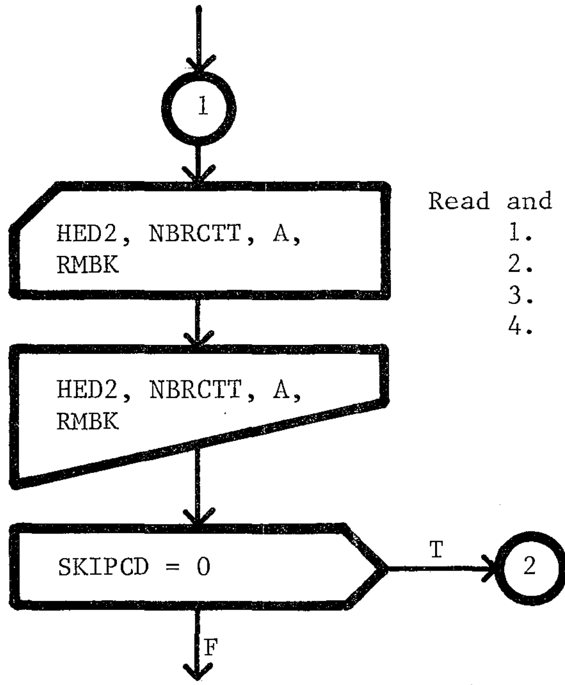
VI--<u>RM-Richter Magnitude values</u> (FMT)--NBRCTT number of cards

Col. --	RM	Independent variable {Richter Magnitude} (Only if SKIPCD = 0)

NOTE: Several data sets can be processed in one run by repeating the input sequence described above starting at data set III.

6.4 Macro Flow Chart for Program REGRESSION.ANALYSIS



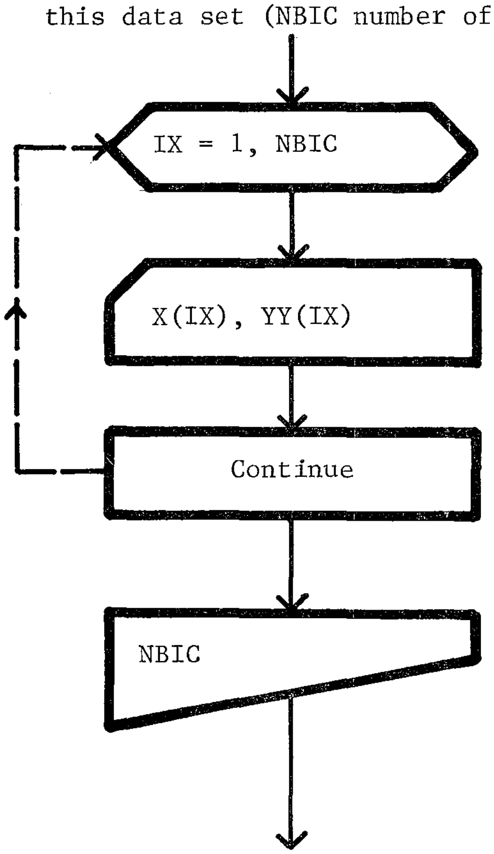


Read and write:

1. Heading information for this run
2. Number of records to be read
3. Length or area of source
4. Break-off magnitude

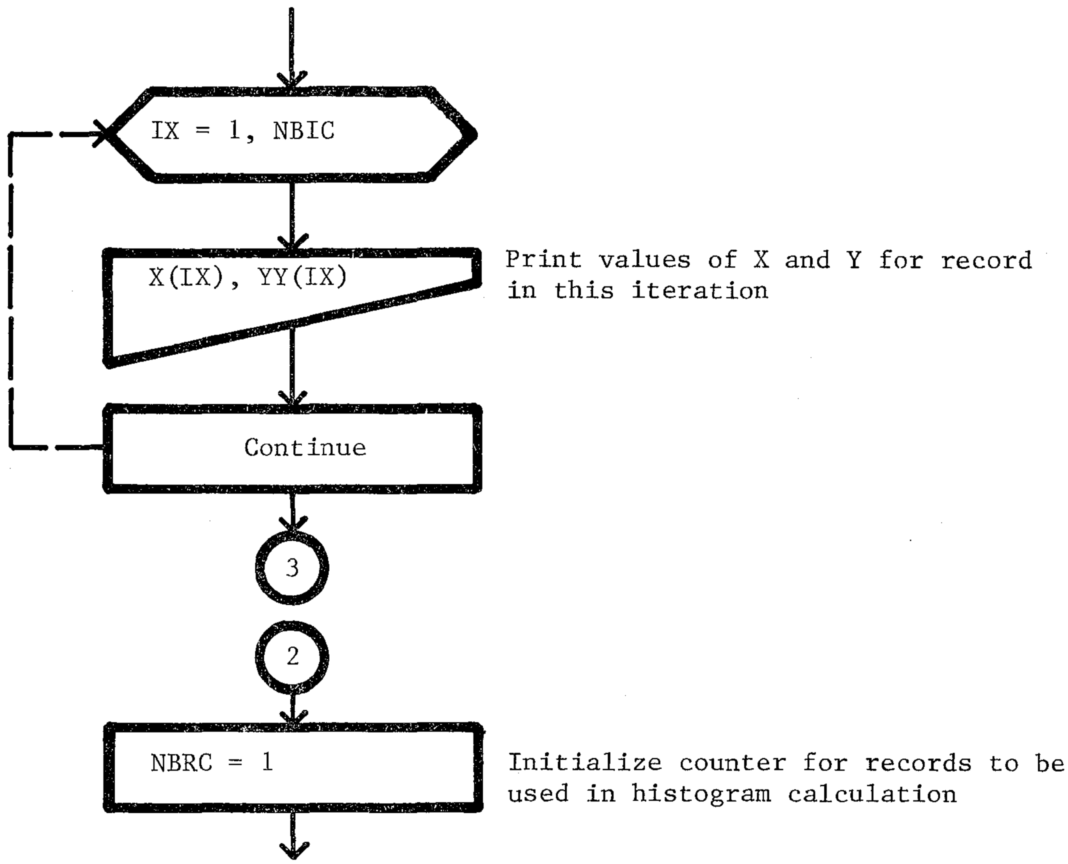
Read only the independent variable X (RM), the dependent variable Y (N) will be computed from histogram.

II. Iterations on the number of records for this data set (NBIC number of records)

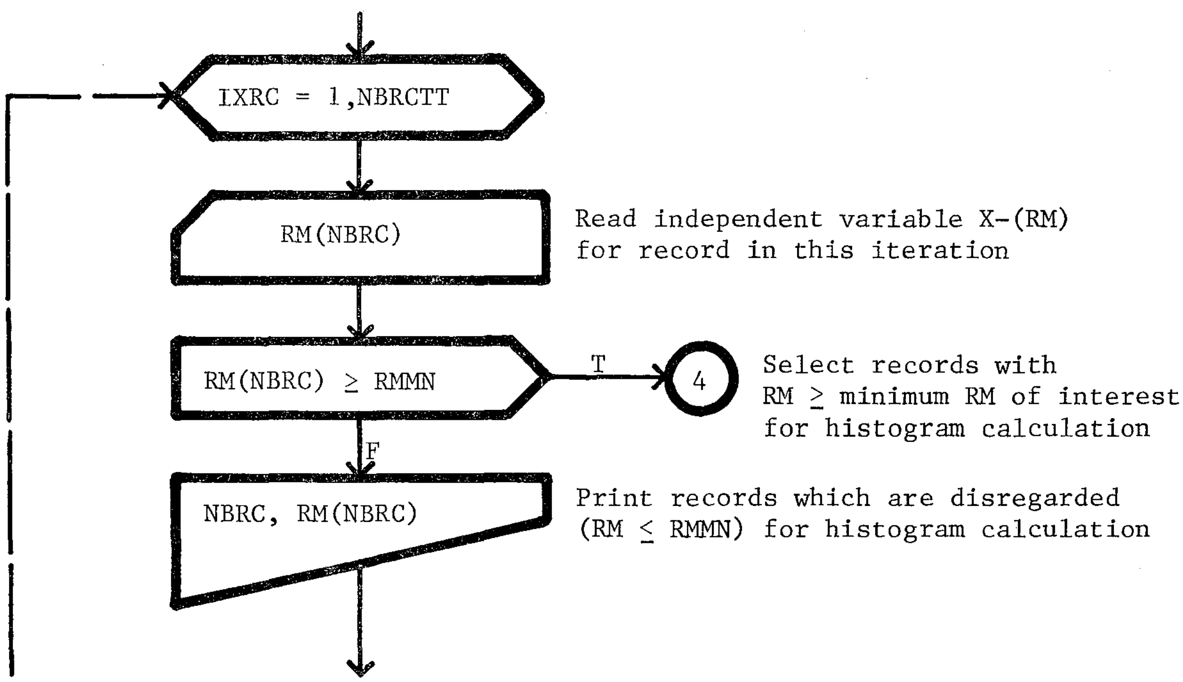


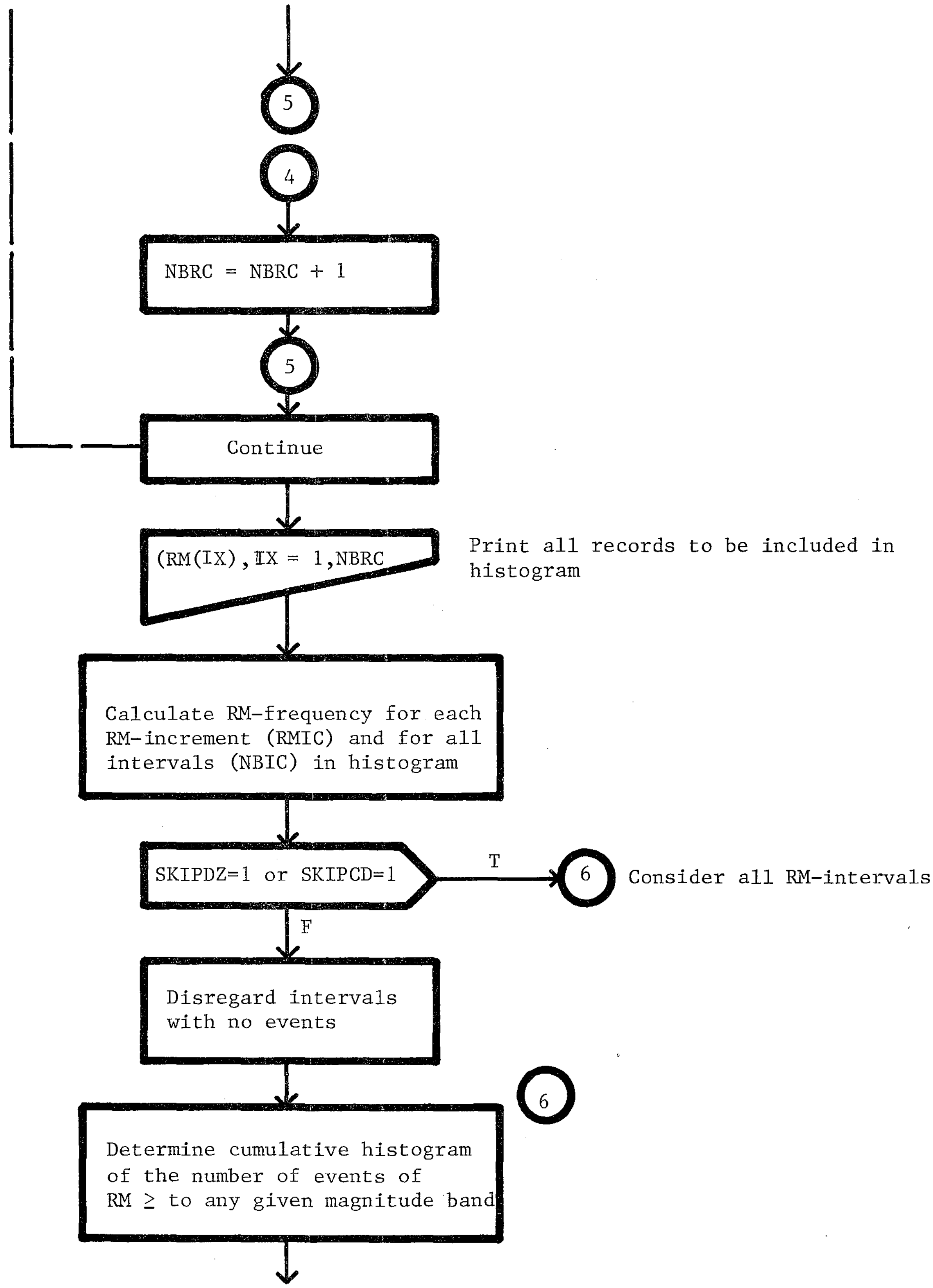
Read independent and dependent variables for record in this iteration.

Print the number of records in this data set

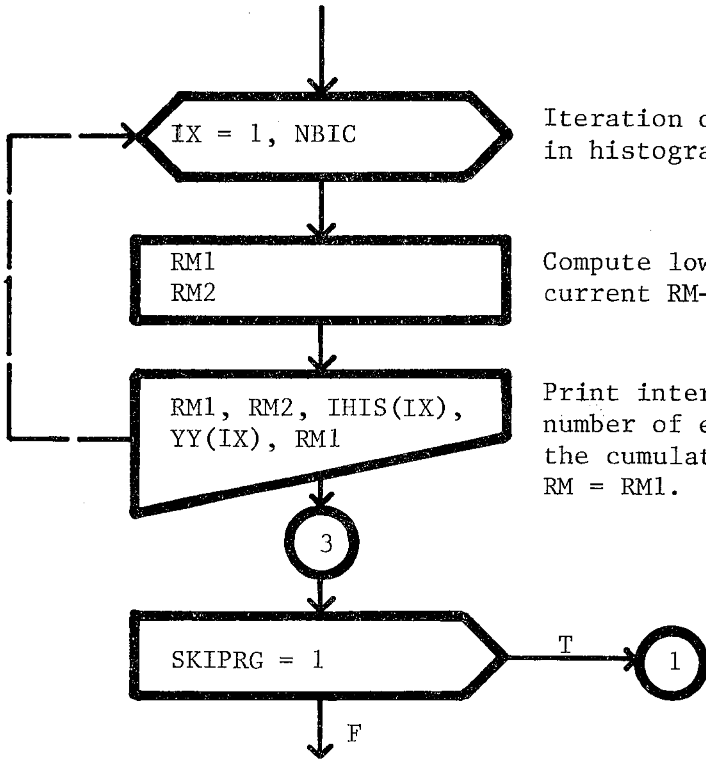


III. Iteration on the number of records for this data set (NBRCTT records) SKIPCD has been read as zero.





5
4
NBRC = NBRC + 1
5
Continue
(RM(IX),IX = 1,NBRC
Print all records to be included in histogram
Calculate RM-frequency for each RM-increment (RMIC) and for all intervals (NBIC) in histogram
SKIPDZ=1 or SKIPCD=1
T
6
Consider all RM-intervals
F
Disregard intervals with no events
6
Determine cumulative histogram of the number of events of RM ≥ to any given magnitude band



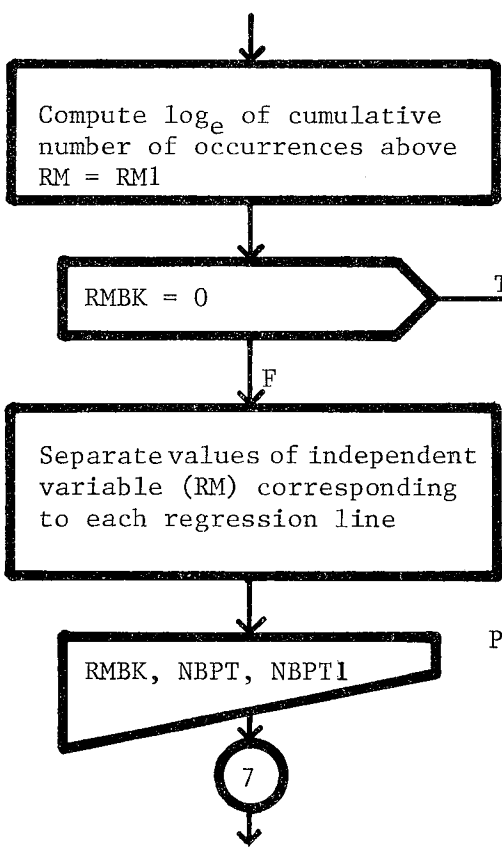
Iteration on the number of intervals in histogram

Compute lower and upper limits for current RM-interval

Print interval's lower and upper limits, number of events contained in interval and the cumulative number of occurrences above RM = RM1.

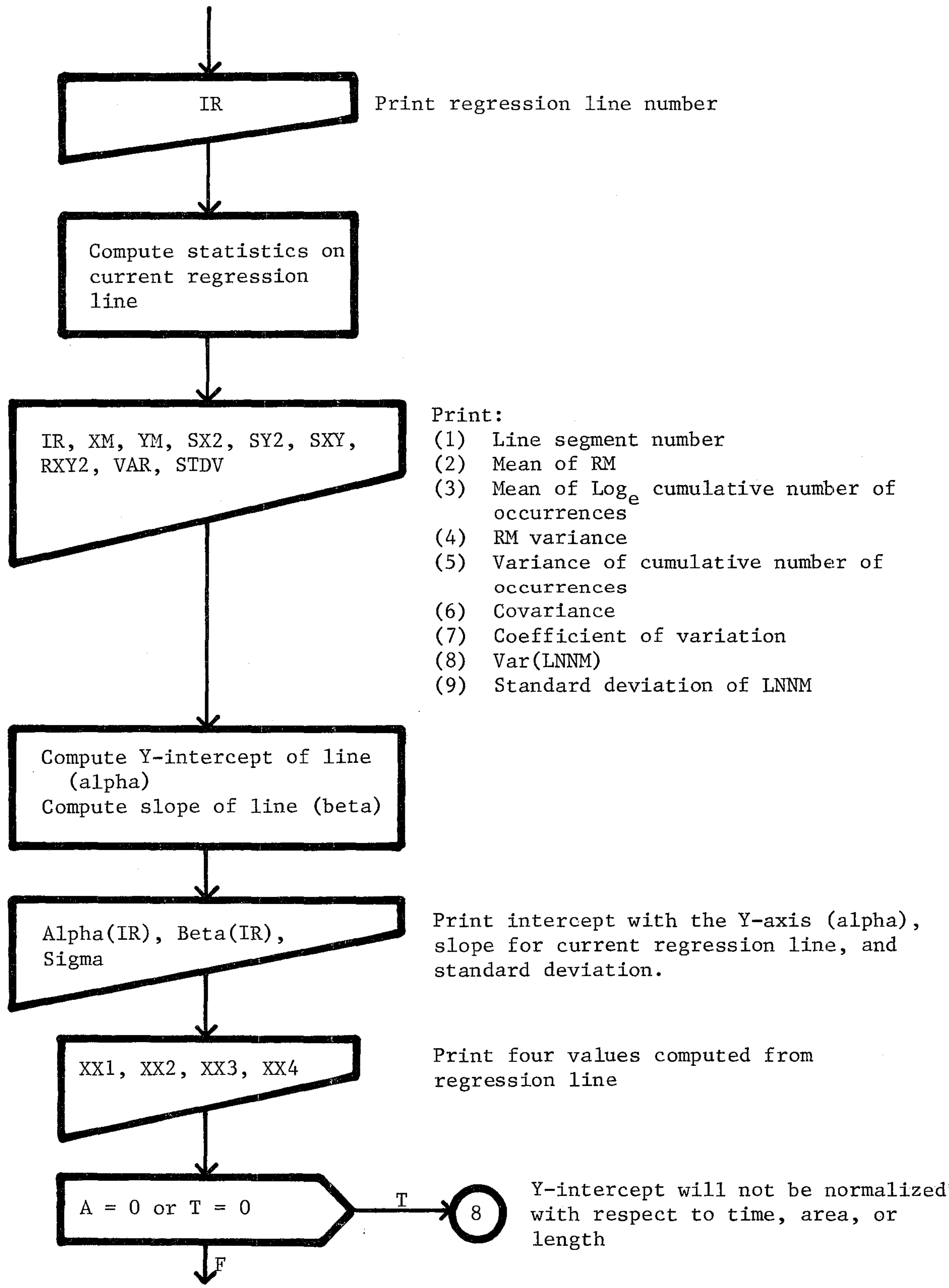
No regression analysis will be executed, check for more data sets. If none, end of execution.

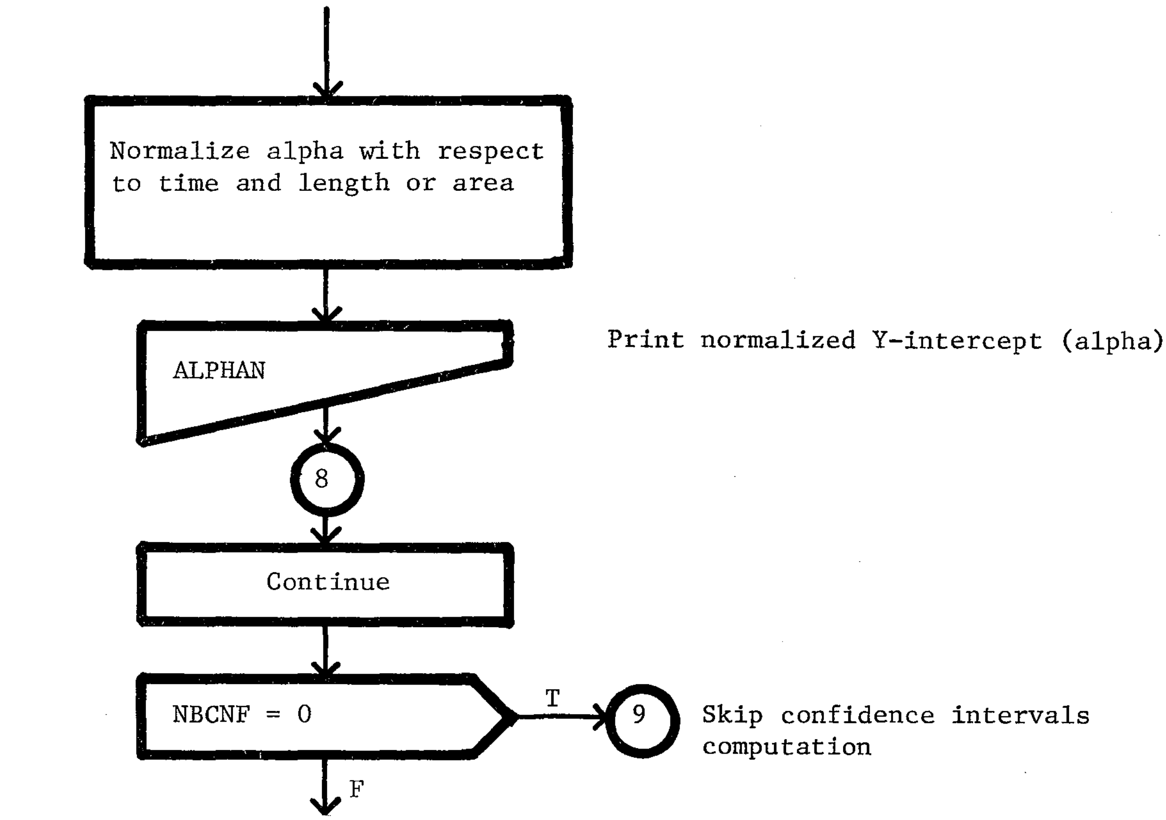
IV. Regression analysis



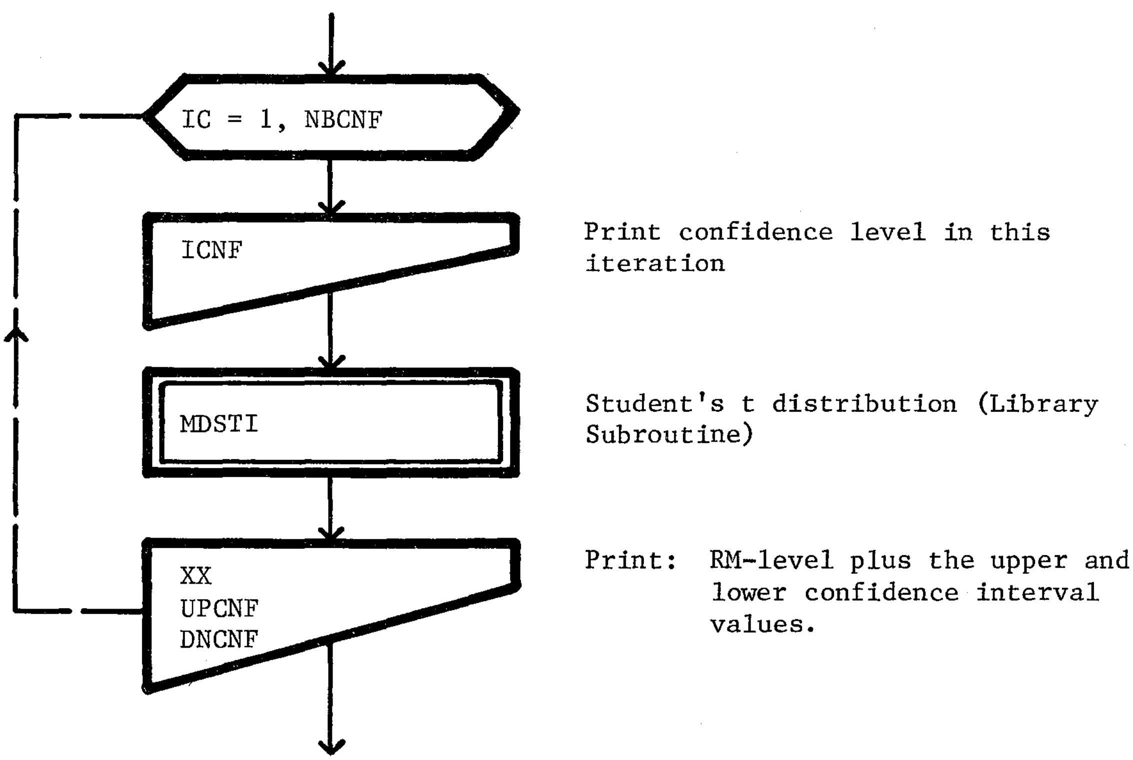
Only one regression line will be fitted through the data

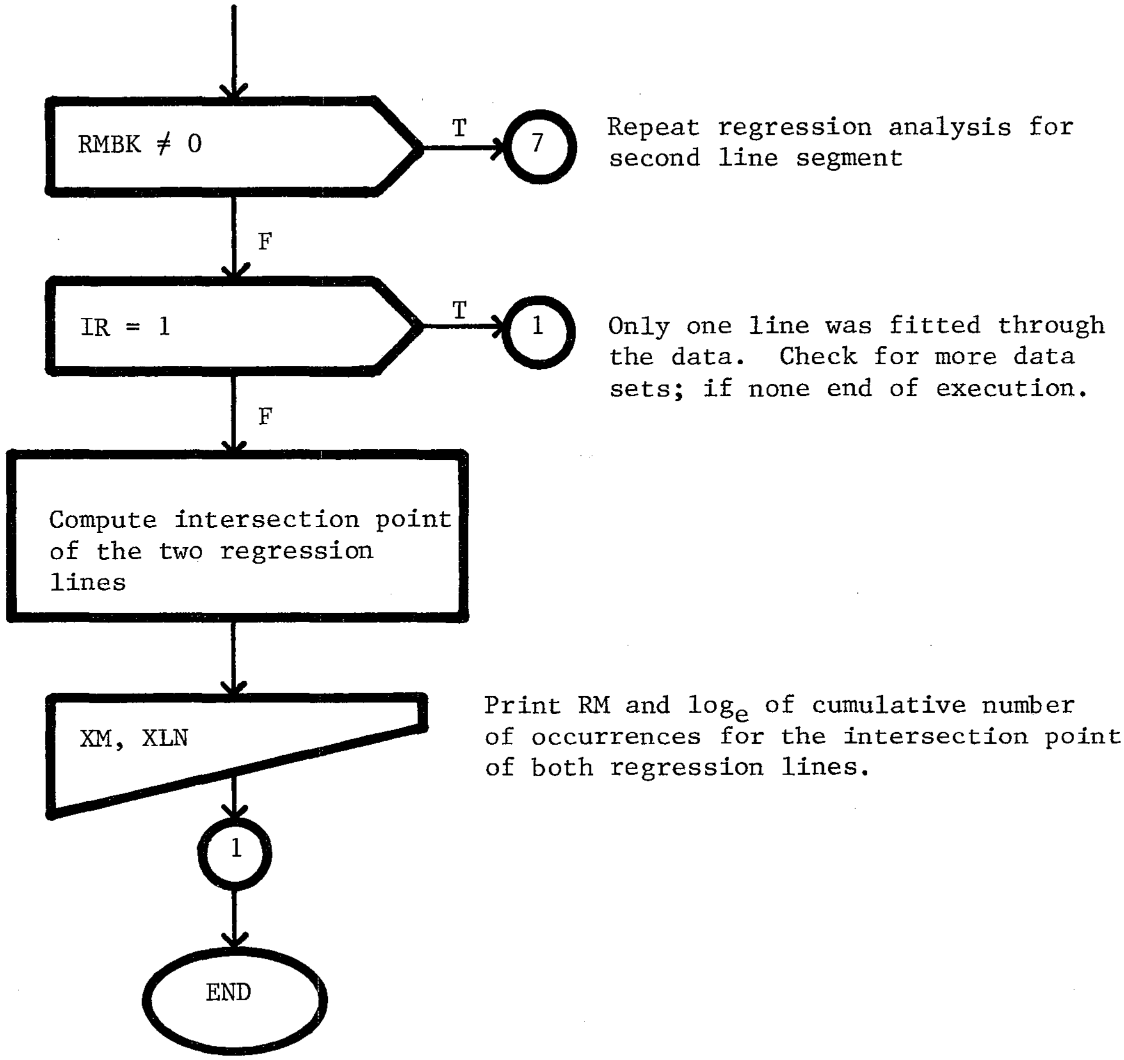
Print:
1. Breakpoint magnitude
2. Number of RM intervals for line 1
3. Number of RM intervals for line 2


IR
Print regression line number
Compute statistics on current regression line
IR, XM, YM, SX2, SY2, SXY, RXY2, VAR, STDV
Print:
(1) Line segment number
(2) Mean of RM
(3) Mean of Log_e cumulative number of occurrences
(4) RM variance
(5) Variance of cumulative number of occurrences
(6) Covariance
(7) Coefficient of variation
(8) Var(LNNM)
(9) Standard deviation of LNNM
Compute Y-intercept of line (alpha)
Compute slope of line (beta)
Alpha(IR), Beta(IR), Sigma
Print intercept with the Y-axis (alpha), slope for current regression line, and standard deviation.
XX1, XX2, XX3, XX4
Print four values computed from regression line
A = 0 or T = 0
T
8
Y-intercept will not be normalized with respect to time, area, or length
F



V. Iteration on the number of confidence levels for this data set (NBCNF)




RMBK ≠ 0
T
7
Repeat regression analysis for second line segment
F
IR = 1
T
1
Only one line was fitted through the data. Check for more data sets; if none end of execution.
F
Compute intersection point of the two regression lines
XM, XLN
Print RM and log$_e$ of cumulative number of occurrences for the intersection point of both regression lines.
1
END

6.5 Sample Problems

6.5.1 Sample Problem No. 1

Obtain the recurrence relationship (Eq. 6.1) for a seismic source with 18 epicenters associated to it. Figure 6-1 shows the listing of the events (recorded for a time period of 125 years) in chronological order. The following assumptions will be made for this particular case, namely:

1) The parameter alpha (α) in Eq. 6.1 will not be normalized with respect to time nor area or length of the seismic source.

2) A minimum Richter Magnitude level (RMMN--data set II) equal to 3.00 will be used in the analysis.

3) A Richter Magnitude increment (RMIC--see data set II) equal to 0.20 will be used to compute the cumulative histogram.

4) As a first trial, (RMBK--breaking point magnitude, see data set II) will be set equal to zero assuming that only one regression line will represent the data in good approximation.

5) A Cutoff Magnitude (obtained from geological information) equal to 6.5 is given for the source. The computation of a 90% confidence interval is required.

Figure 6-3 shows the output for program REGRESSION.ANALYSIS (sample problem No. 1) where:

NBRC = number of earthquake records used in the analysis.

AREA = area or length of the seismic source under consideration (shown as zero since normalization of alpha is not required).

RMBK = breakoff magnitude

X-Mean = mean of independent variable (RM in this case).

Y-Mean = mean of dependent variable (number of earthquakes in this case--log scale).

EARTHQUAKE DATA IN CHRONOLOGICAL ORDER

SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	LATITUDE	LONGITUDE	CLASS	MMI	RADIUS	DEPTH	MS	MB	MR1	MR2	SYMBOL
A.GRAN	17	12	1850	12	30	36.500N	07.400E		6.5					4.61	4.61	I
A.GRAN	17	06	1908	00	24	36.500N	07.500E		7.5					5.25	5.25	I
A.GRAN	04	08	1908	02	11	36.400N	06.600E	D	8.0					5.10	5.10	
A.GRAN	03	12	1928	05	30	36.400N	07.200E	D						5.00	5.00	
A.GRAN	10	02	1937	18	16	36.400N	07.500E	D	9.0					5.40	5.40	
A.GRAN	06	08	1947	09	46	36.300N	06.667E	D	8.5					5.30	5.30	
A.GRAN	27	10	1947	10	29	37.600N	08.500E	D	5.5						5.40	L
A.GRAN	22	11	1950	02	43	36.100N	07.200E	E	5.0						4.10	L
A.GRAN	01	04	1952	04	21	36.500N	07.300E	E	6.0					4.50	4.50	
A.GRAN	12	04	1952	16	23	36 500N	07.300E	E	5.5					4.20	4.20	
A.GRAN	23	05	1956	06	37	36.400N	07.300E	E	7.5						5.00	L
A.GRAN	26	06	1956	01	50	36.000N	08.100E	E	7.0						4.15	L
A.GRAN	02	09	1958	12	26	36.500N	07.400E	F	5.0						3.55	L
A.GRAN	14	11	1959	16	10	36.400N	07.500E	F	4.5						3.05	L
A.GRAN	05	03	1960	04	18	36.600N	07.100E	F	5.5						4.00	L
A.GRAN	02	12	1961	12	40	36.500N	08.200E							5.50	5.50	
A.GRAN	14	03	1963	12	25	36.200N	06.100E	E	7.0						4.40	L
A.GRAN	14	04	1967	23	44	36 500N	07.800E	E						4.30	4.30	

Figure 6-1

Figure 6-2 shows a listing of the data deck for sample problem Number 1. Each data set as described in Section 6.2 is indicated with the corresponding item number.

INPUT DATA FOR PROGRAM REGRESSION ANALYSIS (SAMPLE PROBLEM 1)

```
(72X,F3.2) ------------------------------------------------------------------------- I
   3.0      .2        0.        125.     5    0    0    1    1 -------------------- II
0.9 ------------------------------------------------------------------------------- III
SAMPLE PROBLEM 1  18 -------------------------------------------------------------- IV
A.GRAN 17 12 1850 12 30 36.500N 07.400E   6.5                  4.61     4.61 I --+
A.GRAN 17 06 1908 00 24 36.500N 07.500E   7.5                  5.25     5.25 I   |
A.GRAN 04 08 1908 02 11 36.400N 06.600E D 8.0                  5.10     5.10     |
A.GRAN 03 12 1928 05 30 36.400N 07.200E D                      5.00     5.00     |
A.GRAN 10 02 1937 18 16 36.400N 07.500E D 9.0                  5.40     5.40     |
A.GRAN 06 08 1947 09 46 36.300N 06.667E D 8.5                  5.30     5.30     |
A.GRAN 27 10 1947 10 29 37.600N 08.500E D 5.5                           5.40 L   |
A.GRAN 22 11 1950 02 43 36.100N 07.200E E 5.0                           4.10 L   |    VI
A.GRAN 01 04 1952 04 21 36.500N 07.300E E 6.0                  4.50     4.50     |
A.GRAN 12 04 1952 16 23 36 500N 07.300E E 5.5                  4.20     4.20     |
A.GRAN 23 05 1956 06 37 36.400N 07.300E E 7.5                           5.00 L   |
A.GRAN 26 06 1956 01 50 36.000N 08.100E E 7.0                           4.15 L   |
A.GRAN 02 09 1958 12 26 36.500N 07.400E F 5.0                           3.55 L   |
A.GRAN 14 11 1959 16 10 36.400N 07.500E F 4.5                           3.05 L   |
A.GRAN 05 03 1960 04 18 36.600N 07.100E F 5.5                           4.00 L   |
A.GRAN 02 12 1961 12 40 36.500N 08.200E                        5.50     5.50     |
A.GRAN 14 03 1963 12 25 36.200N 06.100E E 7.0                           4.40 L   |
A.GRAN 14 04 1967 23 44 36 500N 07.800E E                      4.30     4.30 ----+
```

Figure 6-2

OUTPUT FOR PROGRAM REGRESSION ANALYSIS (SAMPLE PROBLEM 1)

Figure 6-3

```
REGRESSION ANALYSIS
LINEAR-LN SCALE      NBRC    AREA      RMBK
SAMPLE PROBLEM 1      18     0.0       0.0

NUMBER OF RECORDS INCLUDED     18
AREA                 0.0
TIME (YEARS)       125.00
MINIMUM MAGNITUDE                3.00
MAGNITUDE INCREMENT FOR CDF      0.20
EARTHQUAKE MAGNITUDES
      4.60      5.20      5.10      5.00      5.40      5.30      5.40      4.10      4.50      4.20      5.00      4.10
      3.50      3.00      4.00      5.50      4.40      4.30
       RM        INTERVAL            CUMULATIVE FREQUENCY
     INTERVAL    FREQUENCY           OCCURRENCES ABOVE RM

   3.00 - 3.19      1                   18.          3.00
   3.20 - 3.39      0                   17.          3.20
   3.40 - 3.59      1                   17.          3.40
   3.60 - 3.79      0                   16.          3.60
   3.80 - 3.99      0                   16.          3.80
   4.00 - 4.19      3                   16.          4.00
   4.20 - 4.39      2                   13.          4.20
   4.40 - 4.59      2                   11.          4.40
   4.60 - 4.79      1                    9.          4.60
   4.80 - 4.99      0                    8.          4.80
   5.00 - 5.19      3                    8.          5.00
   5.20 - 5.39      2                    5.          5.20
   5.40 - 5.59      3                    3.          5.40
INTERCEPT AND SLOPE OF LINE     1
 STATISTICS FORM REGRESSION LINE SEGMENT =  1
X-MEAN=    4.19999    Y-MEAN=    2.37704     XVAR=     0.56004     YVAR=     0.27831
COVARXY=   -0.36135     COEFF. OF VAR.=    0.83776     VAR(LNNM)=    0.05336     STDV(LNNM)=    0.23100

ALPHA  5.086987
BETA  -0.645227
INTERCPT AT 3.         5.        6.        7.
        23.36659   6.42923   3.37241   1.76898
   90 %  CONFIDENCE INTERVALS

 CONF. VALUE=     2.20098     ERROR INDIC.=     0

X =         3.000     3.200     3.400     3.600     3.800     4.000     4.200     4.400     4.600     4.800
UPCNF=     30.502    25.987    22.190    19.009    16.363    14.183    12.404    10.957     9.765     8.764
DNCNF=     17.900    16.231    14.685    13.243    11.885    10.592     9.356     8.183     7.093     6.105
X =         5.000     5.200     5.400
UPCNF=      7.903     7.150     6.483
DNCNF=      5.230     4.466     3.805
```

XVAR = variance of independent variable.

YVAR = variance of dependent variable

COVARXY = covariance

VAR(LNNM) = variance of the $\log_e$ {cumulative number of occurrences}.

STDV(LNNM) = standard deviation of {cumulative number of occurrences}.

CONF.VALUE = value of t-student's distribution as computed by library subprogram (see Macro Flow Chart).

UPCNF = value of upper confidence interval for a given RM.

DNCNF = value of lower confidence interval for a given RM.

The rest of the terms shown in Figure 6-3 and the output itself is self-explanatory. Figure 6-4 is a plot of the recurrence relationship and confidence interval obtained. Note that the regression line has been extended beyond the last data point in order to intercept the cutoff magnitude line.

6.5.2 Sample Problem No. 1 (Part 2)

In Sample Problem No. 1 (see page 73), the value of the parameter RMBK (breakoff magnitude) was defined as zero in the input data, implying a one line fit to the data. It can be observed from Figure 6-4 that one regression line does not represent the data well since for the magnitude range between 4.0 and 5.0 the cumulative number of occurrences is underestimated and beyond Richter Magnitude = 5.0, it is overestimated. Therefore, it seems reasonable to run a second trial, this time with the parameter RMBK = 4.20, implying a bi-linear fit. The rest of the input data (Figure 6-2) will remain the same, except that this time no confidence interval will be required. Figure 6-5 shows the updated listing of the input data deck.

Figure 6-6 shows the output for program REGRESSION. ANALYSIS (Sample Problem No. 1, Part 2). This time, two sets of values regarding regression

Figure 6-4 Recurrence Relationship for Seismic Source (Sample Problem No. 1)

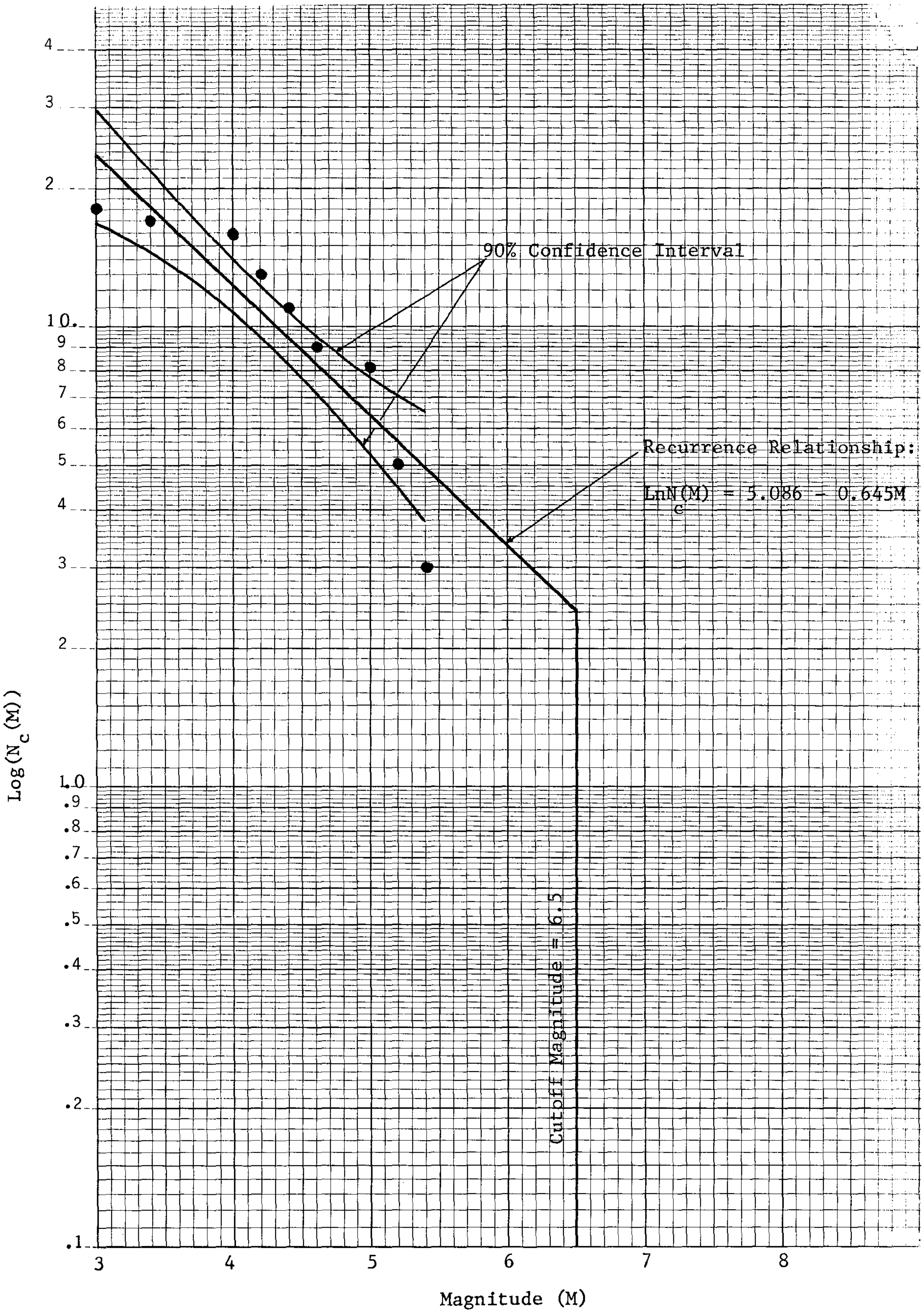


Figure 6-5

INPUT DATA FOR PROGRAM REGRESSION ANALYSIS (SAMPLE PROBLEM 1-PART 2)

```
(72X,F3.2) ------------------------------------------------------------------ I
   3.0       .20        4.2          125.       5    0    0    1    0 ------- II
SAMPLE PROBLEM 1  18 -------------------------------------------------------- IV
A.GRAN 17 12 1850 12 30 36.500N 07.400E   6.5                4.61     4.61 I -+
A.GRAN 17 06 1908 00 24 36.500N 07.500E   7.5                5.25     5.25 I  |
A.GRAN 04 08 1908 02 11 36.400N 06.600E D 8.0                5.10     5.10    |
A.GRAN 03 12 1928 05 30 36.400N 07.200E D                    5.00     5.00    |
A.GRAN 10 02 1937 18 16 36.400N 07.500E D 9.0                5.40     5.40    |
A.GRAN 06 08 1947 09 46 36.300N 06.667E D 8.5                5.30     5.30    |
A.GRAN 27 10 1947 10 29 37.600N 08.500E D 5.5                         5.40 L  |
A.GRAN 22 11 1950 02 43 36.100N 07.200E E 5.0                         4.10 L  | VI
A.GRAN 01 04 1952 04 21 36.500N 07.300E E 6.0                4.50     4.50    |
A.GRAN 12 04 1952 16 23 36 500N 07.300E E 5.5                4.20     4.20    |
A.GRAN 23 05 1956 06 37 36.400N 07.300E E 7.5                         5.00 L  |
A.GRAN 26 06 1956 01 50 36.000N 08.100E E 7.0                         4.15 L  |
A.GRAN 02 09 1958 12 26 36.500N 07.400E F 5.0                         3.55 L  |
A.GRAN 14 11 1959 16 10 36.400N 07.500E F 4.5                         3.05 L  |
A.GRAN 05 03 1960 04 18 36.600N 07.100E F 5.5                         4.00 L  |
A.GRAN 02 12 1961 12 40 36.500N 08.200E                      5.50     5.50    |
A.GRAN 14 03 1963 12 25 36.200N 06.100E E 7.0                         4.40 L  |
A.GRAN 14 04 1967 23 44 36 500N 07.800E E                    4.30     4.30 ---+
```

OUTPUT FOR PROCRAM REGRESSION ANALYSIS (SAMPLE PROBLEM 1-PART B)

Figure 6-6

```
REGRESSION ANALYSIS
LINEAR-LN SCALE      NBRC    AREA      RMBK
SAMPLE PROBLEM 1      18     0.0      4.200

NUMBER OF RECORDS INCLUDED    18
AREA                  0.0
TIME (YEARS)        125.00
MINIMUM MAGNITUDE                3.00
MAGNITUDE INCREMENT FOR CDF      0.20
EARTHQUAKE MAGNITUDES
      4.60      5.20      5.10      5.00      5.40      5.30      5.40      4.10      4.50      4.20      5.00      4.10
      3.50      3.00      4.00      5.50      4.40      4.30
       RM       INTERVAL          CUMULATIVE FREQUENCY
     INTERVAL     FREQUENCY          OCCURRENCES ABOVE RM

   3.00 - 3.19      1                  18.         3.00
   3.20 - 3.39      0                  17.         3.20
   3.40 - 3.59      1                  17.         3.40
   3.60 - 3.79      0                  16.         3.60
   3.80 - 3.99      0                  16.         3.80
   4.00 - 4.19      3                  16.         4.00
   4.20 - 4.39      2                  13.         4.20
   4.40 - 4.59      2                  11.         4.40
   4.60 - 4.79      1                   9.         4.60
   4.80 - 4.99      0                   8.         4.80
   5.00 - 5.19      3                   8.         5.00
   5.20 - 5.39      2                   5.         5.20
   5.40 - 5.59      3                   3.         5.40
TWO STRAIGHT LINES WILL BE USED TO FIT THE DATA
BREAK POINT MAGNITUDE    4.20
    7 POINTS IN THE FIRST LINE
    7 POINTS IN THE SECOND LINE
INTERCEPT AND SLOPE OF LINE    1
 STATISTICS FORM REGRESSION LINE SEGMENT =  1
X-MEAN=     3.59999     Y-MEAN=     2.77707     XVAR=     0.16003     YVAR=     0.00918
COVARXY=    -0.03307     COEFF. OF VAR.=     0.74502     VAR(LNNM)=     0.00328     STDV(LNNM)=     0.05723

ALPHA  3.521115
BETA  -0.206679
INTERCPT AT 3.         5.        6.         7.
        18.19374  12.03380   9.78686   7.95946
INTERCEPT AND SLOPE OF LINE    2
 STATISTICS FORM REGRESSION LINE SEGMENT =  2
X-MEAN=     4.79999     Y-MEAN=     2.00386     XVAR=     0.16003     YVAR=     0.21342
COVARXY=    -0.17410     COEFF. OF VAR.=     0.88750     VAR(LNNM)=     0.03361     STDV(LNNM)=     0.18334

ALPHA  7.225788
BETA  -1.087904
INTERCPT AT 3.         5.        6.         7.
        52.56635   5.96714   2.01046   0.67737
INTERSECTION POINT
MAGNITUDE     4.20
LN OF N       2.65
```

coefficients for Lines 1 and 2 are presented. The last two lines of output represent the coordinates of the real breakpoint magnitude as computed by the program.

Figure 6-7 shows the new bi-linear recurrence relationship for the seismic source under consideration. As it can be observed, the approximation obtained with two lines is better than with one.

6.5.3 Sample Problem No. 2

This example will illustrate the application of program REGRESSION.ANALYSIS in computing the histogram of number of events versus Richter Magnitude necessary for the construction of a CDF on magnitude and for the implementation of program GENER.MAGNITUDE (discussed previously in Chapter IV).

In order to use program REGRESSION.ANALYSIS for this purpose, one of the program's optional capabilities will be set by declaring the parameters SKIPCD (see data set II) equal to zero, and SKIPRG (see data set II) equal to 1 in the input data deck.

The earthquake records selected for this example are listed in Figure 6-8. Only seismic events containing Richter Magnitude values between 3.0 and 5.0 have been included. The reasons for doing this are as follows:

1) Earthquakes with Richter Magnitude levels below 3.0 are considered to have practically no effect on damage to structures and hence these will be disregarded for the analysis.

2) Richter Magnitude = 5.0 has been selected as an upper limit, based on the assumption that any large event would be thoroughly documented, implying that only small events may be missing magnitude information.

Figure 6-9 shows the listing of the input data deck for this sample problem.

6.5.4 Output for Program REGRESSION.ANALYSIS (Sample Problem No. 2)

Figure 6-10 shows the listing of the output for sample problem No. 2. The program has computed the number of events or frequency for each Richter

Figure 6-7 Recurrence Relationship for Seismic Source--Sample Problem No. 1 Part B.

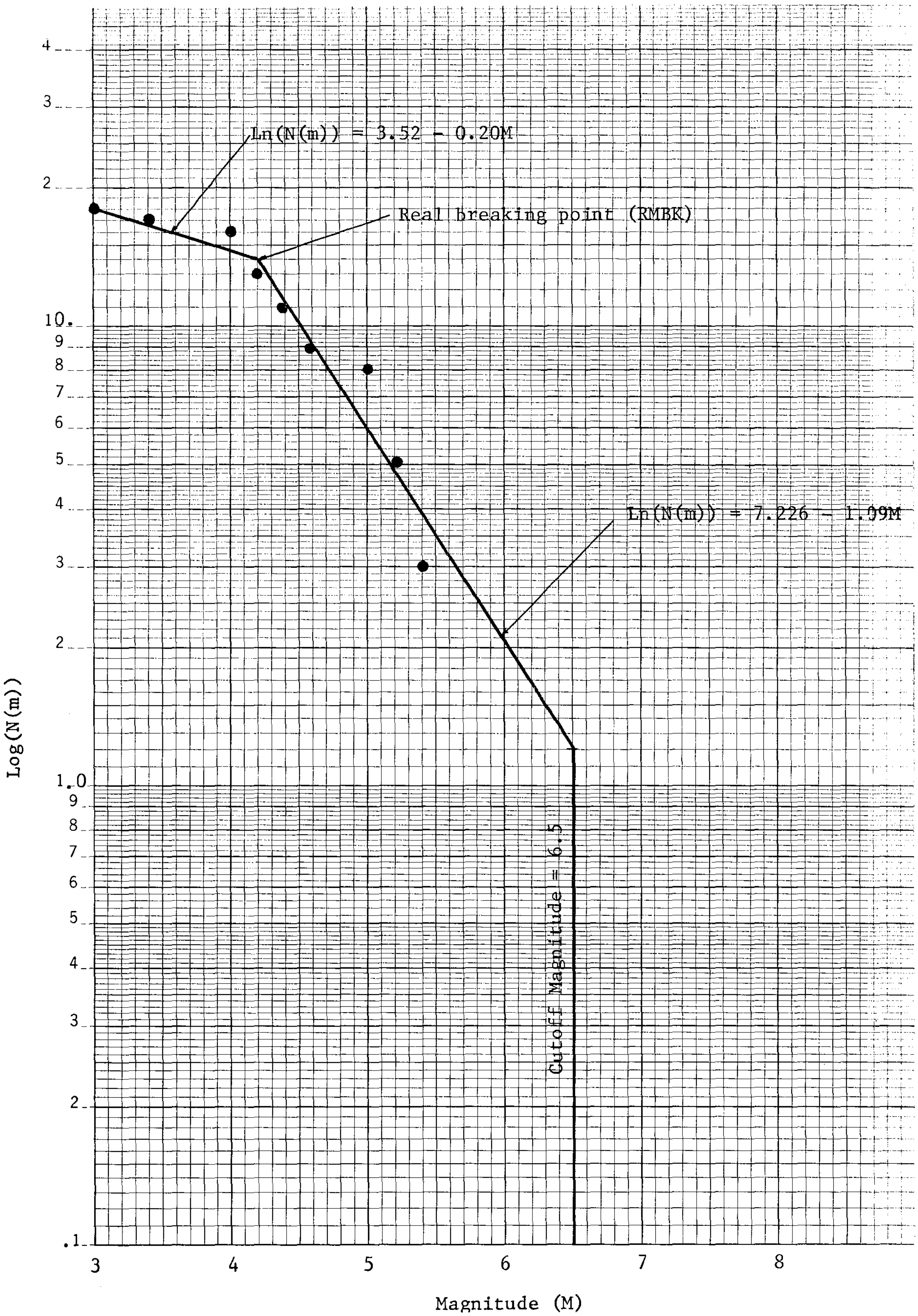


Figure 6-8

EARTHQUAKE DATA IN CHRONOLOGICAL ORDER

SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	LATITUDE	LONGITUDE	CLASS	MMI	RADIUS	DEPTH	MS	MB	MR1	MR2	SYMBOL
A.GRAN	02	03	1900	07	00	32.600N	30.750E							3.50	3.50	
A.GRAN	03	05	1902	05	00	32.500N	30.900E							3.75	3.75	
A.GRAN	05	03	1905	01	00	32.350N	30.900E							4.75	4.75	
A.GRAN	05	03	1912	02	00	32.000N	30.500E							3.25	3.25	
A.GRAN	04	09	1916	01	00	31.600N	30.530E							3.50	3.50	
A.GRAN	08	01	1920	02	30	32.200N	30.700E							3.50	3.50	
A.GRAN	06	08	1921	09	10	31.700N	30.650E							4.50	4.50	
A.GRAN	17	02	1923	08	00	31.050N	32.350E							4.35	4.35	
A.GRAN	16	01	1925	14	00	30.700N	32.700E							3.50	3.50	
A.GRAN	30	11	1925	12	15	31.500N	32.400E							3.50	3.50	
A.GRAN	04	01	1935	15	30	31.450N	31.000E							4.00	4.00	
A.GRAN	10	08	1937	01	15	31.200N	30.900E							3.80	3.80	
A.GRAN	04	12	1940	03	00	31.250N	31.200E							4.10	4.10	
A.GRAN	14	02	1948	01	00	31.250N	32.450E							3.50	3.50	
A.GRAN	13	04	1950	13	30	31.150N	32.600E							3.80	3.80	
A.GRAN	18	11	1951	02	15	31.300N	32.150E							3.75	3.75	
A.GRAN	15	06	1954	06	35	31.100N	32.000E							3.75	3.75	
A.GRAN	02	12	1958	06	15	30.900N	31.800E							3.00	3.00	
A.GRAN	18	01	1960	04	18	30.620N	32.250E							4.50	4.50	
A.GRAN	04	08	1965	09	30	32.000N	30.600E							4.65	4.65	
A.GRAN	01	01	1968	13	14	30.550N	32.570E							3.40	3.40	
A.GRAN	04	10	1969	02	00	30.850N	32.150E							3.15	3.15	
A.GRAN	03	12	1970	10	12	30.350N	32.570E							3.00	3.00	
A.GRAN	12	01	1972	11	05	31.750N	30.900E							4.65	4.65	
A.GRAN	17	03	1972	13	05	30.850N	32.460E							4.50	4.50	
A.GRAN	03	08	1973	08	30	32.400N	30.750E							4.50	4.50	
A.GRAN	08	11	1973	15	00	32.600N	32.750E							3.50	3.50	
A.GRAN	11	05	1975	01	15	31.500N	30.750E							3.50	3.50	
A.GRAN	06	04	1976	05	00	32.150N	30.530E							3.25	3.25	
A.GRAN	01	08	1976	08	12	30.500N	31.250E							3.50	3.50	
A.GRAN	16	10	1976	10	00	31.400N	32.650E							3.65	3.65	
A.GRAN	01	07	1978	03	15	30.500N	32.420E							4.25	4.25	

Figure 6-9

INPUT DATA FOR PROGRAM REGRESSION ANALYSIS (SAMPLE PROBLEM 2)

```
(72X,F3.2) ------------------------------------------------------------------- I
  0.0       .2        0.         78.0      5    0    1    1    0 ------------ II
SAMPLE PROBLEM 2  32 --------------------------------------------------------- IV
A.GRAN 02 03 1900 07 00 32.600N 30.750E                          3.50    3.50
A.GRAN 03 05 1902 05 00 32.500N 30.900E                          3.75    3.75
A.GRAN 05 03 1905 01 00 32.350N 30.900E                          4.75    4.75
A.GRAN 05 03 1912 02 00 32.000N 30.500E                          3.25    3.25
A.GRAN 04 09 1916 01 00 31.600N 30.530E                          3.50    3.50
A.GRAN 08 01 1920 02 30 32.200N 30.700E                          3.50    3.50
A.GRAN 06 08 1921 09 10 31.700N 30.650E                          4.50    4.50
A.GRAN 17 02 1923 08 00 31.050N 32.350E                          4.35    4.35
A.GRAN 16 01 1925 14 00 30.700N 32.700E                          3.50    3.50
A.GRAN 30 11 1925 12 15 31.500N 32.400E                          3.50    3.50
A.GRAN 04 01 1935 15 30 31.450N 31.000E                          4.00    4.00
A.GRAN 10 08 1937 01 15 31.200N 30.900E                          3.80    3.80
A.GRAN 04 12 1940 03 00 31.250N 31.200E                          4.10    4.10
A.GRAN 14 02 1948 01 00 31.250N 32.450E                          3.50    3.50
A.GRAN 13 04 1950 13 30 31.150N 32.600E                          3.80    3.80      VI
A.GRAN 18 11 1951 02 15 31.300N 32.150E                          3.75    3.75
A.GRAN 15 06 1954 06 35 31.100N 32.000E                          3.75    3.75
A.GRAN 02 12 1958 06 15 30.900N 31.800E                          3.00    3.00
A.GRAN 18 01 1960 04 18 30.620N 32.250E                          4.50    4.50
A.GRAN 04 08 1965 09 30 32.000N 30.600E                          4.65    4.65
A.GRAN 01 01 1968 13 14 30.550N 32.570E                          3.40    3.40
A.GRAN 04 10 1969 02 00 30.850N 32.150E                          3.15    3.15
A.GRAN 03 12 1970 10 12 30.350N 32.570E                          3.00    3.00
A.GRAN 12 01 1972 11 05 31.750N 30.900E                          4.65    4.65
A.GRAN 17 03 1972 13 05 30.850N 32.460E                          4.50    4.50
A.GRAN 03 08 1973 08 30 32.400N 30.750E                          4.50    4.50
A.GRAN 08 11 1973 15 00 32.600N 32.750E                          3.50    3.50
A.GRAN 11 05 1975 01 15 31.500N 30.750E                          3.50    3.50
A.GRAN 06 04 1976 05 00 32.150N 30.530E                          3.25    3.25
A.GRAN 01 08 1976 08 12 30.500N 31.250E                          3.50    3.50
A.GRAN 16 10 1976 10 00 31.400N 32.650E                          3.65    3.65
A.GRAN 01 07 1978 03 15 30.500N 32.420E                          4.25    4.25
```

OUTPUT FOR PROGRAM REGRESSION ANALYSIS (SAMPLE PROBLEM 2)

Figure 6-10

```
REGRESSION ANALYSIS
LINEAR-LN SCALE     NBRC    AREA      RMBK
SAMPLE PROBLEM 2     32     0.0       0.0

NUMBER OF RECORDS INCLUDED    32
AREA                0.0
TIME (YEARS)       78.00
MINIMUM MAGNITUDE                3.00
MAGNITUDE INCREMENT FOR CDF      0.25
EARTHQUAKE MAGNITUDES
      3.50      3.70      4.70      3.20      3.50      3.50      4.50      4.30      3.50      3.50      4.00      3.80
      4.10      3.50      3.80      3.70      3.70      3.00      4.50      4.60      3.40      3.10      3.00      4.60
      4.50      3.50      3.50      3.20      3.50      3.60      4.20
       RM         INTERVAL           CUMULATIVE FREQUENCY
    INTERVAL     FREQUENCY           OCCURRENCES ABOVE RM

   3.00 - 3.24      3                   32.         3.00
   3.25 - 3.49      3                   29.         3.25
   3.50 - 3.74     10                   26.         3.50
   3.75 - 3.99      5                   16.         3.75
   4.00 - 4.24      2                   11.         4.00
   4.25 - 4.49      2                    9.         4.25
   4.50 - 4.74      6                    7.         4.50
   4.75 - 4.99      1                    1.         4.75
```

Magnitude interval (defined as 0.25 in this case). Using the results listed under the heading "Interval Frequency" (see Figure 6-10) will facilitate the construction of the histogram on magnitude and hence of the CDF necessary for the implementation of program GENER.MAGNITUDE.

A plot of the normalized historgram and of the CDF is shown in Figure 6-11.

6.5.5 Sample Problem No. 3

This example will illustrate the application of program REGRESSION.ANALYSIS in computing the coefficients A and B (see equation below) and the parameter SIGMA (standard deviation) necessary for the implementation of program INTENSITY.MAGNITUDE (discussed previously in Chapter III).

$$M = BI + A \qquad (3.1) \text{ (repeated)}$$

where: M = Richter Magnitude

I = MMI-Modified Mercalli Intensity

The earthquake records selected for this example are listed in Figure 6-12. Only events containing both Richter Magnitude and MMI values have been included. (Recall that since a relation of the form shown above has to be established on a regional basis, only those earthquake records containing both parameters RM,MMI are used.)

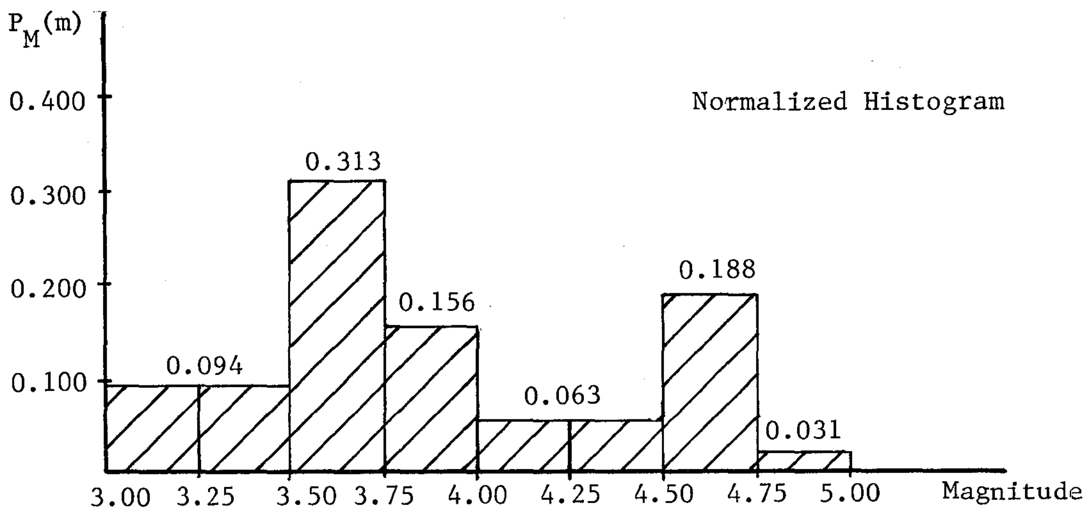
In order to use program REGRESSION.ANALYSIS for this purpose, one of the program's optional capabilities will be set by declaring the parameters SKIPCD (see data set II) equal to 1, SKIPRG (see data set II) equal to zero, and SKIPDZ (see data set II) equal to zero.

Figure 6-13 shows the listing of the input data deck for this sample problem.

6.5.6 Output for Program REGRESSION.ANALYSIS (Sample Problem No. 3)

Figure 6-14 shows the listing of the output for Sample Problem No. 3. The program has computed the values of the coefficients A and B (identified

Figure 6-11 RM-Hisotgram and CDF--Sample Problem No. 2



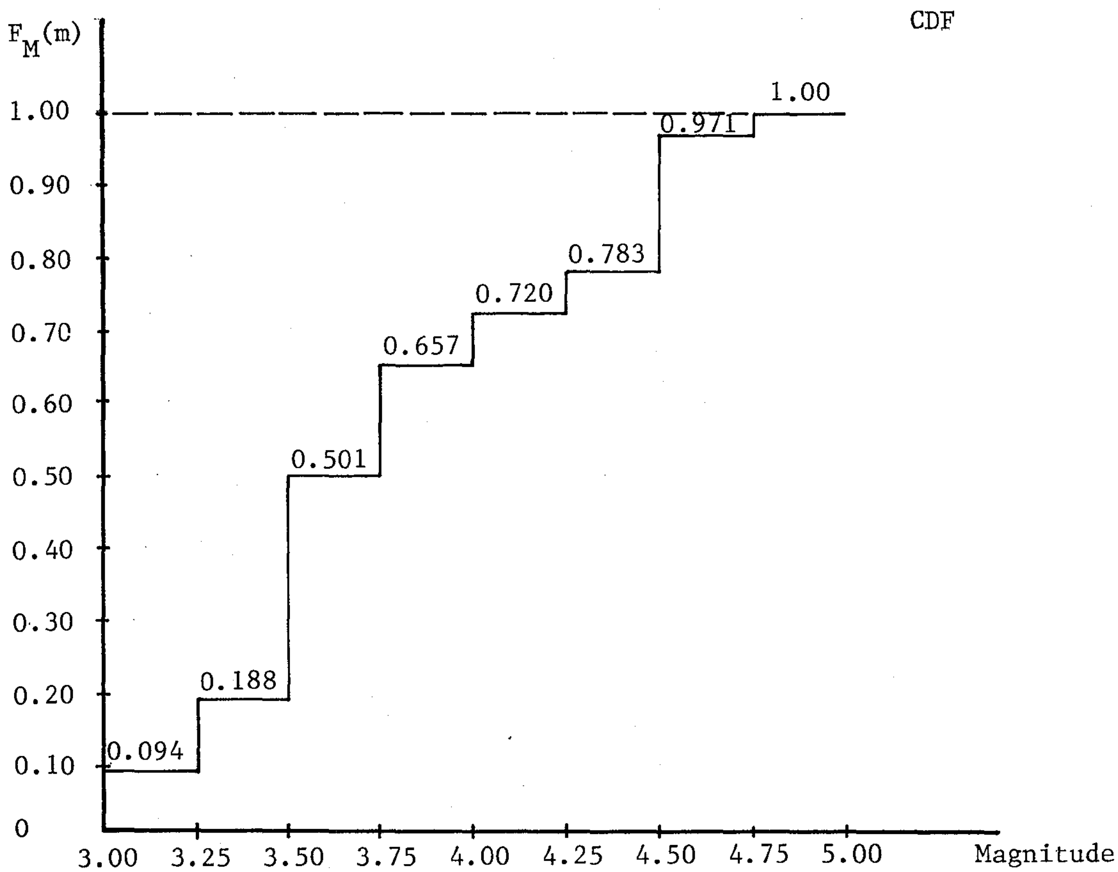


Figure 6-12

EARTHQUAKE DATA IN CHRONOLOGICAL ORDER

SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	LATITUDE	LONGITUDE	CLASS	MMI	RADIUS	DEPTH	MS	MB	MR1	MR2	SYMBOL
A.GRAN	17	12	1850	12	30	36.500N	07.400E		6.5					4.61	4.61	I
A.GRAN	17	06	1908	00	24	36.500N	07.500E		7.5					5.25	5.25	I
A.GRAN	04	08	1908	02	11	36.400N	06.600E	D	8.0					5.10	5.10	
A.GRAN	03	12	1928	05	30	36.400N	07.200E	D						5.00	5.00	
A.GRAN	10	02	1937	18	16	36.400N	07.500E	D	9.0					5.40	5.40	
A.GRAN	06	08	1947	09	46	36.300N	06.667E	D	8.5					5.30	5.30	
A.GRAN	27	10	1947	10	29	37.600N	08.500E	D	5.5						5.40	L
A.GRAN	22	11	1950	02	43	36.100N	07.200E	E	5.0						4.10	L
A.GRAN	01	04	1952	04	21	36.500N	07.300E	E	6.0					4.50	4.50	
A.GRAN	12	04	1952	16	23	36 500N	07.300E	E	5.5					4.20	4.20	
A.GRAN	23	05	1956	06	37	36.400N	07.300E	E	7.5						5.00	L
A.GRAN	26	06	1956	01	50	36.000N	08.100E	E	7.0						4.15	L
A.GRAN	02	09	1958	12	26	36.500N	07.400E	F	5.0						3.55	L
A.GRAN	14	11	1959	16	10	36.400N	07.500E	F	4.5						3.05	L
A.GRAN	05	03	1960	04	18	36.600N	07.100E	F	5.5						4.00	L
A.GRAN	02	12	1961	12	40	36.500N	08.200E							5.50	5.50	
A.GRAN	14	03	1963	12	25	36.200N	06.100E	E	7.0						4.40	L
A.GRAN	14	04	1967	23	44	36 500N	07.800E	E						4.30	4.30	

INPUT DATA FOR PROGRAM REGRESSION ANALYSIS (SAMPLE PROBLEM 3)

```
(42X,3F.2,27X,F3.2) ------------------------------------------------------ I
   0.0        0.0          0.          125.       5    1    0    0    0 -- II
SAMPLE PROBLEM 3  18 ----------------------------------------------------- IV
A.GRAN 17 12 1850 12 30 36.500N 07.400E   6.5                4.61      4.61 I
A.GRAN 17 06 1908 00 24 36.500N 07.500E   7.5                5.25      5.25 I
A.GRAN 04 08 1908 02 11 36.400N 06.600E D 8.0                5.10      5.10
A.GRAN 03 12 1928 05 30 36.400N 07.200E D 8.0                5.00      5.00
A.GRAN 10 02 1937 18 16 36.400N 07.500E D 9.0                5.40      5.40
A.GRAN 06 08 1947 09 46 36.300N 06.667E D 8.5                5.30      5.30
A.GRAN 27 10 1947 10 29 37.600N 08.500E D 5.5                          5.40 L
A.GRAN 22 11 1950 02 43 36.100N 07.200E E 5.0                          4.10 L
A.GRAN 01 04 1952 04 21 36.500N 07.300E E 6.0                4.50      4.50        V
A.GRAN 12 04 1952 16 23 36 500N 07.300E E 5.5                4.20      4.20
A.GRAN 23 05 1956 06 37 36.400N 07.300E E 7.5                          5.00 L
A.GRAN 26 06 1956 01 50 36.000N 08.100E E 7.0                          4.15 L
A.GRAN 02 09 1958 12 26 36.500N 07.400E F 5.0                          3.55 L
A.GRAN 14 11 1959 16 10 36.400N 07.500E F 4.5                          3.05 L
A.GRAN 05 03 1960 04 18 36.600N 07.100E F 5.5                          4.00 L
A.GRAN 02 12 1961 12 40 36.500N 08.200E   7.5                5.50      5.50
A.GRAN 14 03 1963 12 25 36.200N 06.100E E 7.0                          4.40 L
A.GRAN 14 04 1967 23 44 36 500N 07.800E E 6.0                4.30      4.30
```

Figure 6-13

as alpha and beta in Figure 6-14) and the statistics for the regression line.

Figure 6-15 shows the plot of the Magnitude--MMI values and the line fitted to the data.

Figure 6-14

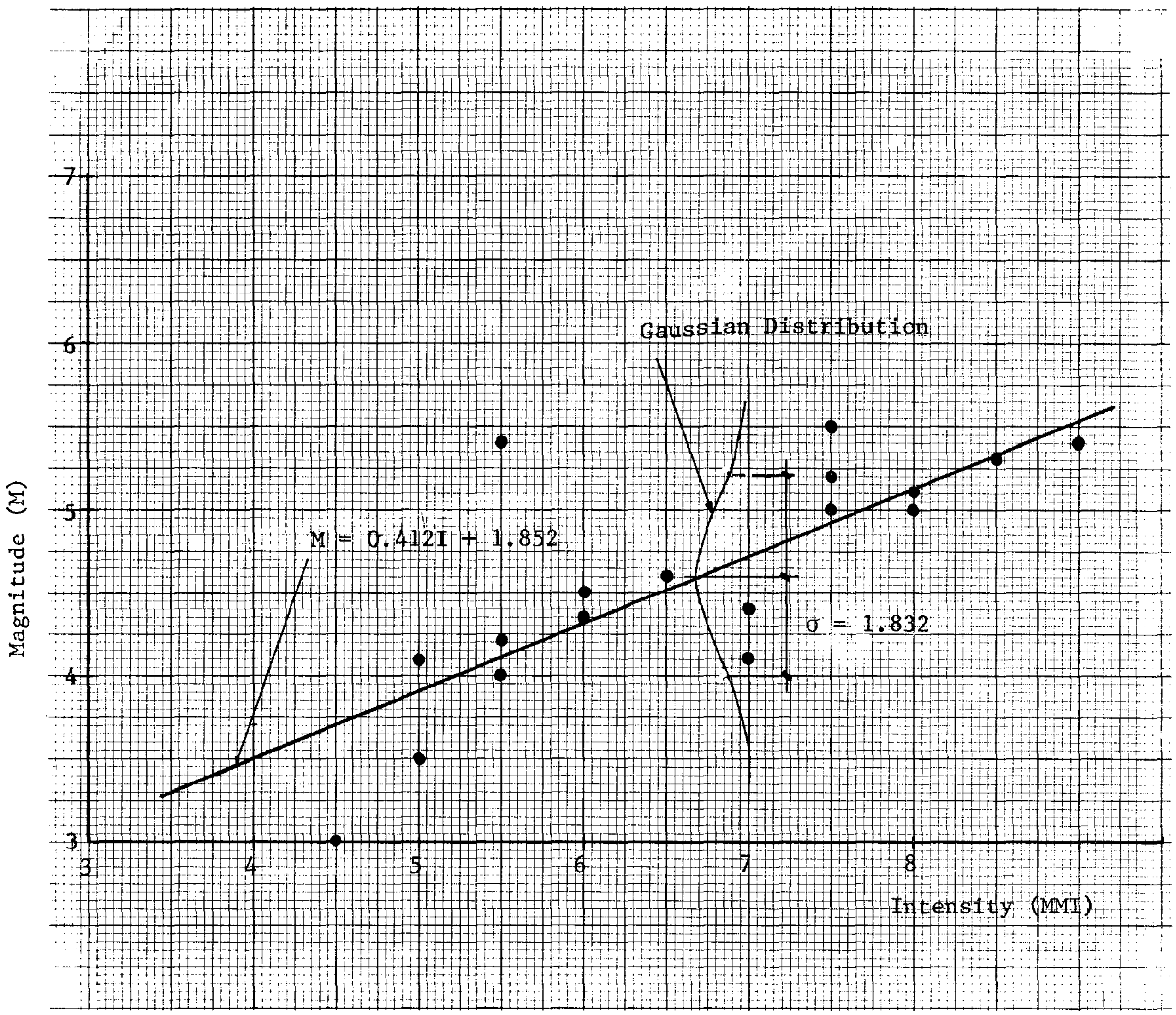
OUTPUT FOR PROGRAM REGRESSION ANALYSIS (SAMPLE PROBLEM 3)*

```
REGRESSION ANALYSIS
LIN-LIN  SCALE      NBRC    AREA       RMBK
SAMPLE PROBLEM 3     18      0.0       0.0

NUMBER OF RECORDS   18
INPUT VARIABLES
INDEPENDENT  DEPENDENT
       6.50       4.60
       7.50       5.20
       8.00       5.10
       8.00       5.00
       9.00       5.40
       8.50       5.30
       5.50       5.40
       5.00       4.10
       6.00       4.50
       5.50       4.20
       7.50       5.00
       7.00       4.10
       5.00       3.50
       4.50       3.00
       5.50       4.00
       7.50       5.50
       7.00       4.40
       6.00       4.30
INTERCEPT AND SLOPE OF LINE    1
 STATISTICS FORM REGRESSION LINE SEGMENT =  1
X-MEAN=    6.63889     Y-MEAN=    4.58888     XVAR=     1.66127     YVAR=     0.46878
COVARXY=    0.68486     COEFF. OF VAR.=     0.60227     VAR=     0.20975     STDV=     0.45799

ALPHA  1.851996
BETA   0.412251
SIGMA  1.831800
INTERCPT AT 3.          5.        6.         7.
        3.08875    3.91325   4.32550    4.73775
```

*Program REGRESSION.ANALYSIS has been modified (see page 61) in order to obtain a linear-linear fit.

Figure 6-15

Intensity vs Magnitude Relationship for Sample Problem 3



CHAPTER VII

CLASSICAL APPROACH--PROGRAM ACC.LINE.AREA

7.1 Introduction

The Classical approach to seismic hazard analysis (one of the two seismic hazard models, see Fig. 1-2) will be discussed and implemented through the use of program ACC.LINE.AREA.

The four key elements associated to seismic hazard models are:

- Earthquake recurrence model
- Source geometry
- Tectonic model and travel path
- Attenuation uncertainty

Their treatment under the present approach, along with a brief summary of the theory behind the Classical model will be presented in the following sections.

7.1.1 Theoretical Background*

Poisson Model of Seismic Occurrences

Earthquake occurrences have been modeled using the Poisson probability law. For earthquake events to follow the Poisson model, the following assumptions must be valid:

1.) Earthquakes are spatially independent.

2.) Earthquakes are temporally independent.

3.) Probability that two seismic events will take place at the same location and at the same time approaches zero.

---

*Summary taken from Reference 1.

In its general form, the Poisson Law can be written as

$$P_n(t) = \frac{e^{-\lambda t}(\lambda t)^n}{n!} \tag{7.1}$$

where: $P_n(t)$ = Probability of having n events in time period t

n = number of events

λ = mean rate of occurrence per unit of time

Recurrence relationships (as obtained in Chapter VI) enable the analyst to obtain mean number of occurrences above Richter Magnitude M for a given source. This relationship in its general form can be written as:

$$N(M) = \phi(M,A,T) \tag{7.2}$$

where: N(M) = Number of occurrences above Richter Magnitude M

M = Richter Magnitude

A = Source characteristic (area source, or line source)

T = Time period of data base

In particular, for the present seismic hazard methodology, the form

$$\mathrm{Ln}_e N(M) = \alpha + \beta M \qquad (6.1)\ \text{(repeated)}$$

has been adopted.

Normalizing the regression coefficient α in Eq. 6.1 with respect to time and area or length of a particular source give the expression:

$$\mathrm{Ln}\ N'(M) = \alpha' + \beta M \tag{7.3}$$

where N'(M) = normalized mean number of events above magnitude M for unit time (1 year) and unit area or unit length

$\alpha' = \alpha - \ln(AT)$ for area source

$\alpha' = \alpha - \ln(LT)$ for line source

A = area of the area source (degrees of latitude and longitude)

L = length of line source (degrees of latitude and longitude)

T = time for which data was obtained.

Thus, depending on the source and the value of M, the mean number of events above magnitude M for a unit area for area source, a unit length for line source, and a unit time is given by:

$$N'(M) = \exp\{\alpha' + \beta M\} \tag{7.4}$$

replacing λ in Eq. 7.1 by N'(M), the following equation is obtained for the probability of having n events in time period t:

$$P_n(t) = \frac{\exp\{-\exp(\alpha' + \beta M)t\}\{\exp(\alpha' + \beta M)t\}^n}{n!} \tag{7.5}$$

Source Mechanisms

The present model considers three different types of sources to represent the seismicity of any geographical location. They are:

- Point source
- Line source
- Area source

Point source

For this type of source, all occurrences (past and future) take place at one point. The recurrence relationship can be normalized with respect to time T as follows:

$$N'(M) = \frac{N(M)}{T} \tag{7.6}$$

Substituting the value of N'(M) in the Poisson law of Eq. 7.1, we get:

$$P_n(M > m,t) = \frac{\exp\{-N'(m)t\}\{N'(m)t\}^n}{n!} \qquad (7.7)$$

where $P_n(M > m,t)$ gives the probability that there will be n events of Richter magnitude greater than m in time period t.

For engineering purposes, we are usually interested in determining the probability of at least one event greater than m in time period t. This probability is given by

$$P\{\text{at least one event of Magnitude } M > m \text{ in time } t\} = 1 - \exp\{-N'(m)t\} \qquad (7.8)$$

Line Source

For a line source, it is assumed that epicenters lie along a linear fault. For a line source of length L (fault length L) and the data base for a time period T, the recurrence relationship of Chapter VI, Eq. 6.1 can be normalized to:

$$N'(m) = \frac{N(M)}{LT} \qquad (7.9)$$

Substituting the value of N'(m) in the Poisson Law of Eq. 7.1 we get:

$$P_n(M > m,t) = \frac{\exp\{-N'(m)t\}\{N'(m)t\}^n}{n!}$$

The probability of at least one event of magnitude greater than m for a future time period t is given by:

$$P(\text{at least one earthquake of } M > m \text{ in time } t) = 1 - \exp\{-N'(m)t\} \qquad (7.8)'$$

Area source

When past earthquake epicenters do not lie on a line (i.e., along a given fault line) but are scattered over a region, the seismic source is considered as an area source. The present model considers horizontal full circles or sections of a circle at constant depth to represent area sources. For an area source of area A and data base for a time period T, the recurrence relationship of Chapter VI, Eq. 6.1 can be normalized to:

$$N'(m) = \frac{N(m)}{AT} \tag{7.10}$$

Substituting (7.10) in the Poisson law of Eq. 7.1 gives:

$$P_n(M > m,t) = \frac{\exp\{-N'(m)t\}\{N'(m)t\}^n}{n!}$$

The probability of at least one event of magnitude greater than m for a future time period t is given by:

$$P\{\text{at least one earthquake of } M > m \text{ in time } t\} = 1 - \exp\{-N'(m)t\} \qquad (7.8)''$$

Peak Ground Acceleration at a Site

As mentioned in Chapter I, the most commonly used parameter to describe the seismic loading at a given site is the peak ground acceleration (PGA). In the previous section, the probability of exceeding a magnitude level (m) in time t was determined by using the Poisson model and the recurrence relationships for a given source. For design purposes we are interested in obtaining information on probable loadings at a site. For this, the following parameters have to be known:

1.) Probabilistic information on Richter Magnitude for a source as a function of future time t.

2.) Distance from site to source.

3.) Attenuation of peak ground acceleration from source to site.

The first parameter was determined in Eqs. 7.8, 7.8', and 7.8" for each type of source. Several attenuation formulas are available which give relationships between the Richter Magnitude (M), the epicentral distance or hypocentral distance and PGA. The most commonly used relationship is of the form given by:

$$A = \frac{b_1 \exp(b_2 M)}{(R_h + b_4)^{b_3}} \tag{7.11}$$

where: A = Peak ground acceleration

R_h = hypocentral distance from source to site

M = Richter Magnitude

b_1, b_2, b_3, and b_4 are attenuation constants

Equation 7.11 is incorporated in Eqs. 7.8, 7.8' and 7.9' for each source type considered (point, line and area source, respectively), in order to determine the peak ground acceleration at a site in a probabilistic sense.

The probability distribution on peak ground acceleration (A) at a site for a point source is given by:

$$P\{A > a,t\} = 1 - \exp\{-\gamma(\frac{a}{b_1})^{\delta} (R_h + b_4)^{\rho} t\} \tag{7.12}$$

where: $\gamma = e^{\alpha'}$

$\delta = \beta/b_2$

$\rho = \frac{\beta b_3}{b_2}$

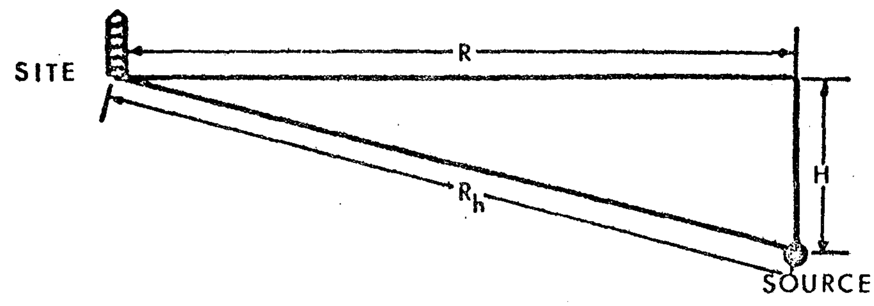
See Figure 7-1.

Similarly, for a line source (see Figure 7-1):

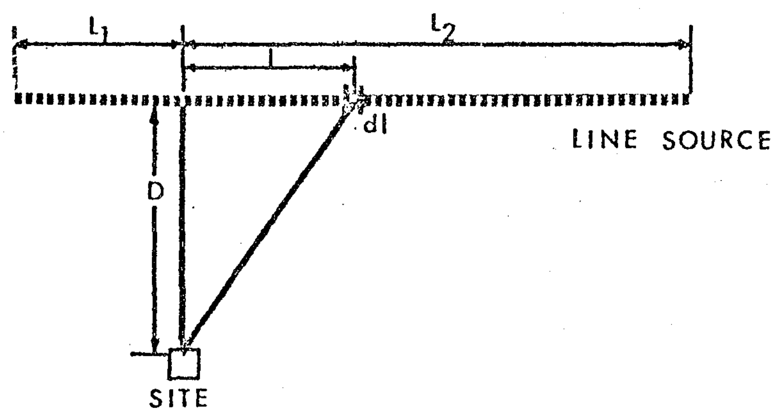
$$P\{A > a,t\} = 1 - \exp\{-\gamma(\frac{a}{b_1})^{\delta} t \int_{\ell_1}^{\ell_2} \{(d^2 + \ell^2 + h^2)^{\frac{1}{2}} + b_4)^{\rho} d\ell\} \tag{7.13}$$

for an area source (see Figure 7-2):

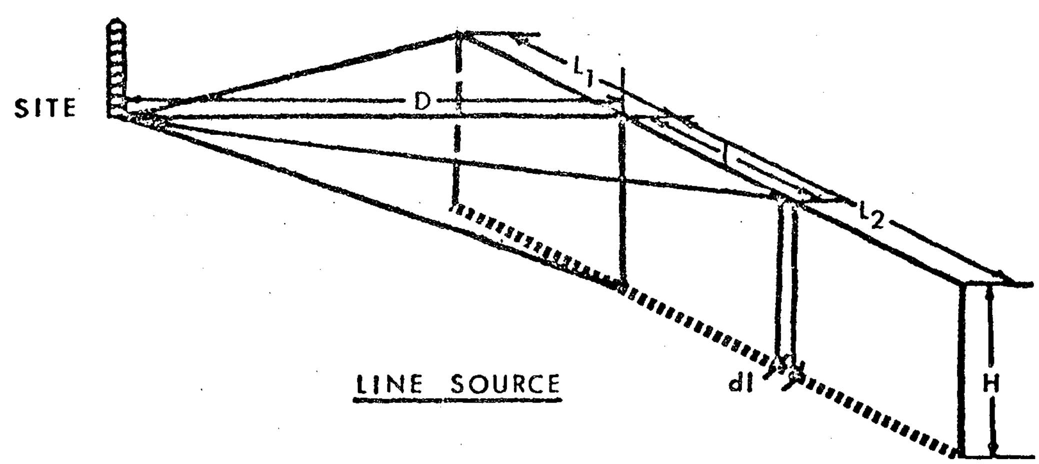
$$P\{A > a,t\} = 1 - \exp\{-\gamma(\frac{a}{b_1})^{\delta} t\theta \int_{R_1}^{R_2} (R_h + b_4)^{\rho} R dr\} \tag{7.14}$$



POINT SOURCE

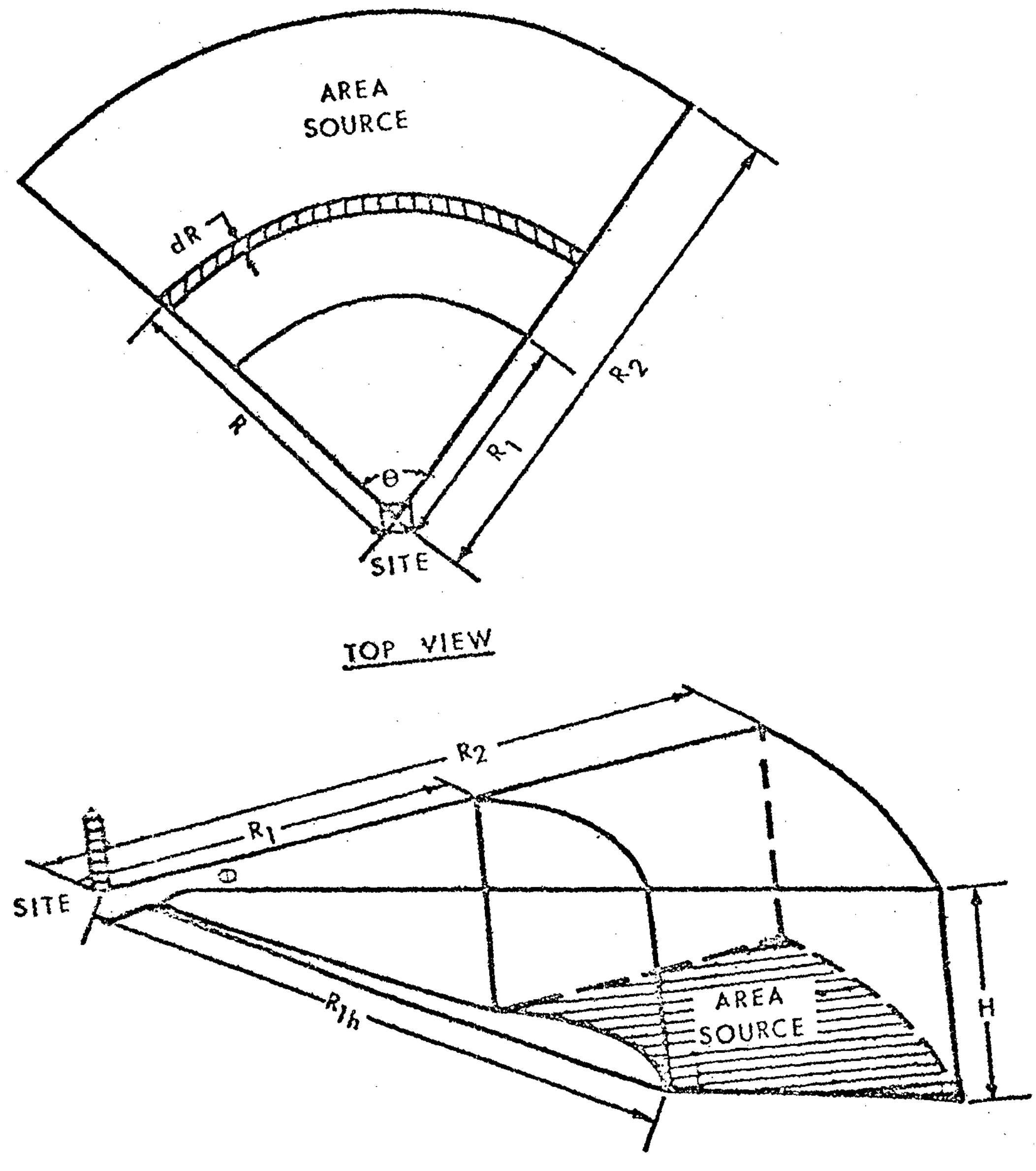


TOP VIEW



LINE SOURCE

Figure 7-1



AREA SOURCE

Figure 7-2

In general, a site is usually surrounded by any or all of the three sources discussed previously. The probabilistic loading due to such a case can be obtained by the following expression:

$$P\{A > a,t\} = 1 - \exp\{- \sum_{i=1}^{NP} \gamma_i \left(\frac{a}{b_1}\right)^{\delta_i} t \,(R_{h_i} + b_4)^{\rho_i}$$

$$- \sum_{j=1}^{NL} \gamma_j \left(\frac{a}{b_1}\right)^{\delta_j} t \int_{\ell_{1j}}^{\ell_{2j}} \{(d_j^{\,2} + \ell^2 + h_j^{\,2})^{\frac{1}{2}} + b_4\}^{\rho_j} \, d\ell$$

$$- \sum_{k=1}^{NA} \gamma_k \left(\frac{a}{b_1}\right)^{\delta_k} t\theta_k \int_{R_k}^{R_{2k}} (R_{h_k} + b_4)^{\rho_k} \, RdR\} \qquad (7.15)$$

NP = number of point sources in the region

NL = number of line sources in the region

NA = number of area sources in the region

It should be pointed out that the present approach assumes that the total energy released during an earthquake is radiated from the hypocenter (point model) and that the maximum intensity at a given site is governed by its distance from the hypocenter. Also the energy attenuation, Eq. 7.11 has been incorporated in the Poisson model in a deterministic sense. An uncertainty about the mean value of the attenuation, to account for the scatter present in the data, is not incorporated in the model.

7.1.2 Purpose and description of program ACC.LINE.AREA

Program ACC.LINE.AREA has been designed to compute the seismic exposure of a site by combining the effect of all the seismic sources identified within the geographic location and to provide an estimate of the probability of occurrence at a site of at least one acceleration greater or equal to a given PGA within the future time period t of interest (see Eq. 7.15). A cumulative distribution function (CDF) or a complementary distribution function (1-CDF) is developed at a site. By choosing a large number of sites at the nodes of a grid covering a given region, seismic exposure within the region can be described. It must be kept in mind that an identical procedure can be applied to any other parameter such as maximum ground velocity, etc., by using different attenuation functions.

Since the hypocentral distance is a parameter in the attenuation relationship (Eq. 7.11), the area and line sources are divided in small segments in order to take into consideration the distance variation to the site from different parts of a source. The size of the segments is chosen small enough such that the approximation from a continuous to discrete computation is acceptable and the replacement of the integration sign in Eq. 7.15 by summation is valid. The seismicity within a source remains the same from segment to segment. The ground parameter (PGA, PGV, etc.) used in the model is also discretized to equal step increments.

The present version can handle only point, line and circular area sources at a constant depth (no dipping planes allowed). The units of length used by the program are degrees of latitude and longitude. The unit of time is normally given in years. The regression parameter (alpha) in Eq. 7.3 must be normalized with respect to time in years and length or area in degrees and degrees square, respectively. The attenuation constants b_1, b_2, b_3, and b_4 must be properly scaled in order to match the degree-latitute-longitude units.

In its present form, program ACC.LINE.AREA has been divided into a main routine and two subprograms. It contains 433 executable FORTRAN statements. The space requirements are approximately 17124 bytes. The actual array dimensions can accomodate up to 62 seismic sources; there is no limitation with respect to the number of sites or nodal points chosen. The number of future time periods of interest is limited to

10 per run. The discretized ground parameter (e.g., PGA, PGV, etc.) is limited to 30 equal step increments. The program can handle several nodal grids in one run.

7.2 Description of Input Data

Input data for program ACC.LINE.AREA will consist of six sets of cards. The organization of data on each card, along with a description of the items, is given in the following paragraphs.

I. Run Identification--(20A4)--One card

Col.	1-80	HED1	(Identification label)

II. Attenuation Constants--Card One--Geometric Constants--(10I5)

Col.	1-10	B1	Constants in attenuation relationship of the form: $A = \dfrac{b_1 \exp(b_2 M)}{(R_h+b_4)^{b_3}}$
	11-20	B2	
	21-30	B3	
	31-40	B4	
	41-50	DELTAL	(step size for line integration in degrees, i.e. 0.05^o)
	51-60	DELTAC	(step size for circle integration in degrees)

III. Problem Description (Three Cards)

Col.	1-5	NL	(Number of line sources for the region)
	6-10	NA	(Number of area sources for the region)
	11-15	NT	(Number of time periods of interest)
	16-20	NY	(Number of step intervals for ground parameter of interest, see Card 3)
	21-30	NBGD	(Number of grids)
	31-35	SKSAVE	If 0, the program will save the output on disc, (logical unit must be specified in JCL). If 1, no output will be saved.

Card 2--Time periods of interest (NT values--maximum 10 per run)

Input 8 values per card (8F10.0)

Col.	1-10	T(1)	(time period of interest #1)
	11-20	T(2)	(time period of interest #2)
	. . .	T(NT)	(time period of interest #NT)
	71-80	T(8)	(time period of interest #8)

Card 3--Discretized ground parameter--NY step increments

Input 8 values per card (maximum of 30 discretized values)--(8F10.0)

Col.	1-10	YG(1)	(ground parameter, discrete value #1)
	11-20	YG(2)	(ground parameter, discrete value #2)
	. . .	YG(NY)	(ground parameter, discrete value #NY)

Note: The program computes the probability of exceeding at least once at the site, the values of the parameter specified above. Usually the YG are input in ascending order to describe a discretized (1-CDF) curve.

IV. Properties of Line Sources (Three Cards per Source)

Card 1--Identification of the line source--(20A4)

Col.	1-80	HED2	(Source's identification label)

Card 2--Properties to the left of breaking point magnitude (RMBK) in sources' recurrence relationship and coordinates' of souces' endpoints--(7F10.0)

Col.	1-10	ALPHA1	(Normalized intercept α', see Eq. 7.3)
	11-20	BETA1	(Slope (β) of line 1, see Eq. 7.3)
	21-30	XL1	(X-coordinate of source's origin (degrees longitude))
	31-40	XL2	(X-coordinate of source's end (degrees longitude))
	41-50	YL1	(Y-coordinate of source's origin (degrees latitude))

Col. 51-60	YL2	(Y-coordinate of source's end (degrees latitude))
61-70	HL	(depth of the source (degrees))

Card 3--Properties to the right of breaking point magnitude--(If only one line has been fitted to the data, see Chapter VI, Problem 1), input same α and β as in Card 2 and breakpoint magnitude = zero)

Col. 1-10	ALPHA2	(normalized intercept)
11-20	BETA2	(slope of Line 2)
21-30	RML	(breaking point magnitude (RMBK--Chapter VI))
31-40	RMMX	(cut-off magnitude--see Figure 6.4)

V. Properties of Area Sources (Three Cards per Source)

Card 1--Identification of the Area Source--(20A4)

Col. 1-80	HED2	(source's identification label)

Card 2--Properties to the left of breaking point magnitude in source's recurrence relationship and coordinates of source's center--(6F10.0)

Col. 1-10	ALPHA1	(Normalized intercept α' of line 1)
11-20	BETA1	(slope β of line 1--refer to Figure 6.7)
21-30	XL1	(X-coordinate of circle's center (degrees longitude))
31-40	YL1	(Y-coordinate of circle's center (degrees latitude))
41-50	XL2	(radius of the circle (degrees))
51-60	HL	(depth of the source (degrees))

Card 3--Properties to the right of breaking point magnitude. If only one line has been fitted to the data, input same α and β as in Card 2 and breakpoint magnitude = zero)

Col.	1-10	ALPHA2	(normalized intercept of line 2, refer to Fig. 6.7)
	11-20	BETA2	(slope of line 2, refer to Fig. 6.7)
	21-30	RML	(breakpoint magnitude)
	31-40	RMMX	(cutoff magnitude for source)

VI. Description of Grid--2 cards per grid

Card 1--Grid's identification--(20A4)

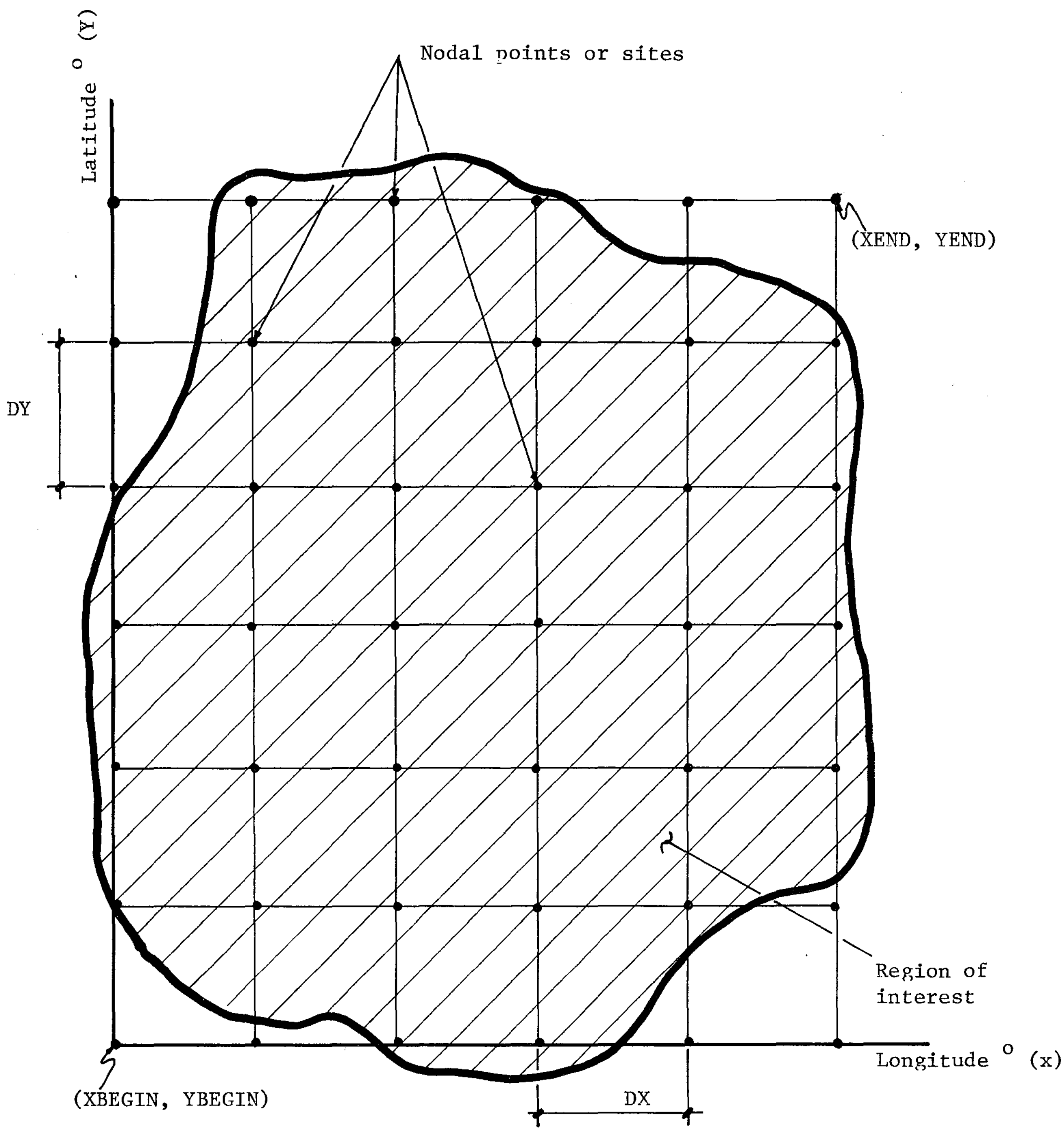
Col.	1-80	HED2	(name of grid)

Card 2--Grid's description--(8F10.0)--See Figure 7-3

Col.	1-10	XBEGIN	(X-coordinate of grid's origin (degrees longitude))
	11-20	YBEGIN	(Y-coordinate of grid's origin (degrees latitude))
	21-30	XEND	(X-coordinate of grid's end (degrees longitude))
	31-40	YEND	(Y-coordinate of grid's end (degrees longitude))
	41-50	DX	(X-increment (degrees longitude))
	51-60	DY	(Y-increment (degrees latitude))

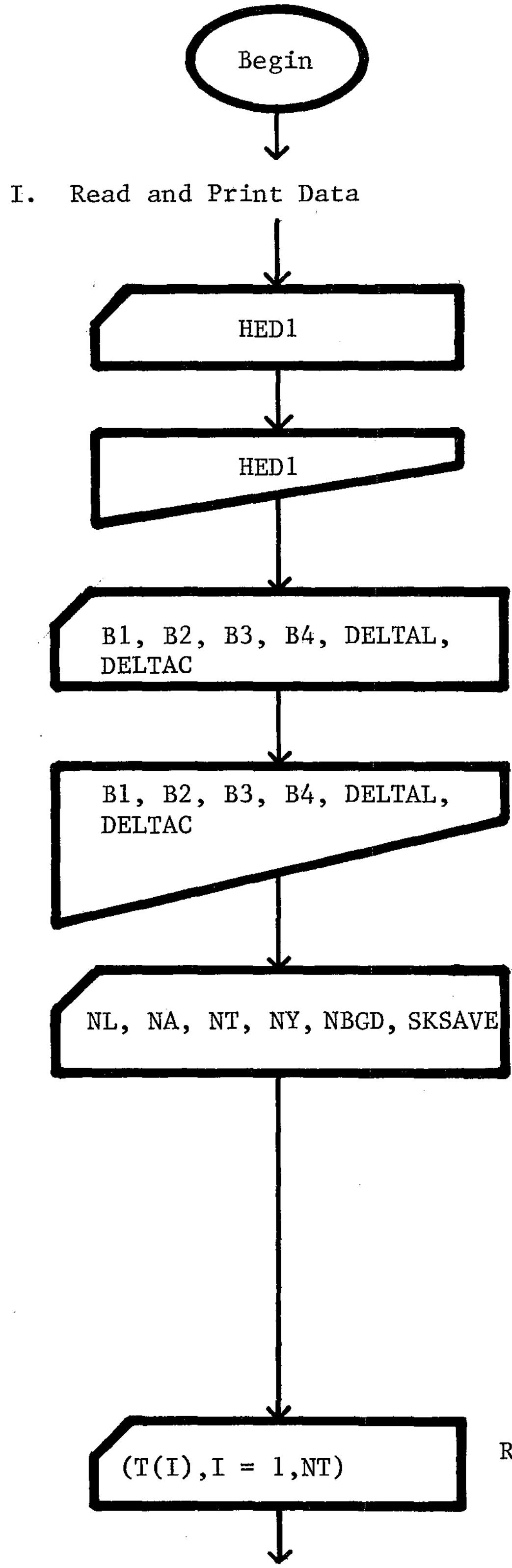
Note: Both origin and end should coincide, and DX, DY input as zero if only one site is considered.

Figure 7-3 Typical Nodal Grid



Note: Grid will be covered row-wise from left to right starting with the bottom row--XBEGIN, YBEGIN / XEND, YEND have to be placed as shown

7.3 Macro Flow Chart for Program ACC.LINE.AREA

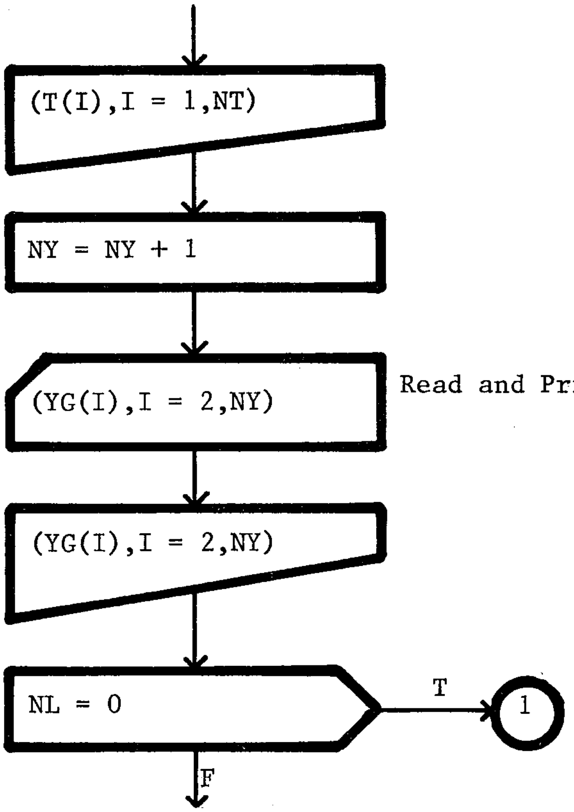


Read and print identification label for this run

Read and Print: Attenuation constants plus the step size for line and circle integration

Read:
1. Number of line sources
2. Number of area sources
3. Number of time periods
4. Number of values in which CDF(s) will be descretized
5. Number of grids
6. SKSAVE = { 0, save results on disk; 1, will not save results on disc

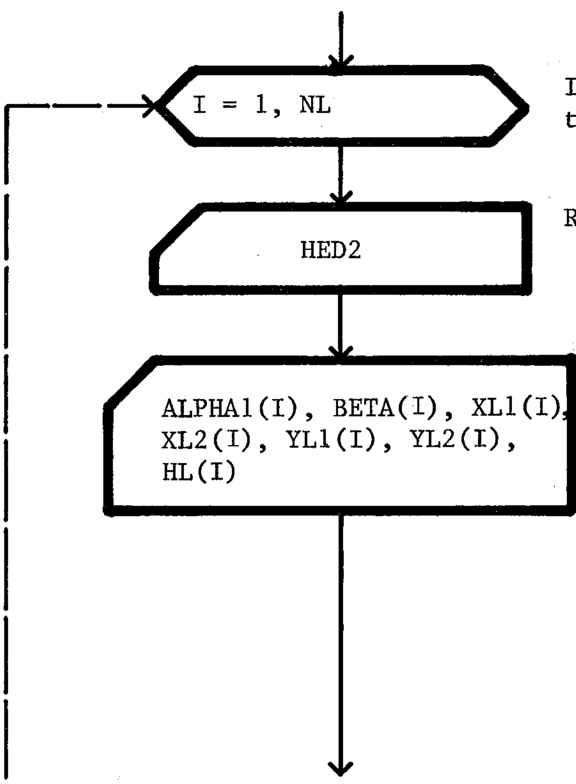
Read and Print: Time periods for which the analysis will be carried out.



Read and Print: The values of the parameter (i.e., PGA, PGV, etc.) in which the CDF(s) will be discretized

No line sources in this run, read area sources' properties

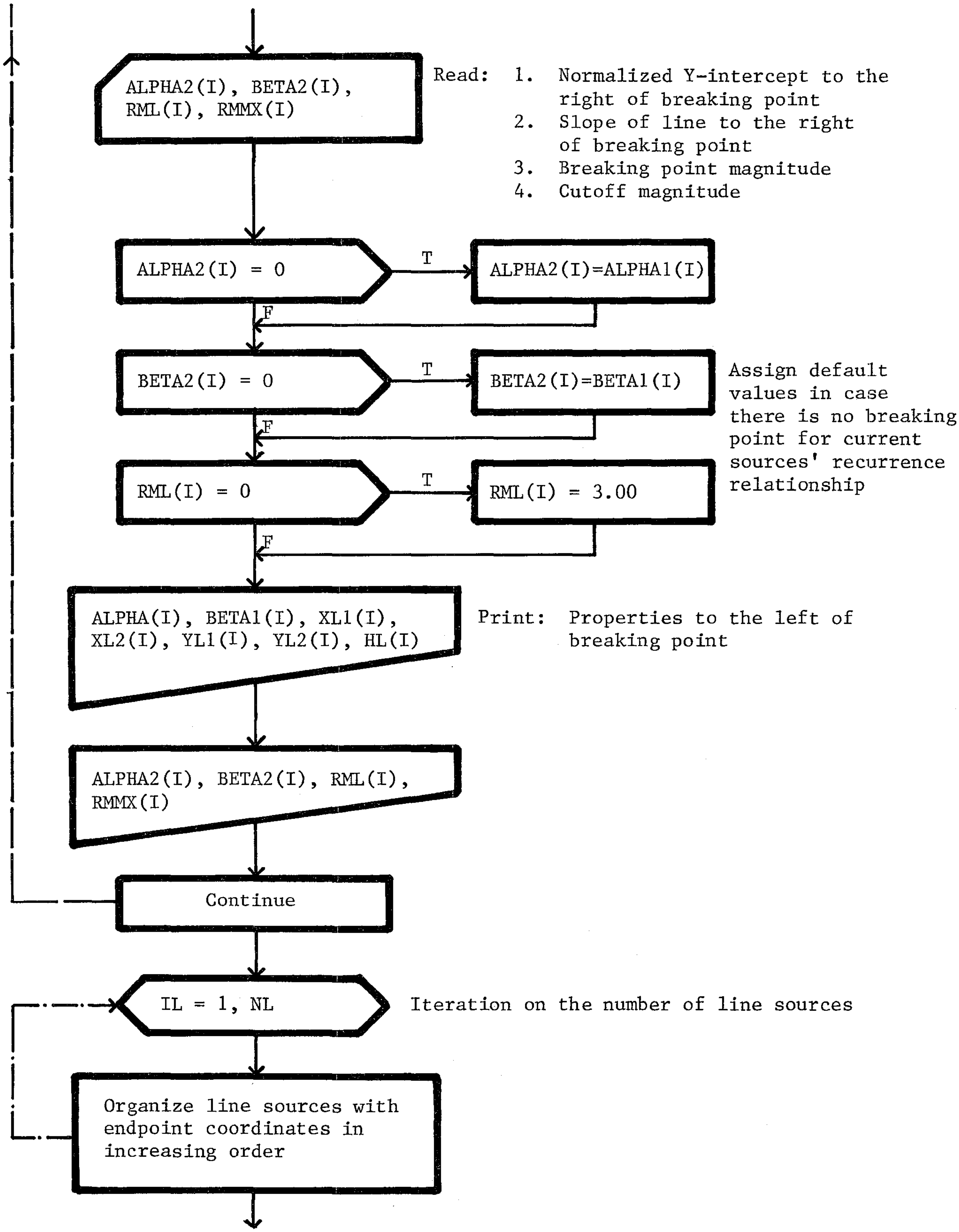
II. Line Sources' Properties



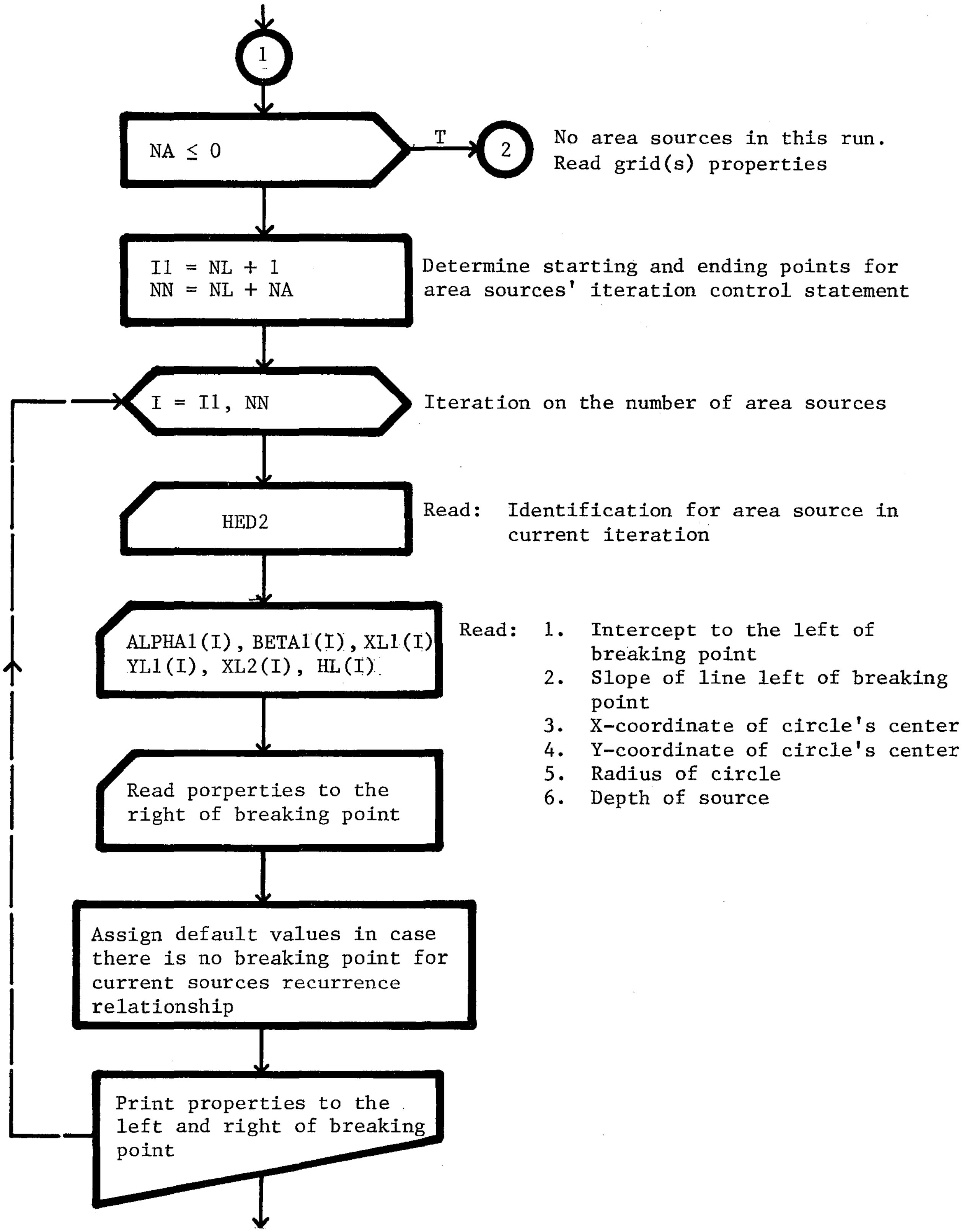
Iteration on the number of line sources in this run.

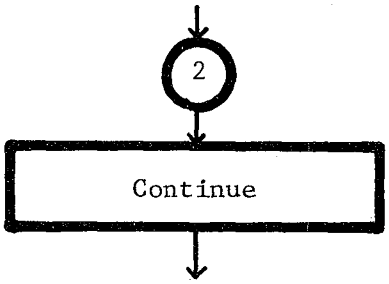
Read: Identification for line source in current iteration

Read:
1. Normalized Y-intercept to the left of breaking point (if any). See program REGRESSION. ANALYSIS.
2. Slope of regression line to the left of breaking point.
3. X-coordinate of sources' origin
4. X-coordinate of sources' end
5. Y-coordinate of sources' origin
6. Y-coordinate of sources' end
7. Depth of line source

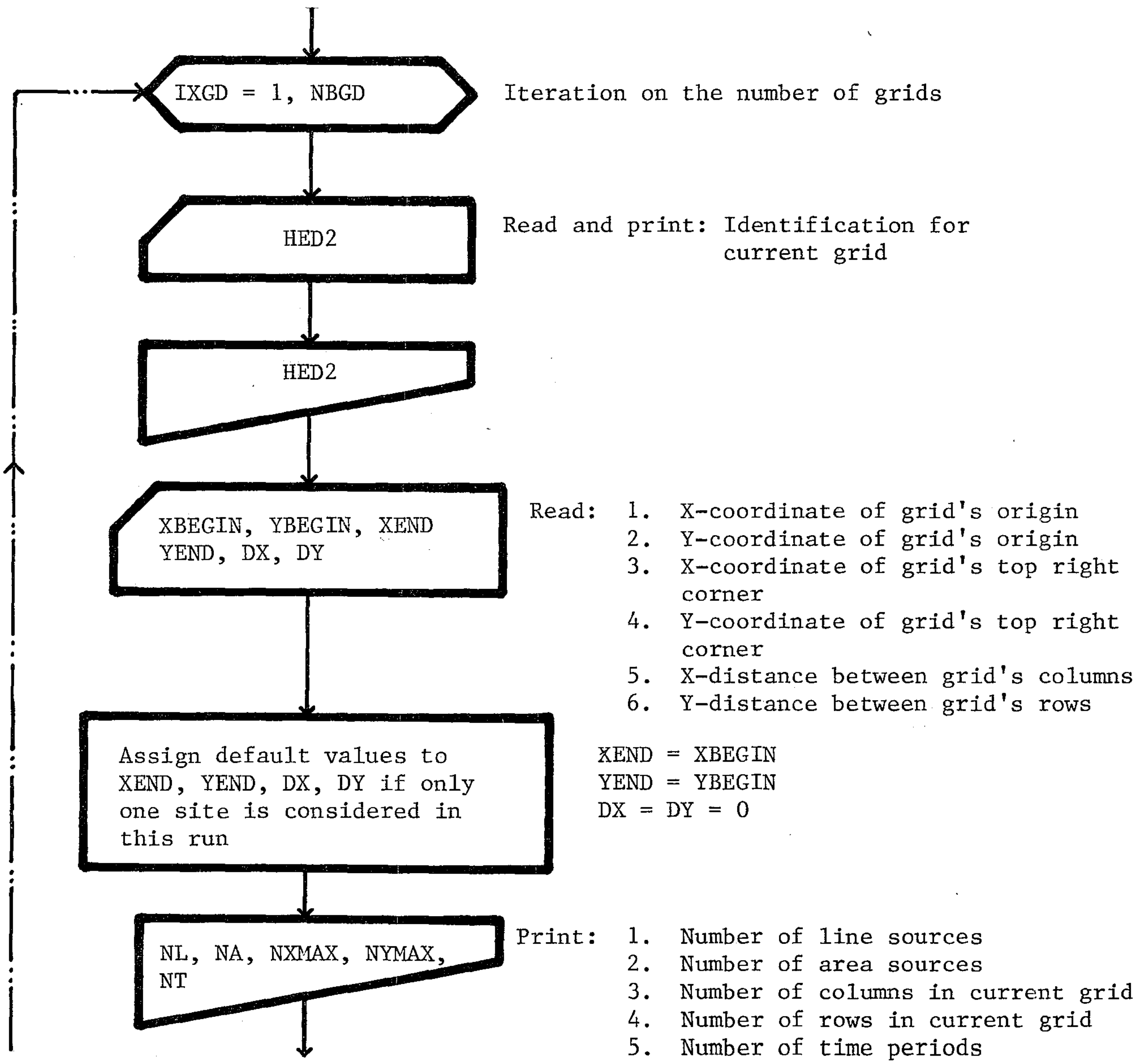

ALPHA2(I), BETA2(I), RML(I), RMMX(I)
Read: 1. Normalized Y-intercept to the right of breaking point
2. Slope of line to the right of breaking point
3. Breaking point magnitude
4. Cutoff magnitude
ALPHA2(I) = 0
T
ALPHA2(I)=ALPHA1(I)
F
BETA2(I) = 0
T
BETA2(I)=BETA1(I)
Assign default values in case there is no breaking point for current sources' recurrence relationship
F
RML(I) = 0
T
RML(I) = 3.00
F
ALPHA(I), BETA1(I), XL1(I), XL2(I), YL1(I), YL2(I), HL(I)
Print: Properties to the left of breaking point
ALPHA2(I), BETA2(I), RML(I), RMMX(I)
Continue
IL = 1, NL
Iteration on the number of line sources
Organize line sources with endpoint coordinates in increasing order

III. Area Sources' Properties



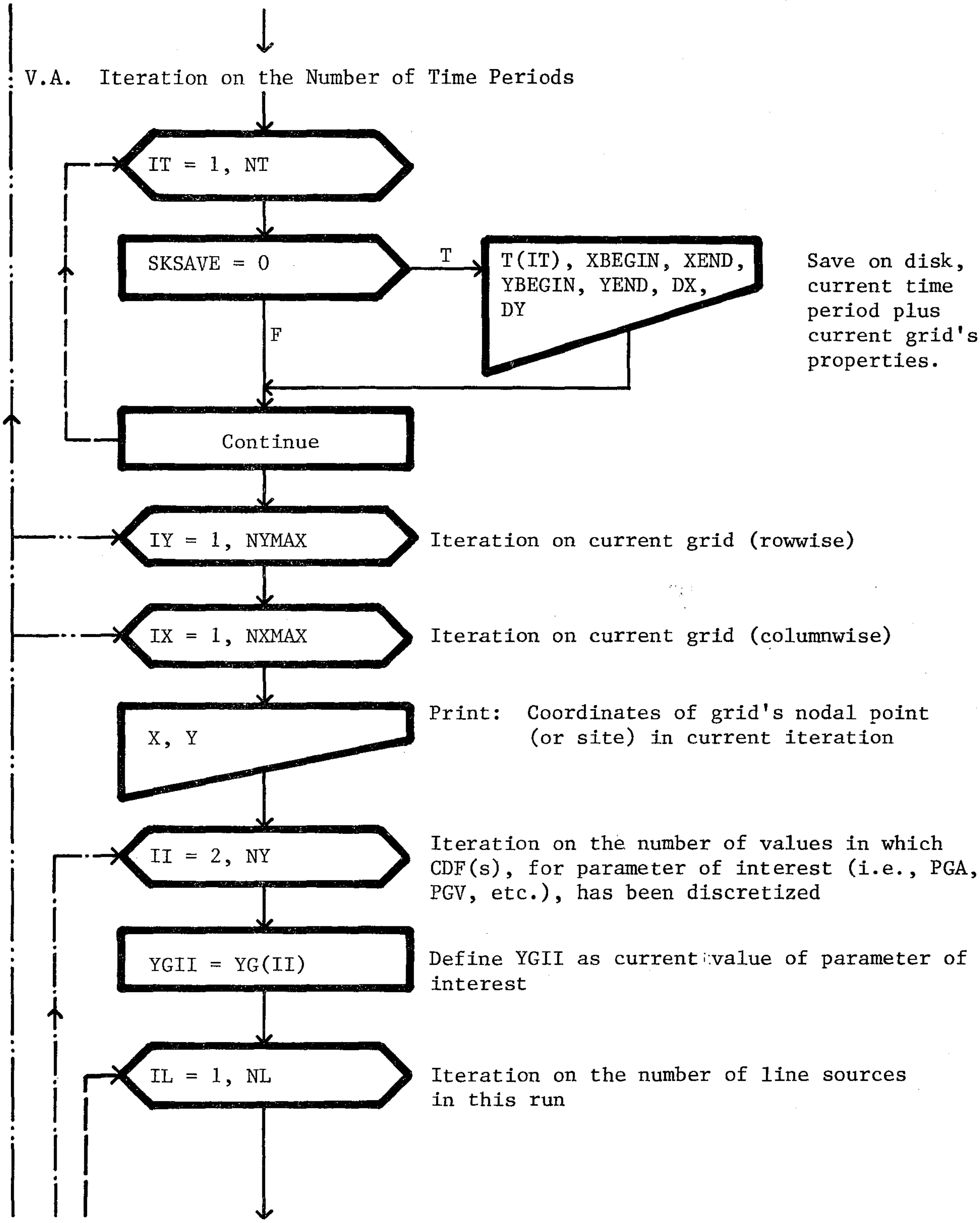


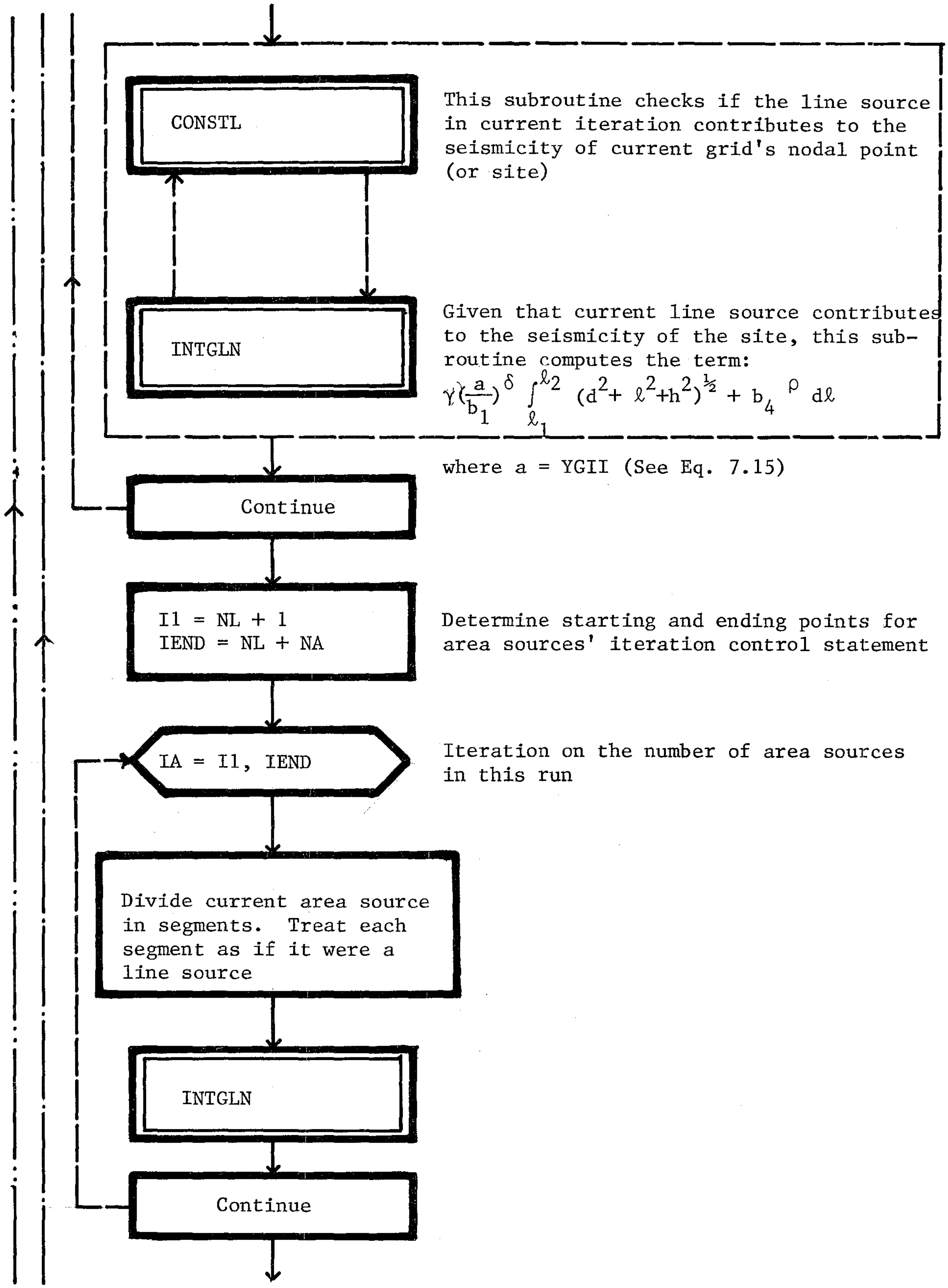
IV. Grid(s) Designation and Properties

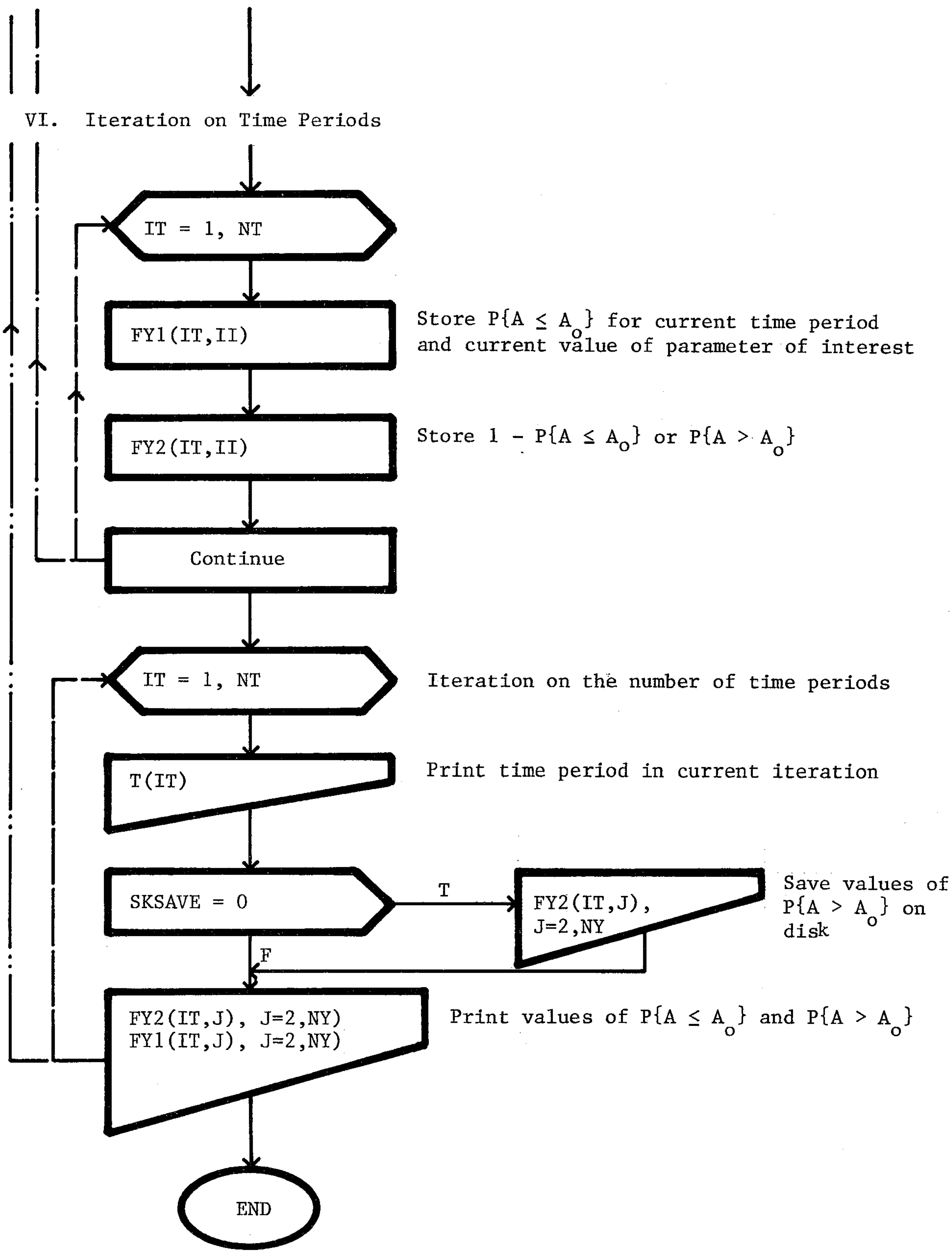


V. Begin Analysis for Nodal Points CDF and PDF Determination

V.A. Iteration on the Number of Time Periods




CONSTL
This subroutine checks if the line source in current iteration contributes to the seismicity of current grid's nodal point (or site)
INTGLN
Given that current line source contributes to the seismicity of the site, this subroutine computes the term:
$\gamma(\frac{a}{b_1})^{\delta} \int_{\ell_1}^{\ell_2} (d^2+\ell^2+h^2)^{\frac{1}{2}} + b_4{}^{\rho}\, d\ell$
where a = YGII (See Eq. 7.15)
Continue
I1 = NL + 1
IEND = NL + NA
Determine starting and ending points for area sources' iteration control statement
IA = I1, IEND
Iteration on the number of area sources in this run
Divide current area source in segments. Treat each segment as if it were a line source
INTGLN
Continue


VI. Iteration on Time Periods
IT = 1, NT
FY1(IT,II)
Store P{A ≤ A_o} for current time period and current value of parameter of interest
FY2(IT,II)
Store 1 - P{A ≤ A_o} or P{A > A_o}
Continue
IT = 1, NT
Iteration on the number of time periods
T(IT)
Print time period in current iteration
SKSAVE = 0
T
FY2(IT,J), J=2,NY
Save values of P{A > A_o} on disk
F
FY2(IT,J), J=2,NY)
FY1(IT,J), J=2,NY)
Print values of P{A ≤ A_o} and P{A > A_o}
END

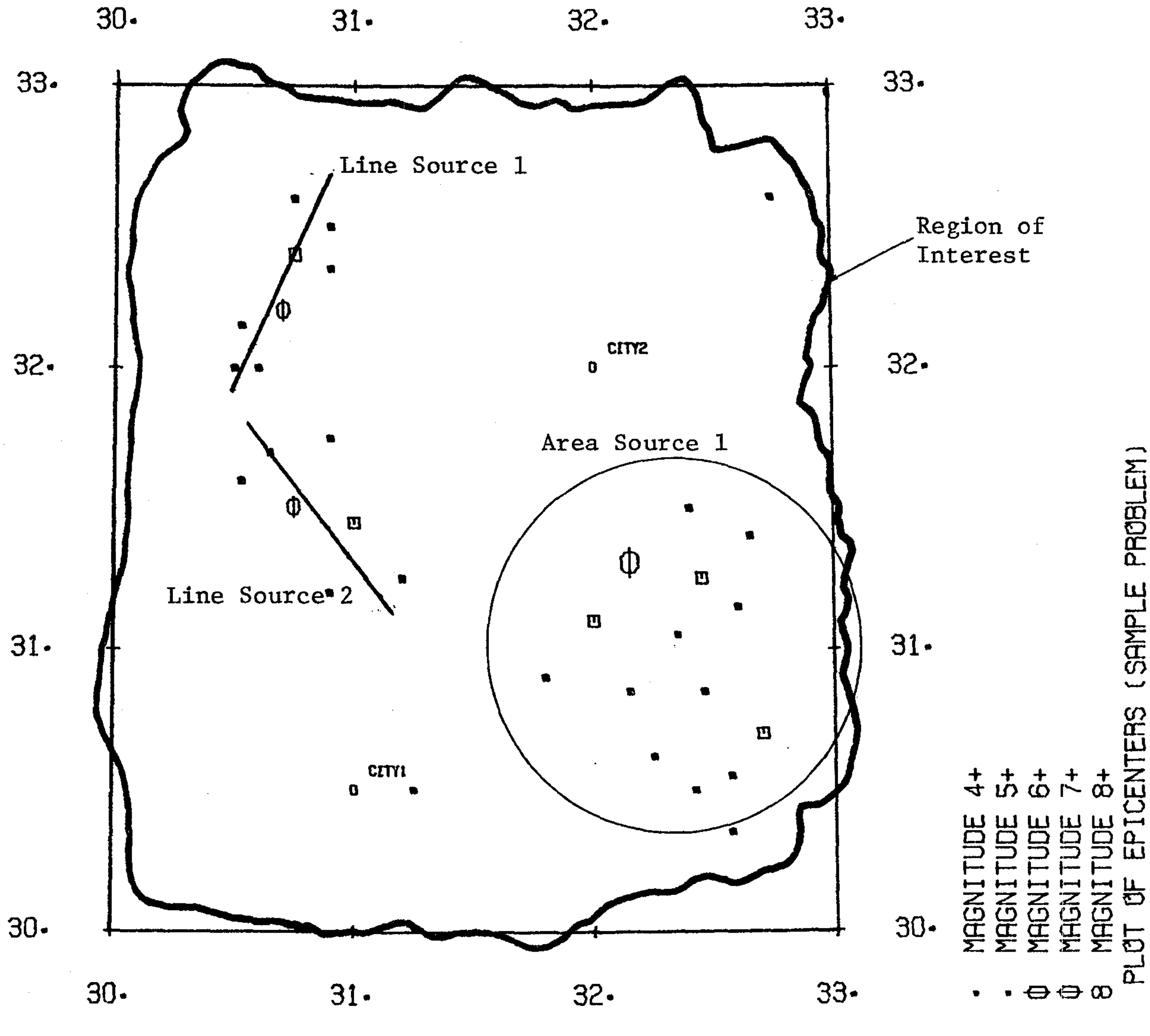


Figure 7-4 Seismic Sources for Region of Interest

7.4 Sample Problem

Suppose that for a particular region of interest, the epicentral map shown in Figure 7-4 has been obtained, and that three seismic sources (two line sources and one area source) have been modeled after correlating past events to major fault systems and tectonic features identified within the region.

The future seismic exposure (PGA) for "CITY2" (see map) for a time period of 50 years is required. For this purpose, the following assumptions are made:

1.) Past earthquake events (as recorded for the region) have been classified as shallow with hypocenters between 0 and 15 km.

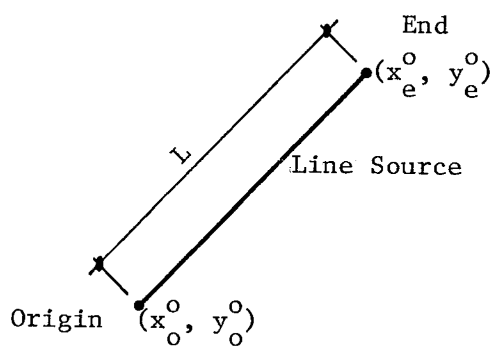
2.) The average depth of the three seismic sources has been set equal to 10 km (0.087 degrees for the particular geographic location).

3.) The length in degrees of the two line sources are, respectively:

Line Source 1 = 0.871^{o}

Line Source 2 = 0.764^{o}

These lengths have been obtained in the following manner:



$$L = \sqrt{(x_e^o - x_o^o)^2 + (y_e^o - y_o^o)^2}$$

4.) The radius (in degrees) of the area source is

$$R = 0.749^{o}$$

and is defined as the distance from the centroid of the epicenters associated to the source to the most distant epicenter in the source.

5.) From regression analysis (Chapter VI), the following recurrence coefficients have been obtained.

Line Source 1 (bi-linear recurrence relationship)

ALPHA1 = 2.58, BETA1 = -1.09; ALPHA2 = 24.00, BETA2 = -4.55

Cutoff magnitude = 6.8, breakpoint magnitude = 6.45

Line Source 2 (bi-linear recurrence relationship)

ALPHA1 = 3.17, BETA1, = -0.74; ALPHA2 = 79.15, BETA2 = -12.4

Cutoff Magnitude = 7.8, breakpoint magnitude = 6.50

Area Source 1 (bi-linear recurrence relationship)

ALPHA1 = 0.14, BETA1 = -0.07, ALPHA2 = 79.90, BETA2 = -13.04

Cutoff magnitude = 6.5, breakpoint magnitude = 6.15

Note: All alpha values have been normalized with respect to time t = 50 years and length or area of source (in degrees).

6.) The attenuation parameters b_1, b_2, b_3, and b_4 in Eq. 7.11 for PGA are as follows:

$b_1 = 0.00429937$

$b_2 = 0.800$

$b_3 = 2.000$

$b_4 = 0.3673769$

7.) Sources' Coordinates and Site

Line Source 1: X-coordinate of origin = 30.50^o (longitude)

Y-coordinate of origin = 31.97^o (latitude)

X-coordinate of end = 30.92^o (longitude)

Y-coordinate of end = 32.62^o (latitude)

Line Source 2: X-coordinate of origin = 30.51^o (longitude)

Y-coordinate of origin = 31.75^o (latitude)

X-coordinate of end = 31.30^o (longitude)

Y-coordinate of end = 31.00^o (latitude)

Area Source 1: X-coordinate of center = 32.39^o (longitude)

Y-coordinate of center = 31.078^o (latitude)

INPUT DATA FOR PROGRAM ACC.LINE.AREA (SAMPLE PROBLEM)

```
PROGRAM ACC.LINE.AREA (SAMPLE PROBLEM) ------------------------------------ I
.000429937 .8       2.0       .3673769    .05       .05 ------------------II
   2    1    1   16    1    1 -------------------------------------------+
  50.                                                                     |
  .05       .10       .15        .20       .25       .30       .35       .40  |III
  .45       .50       .55        .60       .65       .70       .75       .80 --+
LINE SOURCE 1 ------------------------------------------------------------+
 2.58      -1.09      30.50     30.92     31.97     32.62      .087       |
 24.00     -4.55       6.45      6.80                                     |
LINE SOURCE 2                                                             | IV
3.17        -.74     30.51      31.30     31.75     31.00     .087        |
79.15      -12.40      6.50      7.80 ------------------------------------+
AREA SOURCE 1 ------------------------------------------------------------+
.14         -.07     32.39      31.078     .749      .087                 | V
79.90      -13.04      6.15      6.500 -----------------------------------+
SITE OF INTEREST (CITY 2) ------------------------------------------------+
32.00       32.06     32.00      32.06      0.        0. -----------------+ VI
```

Figure 7-5

Site (City2): X-coordinate = 32.00^{o} (longitude)

Y-coordinate = 32.06^{o} (latitude)

Figure 7-5 shows the listing of the input data deck for program ACC.LINE.AREA (Sample Problem). Each data set as described in Section 7.2 is indicated with the corresponding item number.

7.5 Output for Program ACC.LINE.AREA

Figure 7-6 shows the listing of the output for program ACC.LINE.AREA as obtained on the line printer. It contains basically the parameters given in the input list (echo printing), plus the probabilities of exceedance and non-exceedance for each discrete value of the ground parameter of interest (PGA discretized at equal increments of 0.05g) listed under the heading "Probability Distribution of Peak Ground Acceleration."

Figure 7-7 shows a plot of the complementary cumulative distribution function (1-CDF) as computed for the site of interest (CITY2).

7.6 Acceleration Zone Graph (AZG)

Consider the complementary cumulative distribution function on peak ground acceleration for CITY2 and for an exposure time of 50 years (see Fig. 7-7); then

$$P_{50}\{A > 0.10g\} = 0.7512 \qquad (7.16)$$

Equation 7.16 can be interpreted in the following way: for CITY2, there is a 75% chance that during the next 50 years the peak ground acceleration of 0.10g will be exceeded at least once.

Thus, there's a 25% chance that for "CITY2," 0.10g PGA will not be exceeded a single time. Hence,

$$P\{\text{zero exceedance of } 0.10g \text{ in } 50 \text{ years}\} \cong 0.25$$

From the binomial probability law, it is known that for independent trials with probability of success p at each trial, the probability of r successes in n trials is given by:

```
OUTPUT FOR PROGRAM ACC.LINE.AREA (SAMPLE PROBLEM 1)


PROGRAM ACC.LINE.AREA (SAMPLE PROBLEM)
ATTENUATION CONSTANTS

B1=  0.4299370D-03   B2=  0.8000000D+00   B3=  0.2000000D+01   B4=  0.3673769D+00
DELTAL =  0.5000000D-01   DELTAC =  0.5000000D-01

TIME PERIODS
     50.00
ACCELERATIONS
      0.05       0.10       0.15       0.20       0.25       0.30       0.35       0.40       0.45       0.50
      0.55       0.60       0.65       0.70       0.75       0.80
LINE SOURCES
************

LINE SOURCE 1
  ALPHA1          BETA1            XL1           XL2           YL1           YL2           HL
  0.25800D+01  -0.10900D+01   0.30500D+02   0.30920D+02   0.31970D+02   0.32620D+02   0.87000D-01
SECOND REGRESSION CONSTANTS
  ALPHAL2         BETAL2           MR
  0.24000D+02  -0.45500D+01   0.64500D+01   0.68000D+01
LINE SOURCE 2
  ALPHA1          BETA1            XL1           XL2           YL1           YL2           HL
  0.31700D+01  -0.74000D+00   0.30510D+02   0.31300D+02   0.31750D+02   0.31000D+02   0.87000D-01
SECOND REGRESSION CONSTANTS
  ALPHAL2         BETAL2           MR
  0.79150D+02  -0.12400D+02   0.65000D+01   0.78000D+01


AREA SOURCES
************

AREA SOURCE 1
  ALPHA1          BETA1            X0            Y0            R             HA
  0.14000D+00  -0.70000D-01   0.32390D+02   0.31078D+02   0.74900D+00   0.87000D-01
SECOND REGRESSION CONSTANTS
  ALPHA2          BETA2           MR
  0.79900D+02  -0.13040D+02   0.61500D+01   0.65000D+01
*********** P R O B A B I L I T Y  D I S T R I B U T  I O N  O F  P E A K  G R O U N D  A C C E L E R A T I O N
***


SITE OF INTEREST (CITY 2)
GEOMETRIC CONSTANTS

NL=     2     NA =     1     NXMAX=     1     NYMAX=     1     NT=     1

SITE LOCATION
X=     32.000     Y=     32.060
TIME PERIOD =  50.00 YRS
PGA =       0.0500    0.1000    0.1500    0.2000    0.2500    0.3000    0.3500    0.4000    0.4500    0.5000
P(Y>Y0)     1.0000    0.7512    0.0043    0.0       0.0       0.0       0.0       0.0       0.0       0.0
P(Y<Y0)     0.0000    0.2488    0.9957    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
PGA =       0.5500    0.6000    0.6500    0.7000    0.7500    0.8000
P(Y>Y0)     0.0       0.0       0.0       0.0       0.0       0.0
P(Y<Y0)     1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

Figure 7-6

Plot of P{A > A_o} or (1 - CDF) for site (CITY2) and t = 50 years

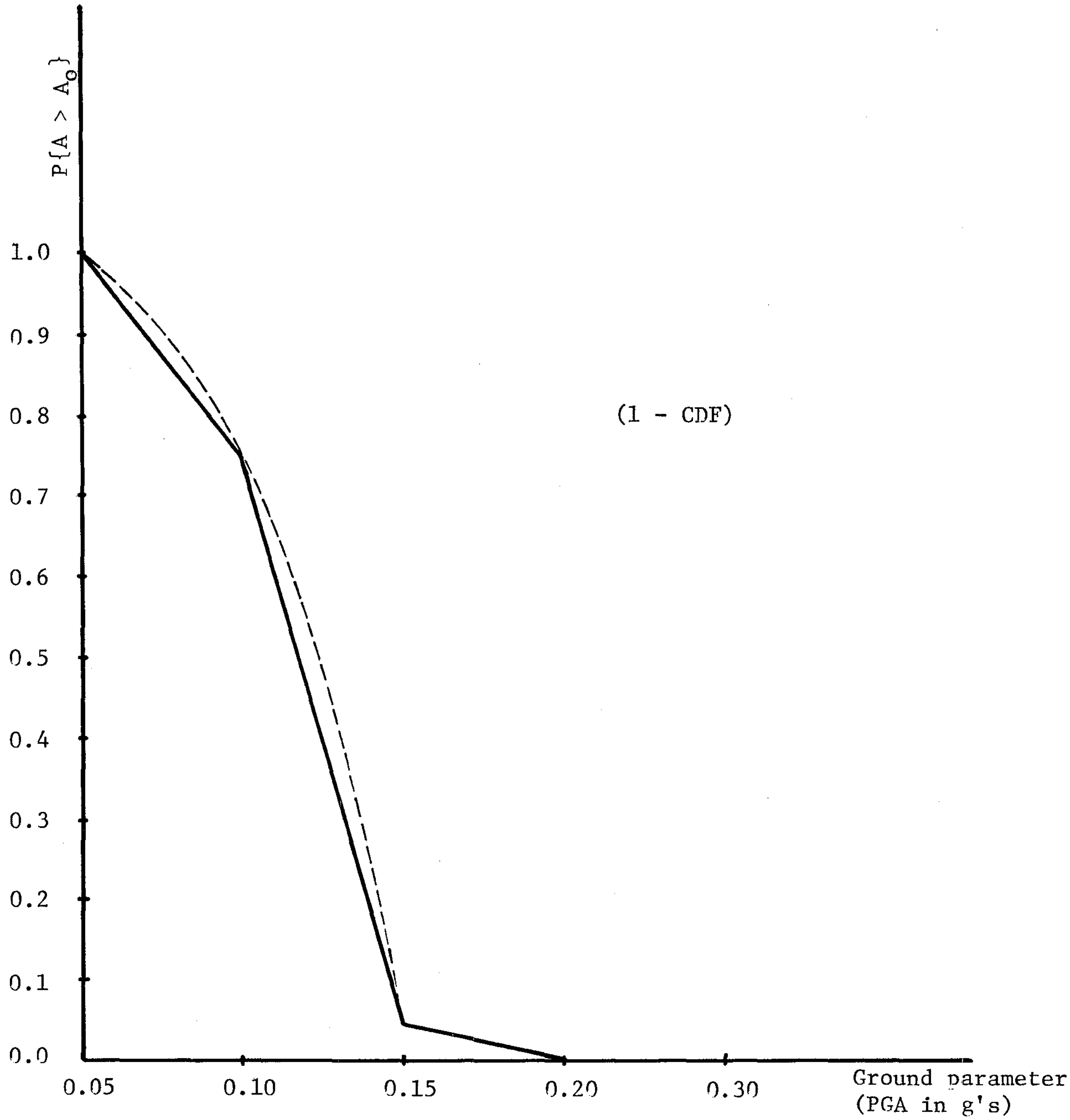


Figure 7-7

$$P_n(r) = \binom{n}{r} p^r (1 - p)^{n-r} \tag{7.17}$$

where $r = 0, 1, 2, \ldots n$ and $\binom{n}{r} = \frac{n!}{r!(n - r)!}$

Let each trial be a one-year duration for which we are observing the level of peak ground acceleration. Define success as that event when the peak ground acceleration for a given trial (year) exceeds 0.10g. Thus, the probability of zero exceedance of level 0.10g in 50 years is the same as the probability of zero successes in 50 trials. Hence from Eq. 7.17:

$$P_{50}(0) = \binom{50}{0} p^o (1 - p)^{50}$$

$$P_{50}(0) = (1 - p)^{50}$$

However,

$$P_{50}(0) = 0.250$$

$$(1 - p)^{50} = 0.250$$

$$\text{or} \quad p = 0.027$$

Thus, for CITY2, there is a 2.7 percent chance that in any given year, a peak ground acceleration of 0.10g will be exceeded. Knowing that the Return Period is defined as:

$$RP = 1/p \tag{7.18}$$

the return period RP in "CITY2" for a peak ground acceleration of 0.10g is $1/0.027 \approx 37$ years.

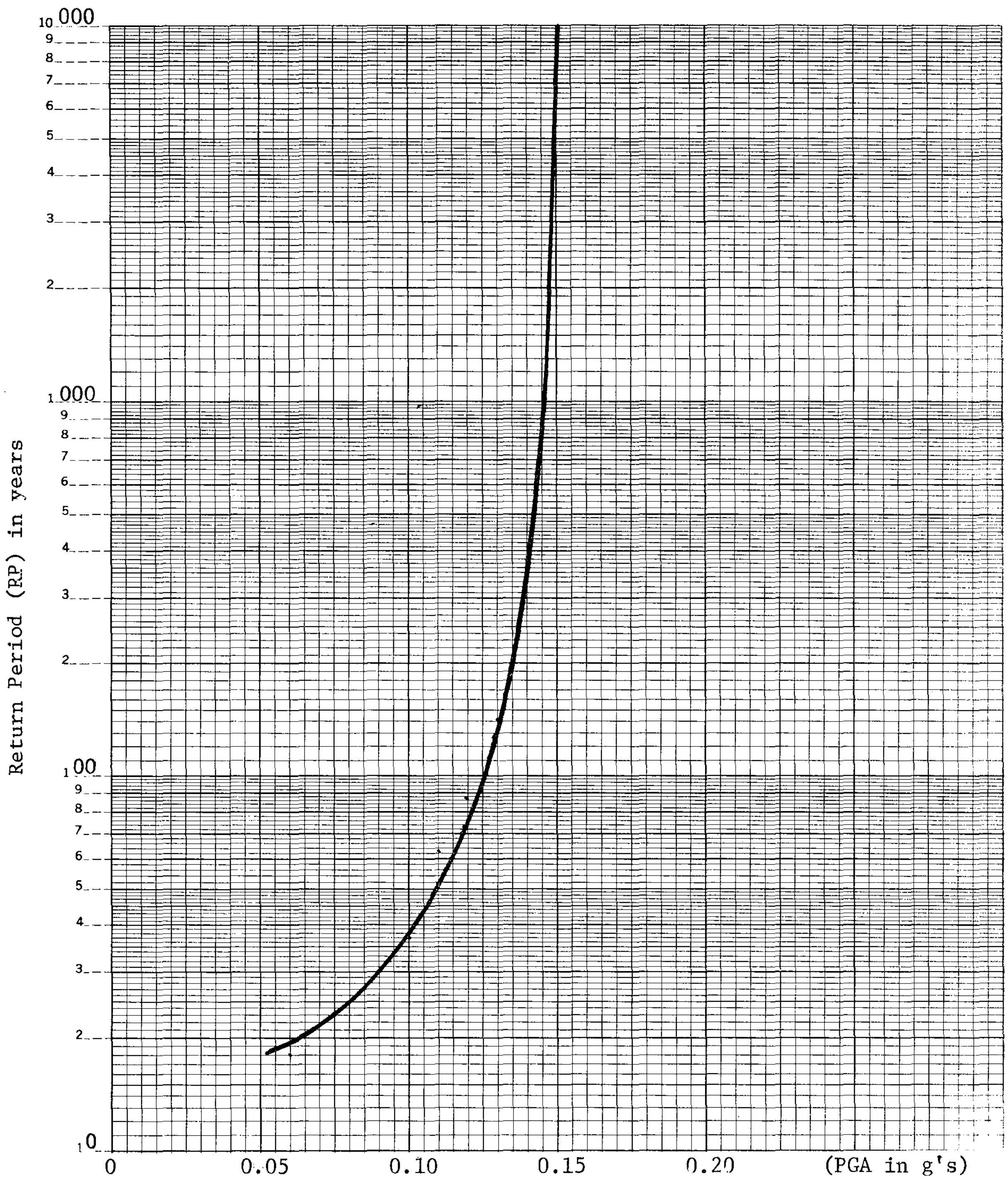
Thus, using the complementary cumulative distribution function computed for "CITY2" (Fig. 7-7), a table of Peak ground acceleration and return period can be developed and plotted to obtain a curve referred to as an Acceleration Zone Graph (AZG). Table 1 and Figure 7-8 show the values of Return Period versus PGA and the AZG for "CITY2."

Table 1

Table of Return Period vs PGA for CITY2

PGA in g units	Return Period in Years
0.06	18
0.075	23
0.100	37
0.110	63
0.120	87
0.130	141
0.140	358
0.150	10000

Figure 7-8 Acceleration Zone Graph (AZG) for CITY2



The acceleration zone graph can be used to estimate the probable future loading on a structure. For this, the designer or analyst must establish a relation between the economic life of the structure (in years), the risk he is willing to take, and the return period. For this, the binomial distribution given by

$$P_n(r) = \binom{n}{r} p^r (1 - p)^{n-r} \qquad (7.17) \text{ (repeated)}$$

is used as follows:

let n = economic life of the structure in years (number of trials)

$P_n(r=0)$ = risk level the analyst is willing to take for the non-exceedance of a loading level.

Assume the exposure life of a structure has been estimated to be 50 years and the risk level taken by the analyst is 10 percent of exceeding a specified load level. Then from Eq. 7.17,

$$0.90 = (1 - p)^{50}$$

$$\text{or} \quad p = 0.0021$$

$$\text{therefore,} \quad RP = \frac{1}{0.0021} \cong 475 \text{ years}$$

From Figure 7-8, for an RP = 475 years, a PGA level of 0.14g is obtained. Normally, this would be the acceleration level used to estimate the lateral load for design purposes.

CHAPTER VIII

Bayesian Approach--Program SORT.MAGNITUDE

8.1 Introduction

In the following chapters, the Bayesian model for seismic hazard analysis will be used. (Figure 1-2, Stage III, Item 1.)

Prior to the execution of the main seismic hazard program, program SEISMIC.HAZARD (Chapter IX), it is necessary for the analyst to sort the seismic events which have been collected for a given region, and which have been organized according to the different seismic sources identified within the region (Figure 5-7), as a function of their Richter Magnitude levels. For this purpose, the implementation of program SORT.MAGNITUDE is necessary.

8.2 Description of Program SORT.MAGNITUDE

Program SORT.MAGNITUDE has been deisgned to sort the earthquake records (in complete form) gathered for a particular region of interest as a function of their Richter Magnitude levels.

The user has to input the earthquake records corresponding to each seismic source and the program will automatically organize the events in increasing order with respect to magnitude bands (where the width of the band has been set equal to 0.25 in the program; see Macro Flow Chart).

The output of the program will be used later (Chapter IX) to obtain the sample likelihood function in the Bernoulli trial of program SEISMIC.HAZARD.

In its present form, program SORT.MAGNITUDE has been organized in a main routine. It contains 38 executable FORTRAN statements and the space requirements is approximately 8400 bytes. The actual version can handle any number of data sets containing any number of earthquake records.

8.3 Description of Input Data

Input data for program SORT.MAGNITUDE will consist of three sets of cards. The organization of the data on each card, along with a description of the items, is given in the following sections.

I. Number of Data Sets to be Sorted--(I5)--One Card

Col.	1-5	NOSC	(number of data sets to be sorted--the earthquake data gathered for each seismic source is considered to constitute a data set).

II. Data Set Identification--(4A4,I4)--One Card

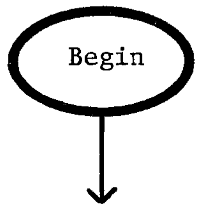
Col.	1-16	HED1	(identification label for data set)
	17-20	NORC	(number of records contained in the set)

III. Earthquake Record--(72X,F4.2)--One Card per Record

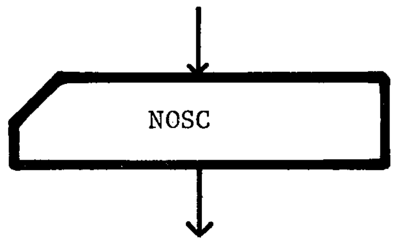
Col.	73-76	RMG	(Richter Magnitude Value for the record)

Note: Do-Loop on NOSC number of data sets, starts at II.

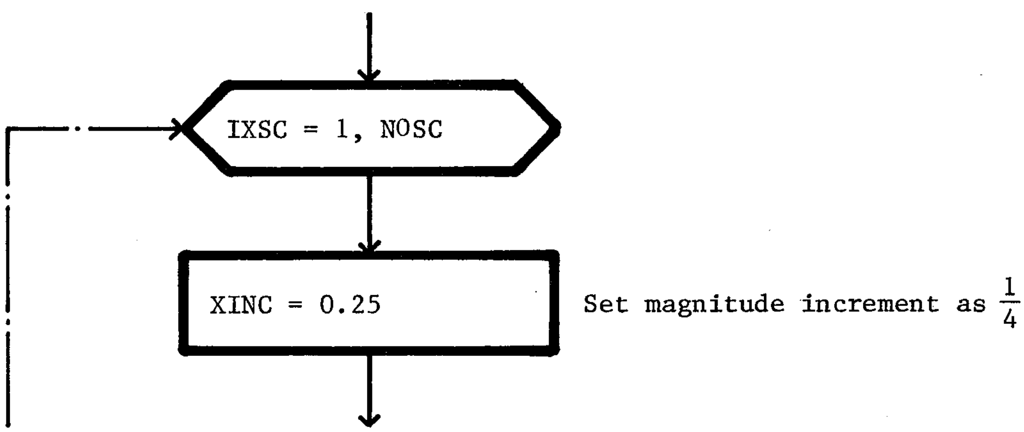
8.4 Macro Flow Chart For Program SORT.MAGNITUDE



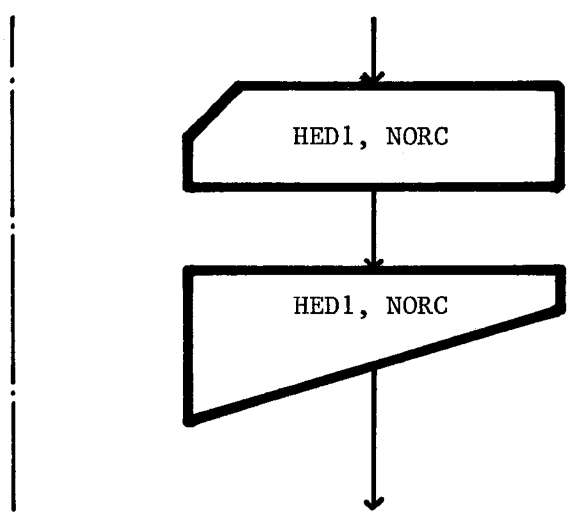
I. Read Number of Data Sets to be Sorted



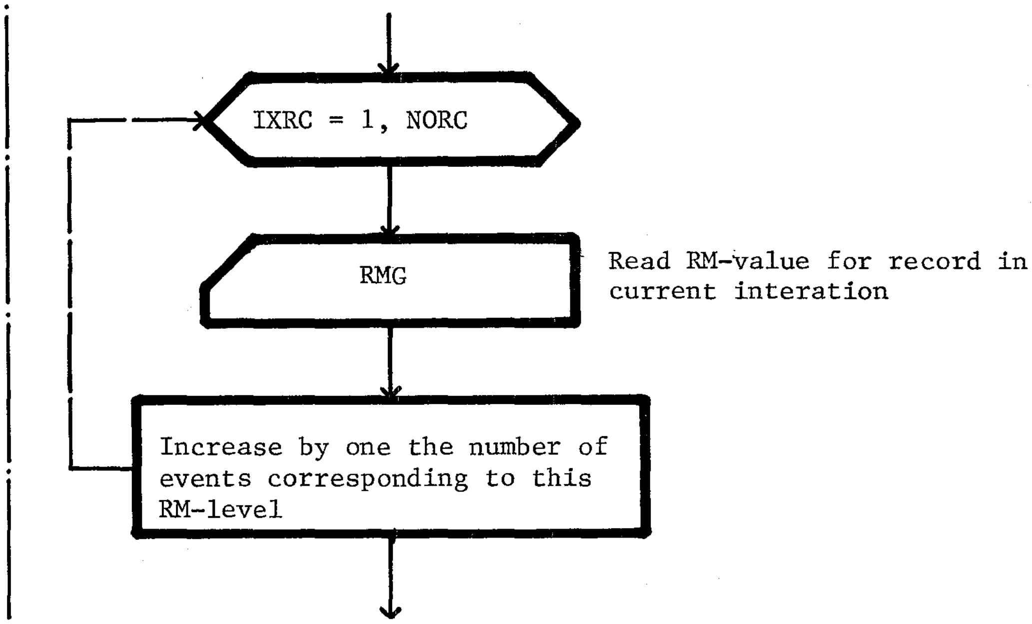
II. Iteration on the Number of Data Sets in this Run



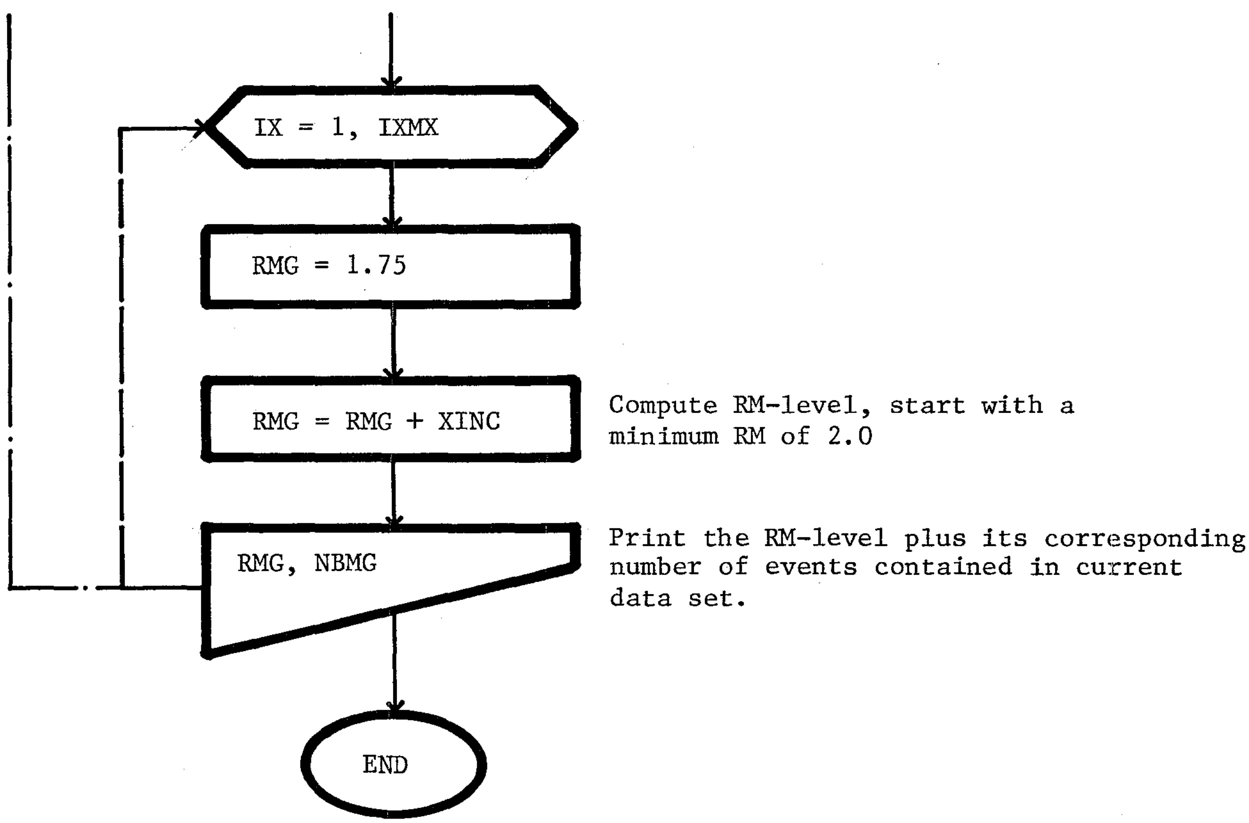
III. Read and Write Data Set Identification plus the Number of Records Contained in the Set



IV. Iteration on the Number of Records in Current Data Set



V. Iteration on the maximum number of RM-increments for current data set.



EARTHQUAKE DATA SORTED BY SOURCES

SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	LATITUDE	LONGITUDE	CLASS	MMI	RADIUS	DEPTH	MS	MB	MR1	MR2	SYMBOL
* SOURCE 1				23												
A.GRAN	24	07	1912	18	06	35.700N	-0.400W	E	7.0			0.00		0.00	4.05	
A.GRAN	19	06	1925	14	44	35.800N	-0.400W	E	6.0			0.00		0.00	4.05	
A.GRAN	20	06	1925	12	33	35.800N	-0.400W	E	6.0			0.00		0.00	4.10	
A.GRAN	21	06	1925	03	01	35.800N	-0.400W	E	6.0			0.00		0.00	4.05	
A.GRAN	04	11	1949	12	36	35.700N	-0.700W	F	5.0	50		0.00		0.00	3.35	
A.GRAN	20	06	1952	16	42	35.800N	-0.200W	F	5.0			0.00		0.00	3.80	
A.GRAN	01	01	1956	07	22	35.800N	-0.300W	F	5.5	20		0.00		0.00	3.70	
A.GRAN	14	02	1957	06	12	35.800N	-0.400W	F	5.0	30		0.00		0.00	3.15	
H.BENH	08	06	1957	18	19	35.700N	-0.500W	E	5.0			0.00		0.00	4.05	
H.BENH	02	10	1957	02	45	35.700N	-0.700W	F	4.5			0.00		0.00	3.20	
H.BENH	12	12	1959	20	00	35.800N	-0.600W	E	7.0	75		0.00		0.00	4.25	
H.BENH	01	06	1960	11	40	35.700N	-0.600W	F	5.0	20		0.00		0.00	3.50	
H.BENH	23	01	1961	02	46	35.800N	-0.300W	F	4.0	25		0.00		0.00	3.25	
H.BENH	15	07	1962	18	56	36.200N	-0.700W	F	4.0			0.00		0.00	3.40	
H.BENH	13	05	1964	13	46	35.500N	-1.500W	E	7.0	70		0.00		4.70	4.70	
H.BENH	27	05	1967	01	54	35.700N	-0.200W	E			011	4.70		4.80	4.80	
H.BENH	24	07	1967	16	36	35.400N	-0.750W	E				0.00		4.50	4.50	
H.BENH	16	08	1967	13	46	35.500N	-1.300W	F				0.00		0.00	3.70	
H.BENH	26	11	1967	07	11	35.500N	-0.500W	F				0.00		0.00	3.90	
H.BENH	31	03	1968	21	25	35.200N	-1.800W	F				0.00		0.00	3.55	
H.BENH	09	09	1970	07	16	35.750N	-0.750W	F	4.5			0.00		0.00	3.70	
A.BENA	12	06	1972	22	38	35.800N	-0.900W		6.0	25		0.00		0.00	3.80	
* SOURCE 2				24												
A.GRAN		03	1819			35.400N	00.100E		10.0			0.00		0.00	5.73	
A.GRAN	22	11	1851	09	30	35.400N	00.100E		8.0			0.00		0.00	5.63	
A.GRAN	08	06	1862	12	45	35.700N	00.500E		6.5			0.00		0.00	4.30	
A.GRAN	29	11	1887	13	30	35.583N	00.333E		9.5			0.00		0.00	5.77	
A.GRAN	30	07	1890			35.700N	00.500E		6.5			0.00		0.00	4.37	
A.GRAN	24	08	1928	09	44	35.900N	00.600E	D	8.0			0.00		5.60	5.60	
A.GRAN	11	01	1929	01	52	35.500N	-0.200W	E	6.5			0.00		0.00	4.25	
A.GRAN	01	04	1939	08	02	35.900N	00.100E	F	6.5			0.00		0.00	3.50	
A.GRAN	28	04	1941	21	12	35.600N	00.000E	F	6.0	40		0.00		0.00	3.85	
A.GRAN	21	05	1950	10	44	35.700N	00.200E	E	5.0	40		0.00		0.00	4.15	
ISS	04	08	1952	12	55	36.700N	00.200E					0.00		0.00	4.50	
A.GRAN	18	08	1953	04	15	35.500N	00.000E	F	5.0			0.00		0.00	3.10	
H.BENH	04	10	1957	17	19	35.700N	00.600E	F	4.0			0.00		0.00	3.75	
A.GRAN	18	10	1957	16	48	35.800N	00.400E	F	5.0	25		0.00		0.00	3.70	
H.BENH	29	10	1957	13	08	35.500N	-0.100W	F	4.5			0.00		0.00	3.95	
H.BENH	01	06	1958	03	16	35.500N	00.000W	F	5.0			0.00		0.00	3.05	
H.BENH	18	03	1959	13	01	35.700N	00.700E	F	4.5			0.00		0.00	3.70	
H.BENH	01	12	1960	15	14	35.800N	00.100E	E	6.5			0.00		0.00	4.25	
H.BENH	20	03	1962	18	15	35.100N	-0.500W	E	7.0			0.00		0.00	4.05	
H.BENH	15	07	1964	11	04	35.500N	00.300E	E	6.0	35		0.00		4.10	4.10	
H.BENH	02	10	1964	09	39	35.600N	00.300E	E	5.0			0.00		4.20	4.20	
H.BENH	13	07	1967	02	10	35.500N	-0.100W	D	7.5		013	5.00		5.10	5.10	
H.BENH	05	04	1969	19	56	35.500N	00.000E	F	6.0			0.00		0.00	3.85	

Figure 8-1

INPUT DATA FOR PROGRAM SORT.MAGNITUDE (SAMPLE PROBLEM)

```
 2                                                                           I
* SOURCE 1        22                                                         II
A.GRAN 24 07 1912 18 06 35.700N -0.400W E  7.0          0.00    0.00    4.05
A.GRAN 19 06 1925 14 44 35.800N -0.400W E  6.0          0.00    0.00    4.05
A.GRAN 20 06 1925 12 33 35.800N -0.400W E  6.0          0.00    0.00    4.10
A.GRAN 21 06 1925 03 01 35.800N -0.400W E  6.0          0.00    0.00    4.05
A.GRAN 04 11 1949 12 36 35.700N -0.700W F  5.0  50      0.00    0.00    3.35
A.GRAN 20 06 1952 16 42 35.800N -0.200W F  5.0          0.00    0.00    3.80
A.GRAN 01 01 1956 07 22 35.800N -0.300W F  5.5  20      0.00    0.00    3.70
A.GRAN 14 02 1957 06 12 35.800N -0.400W F  5.0  30      0.00    0.00    3.15   III
H.BENH 08 06 1957 18 19 35.700N -0.500W E  5.0          0.00    0.00    4.05
H.BENH 02 10 1957 02 45 35.700N -0.700W F  4.5          0.00    0.00    3.20
H.BENH 12 12 1959 20 00 35.800N -0.600W E  7.0  75      0.00    0.00    4.25
H.BENH 01 06 1960 11 40 35.700N -0.600W F  5.0  20      0.00    0.00    3.50
H.BENH 23 01 1961 02 46 35.800N -0.300W F  4.0  25      0.00    0.00    3.25
H.BENH 15 07 1962 18 56 36.200N -0.700W F  4.0          0.00    0.00    3.40
H.BENH 13 05 1964 13 46 35.500N -1.500W E  7.0  70      0.00    4.70    4.70
H.BENH 27 05 1967 01 54 35.700N -0.200W E           011 4.70    4.80    4.80
H.BENH 24 07 1967 16 36 35.400N -0.750W E               0.00    4.50    4.50
H.BENH 16 08 1967 13 46 35.500N -1.300W F               0.00    0.00    3.70
H.BENH 26 11 1967 07 11 35.500N -0.500W F               0.00    0.00    3.90
H.BENH 31 03 1968 21 25 35.200N -1.800W F               0.00    0.00    3.55
H.BENH 09 09 1970 07 16 35.750N -0.750W F  4.5          0.00    0.00    3.70
A.BENA 12 06 1972 22 38 35.800N -0.900W    6.0  25      0.00    0.00    3.80
* SOURCE 2        23                                                         I
A.GRAN    03 1819       35.400N 00.100E   10.0          0.00    0.00    5.73   II
A.GRAN 22 11 1851 09 30 35.400N 00.100E    8.0          0.00    0.00    5.63
A.GRAN 08 06 1862 12 45 35.700N 00.500E    6.5          0.00    0.00    4.30
A.GRAN 29 11 1887 13 30 35.583N 00.333E    9.5          0.00    0.00    5.77
A.GRAN 30 07 1890       35.700N 00.500E    6.5          0.00    0.00    4.37
A.GRAN 24 08 1928 09 44 35.900N 00.600E D  8.0          0.00    5.60    5.60
A.GRAN 11 01 1929 01 52 35.500N -0.200W E  6.5          0.00    0.00    4.25
A.GRAN 01 04 1939 08 02 35.900N 00.100E F  6.5          0.00    0.00    3.50
A.GRAN 28 04 1941 21 12 35.600N 00.000E F  6.0  40      0.00    0.00    3.85
A.GRAN 21 05 1950 10 44 35.700N 00.200E E  5.0  40      0.00    0.00    4.15
ISS    04 08 1952 12 55 36.700N 00.200E                 0.00    0.00    4.50   III
A.GRAN 18 08 1953 04 15 35.500N 00.000E F  5.0          0.00    0.00    3.10
H.BENH 04 10 1957 17 19 35.700N 00.600E F  4.0          0.00    0.00    3.75
A.GRAN 18 10 1957 16 48 35.800N 00.400E F  5.0  25      0.00    0.00    3.70
H.BENH 29 10 1957 13 08 35.500N -0.100W F  4.5          0.00    0.00    3.95
H.BENH 01 06 1958 03 16 35.500N 00.000W F  5.0          0.00    0.00    3.05
H.BENH 18 03 1959 13 01 35.700N 00.700E F  4.5          0.00    0.00    3.70
H.BENH 01 12 1960 15 14 35.800N 00.100E E  6.5          0.00    0.00    4.25
H.BENH 20 03 1962 18 15 35.100N -0.500W E  7.0          0.00    0.00    4.05
H.BENH 15 07 1964 11 04 35.500N 00.300E E  6.0  35      0.00    4.10    4.10
H.BENH 02 10 1964 09 39 35.600N 00.300E E  5.0          0.00    4.20    4.20
H.BENH 13 07 1967 02 10 35.500N -0.100W D  7.5      013 5.00    5.10    5.10
H.BENH 05 04 1969 19 56 35.500N 00.000E F  6.0          0.00    0.00    3.85
```

Figure 8–2

8.5 Sample Problem

Assume that for a given region, the past seismic events have been grouped into two Seismic Sources (Source 1 and Source 2, respectively). Figure (8-1) shows the earthquake data sorted by sources and organized in chronological order. The events are to be sorted as a function of their Richter Magnitude.

In this particular example, two data sets will be processed, namely:

- Earthquakes Associated to Source 1
- Earthquakes Associated to Source 2

Figure (8-2) shows the listing of the input data deck. Each data set as described in Section 8.3 is indicated with the corresponding item number.

8.6 Output for Program SORT.MAGNITUDE

Figure (8-3) shows a listing of the output for program SORT.MAGNITUDE (Sample Problem). Note that for each data set (Source 1 and Source 2), the number of events with Richter Magnitude levels falling within the magnitude ranges (RM $\pm$ 0.125) have been listed.

For example, consider Source 1 and note that between the Magnitude range ($3.875 \leq RM = 4.00 \leq 4.125$), 6 events out of 22 were located.

```
OUTPUT FOR PROGRAM SORT.MAGNITUDE (SAMPLE PROBLEM)


* SOURCE 1             NUMBER OF RECORDS    22
    0 EVENTS SMALLER THAN RM 2.    TOTAL       22
MAGNITUDE 2.00  PLUS          0  EVENTS
MAGNITUDE 2.25  PLUS          0  EVENTS
MAGNITUDE 2.50  PLUS          0  EVENTS
MAGNITUDE 2.75  PLUS          0  EVENTS
MAGNITUDE 3.00  PLUS          0  EVENTS
MAGNITUDE 3.25  PLUS          4  EVENTS
MAGNITUDE 3.50  PLUS          3  EVENTS
MAGNITUDE 3.75  PLUS          5  EVENTS
MAGNITUDE 4.00  PLUS          6  EVENTS
MAGNITUDE 4.25  PLUS          1  EVENTS
MAGNITUDE 4.50  PLUS          1  EVENTS
MAGNITUDE 4.75  PLUS          2  EVENTS
* SOURCE 2             NUMBER OF RECORDS    23
    0 EVENTS SMALLER THAN RM 2.    TOTAL       23
MAGNITUDE 2.00  PLUS          0  EVENTS
MAGNITUDE 2.25  PLUS          0  EVENTS
MAGNITUDE 2.50  PLUS          0  EVENTS
MAGNITUDE 2.75  PLUS          0  EVENTS
MAGNITUDE 3.00  PLUS          2  EVENTS
MAGNITUDE 3.25  PLUS          0  EVENTS
MAGNITUDE 3.50  PLUS          1  EVENTS
MAGNITUDE 3.75  PLUS          5  EVENTS
MAGNITUDE 4.00  PLUS          3  EVENTS
MAGNITUDE 4.25  PLUS          6  EVENTS
MAGNITUDE 4.50  PLUS          1  EVENTS
MAGNITUDE 4.75  PLUS          0  EVENTS
MAGNITUDE 5.00  PLUS          1  EVENTS
MAGNITUDE 5.25  PLUS          0  EVENTS
MAGNITUDE 5.50  PLUS          1  EVENTS
MAGNITUDE 5.75  PLUS          3  EVENTS
```

Figure 8-3

CHAPTER IX

Bayesian Approach--Program SEISMIC.HAZARD

9.1 Introduction

The Bayesian Approach (one of the two seismic hazard models, see Figure 1-2) is discussed and implemented through the use of program SEISMIC.HAZARD.

The four key ëlements associated with the seismic hazard models are:

- Source Geometry
- Earthquake Recurrence Model
- Tectonic Model and Travel Path
- Attenuation Characteristics and Associated Uncertainty

Their treatment under the present approach, along with a summary of the theory behind the present model is presented. A description of the program and a practical example is included.

9.2 Theoretical Background*

Earthquake Recurrence Model

Earthquake occurrences are assumed to follow a Poisson process with mean rate of occurrence independent of magnitude. In its most general form, the conditional Poisson Law can be written as:

$$P_N(n/\lambda) = \frac{e^{-\lambda t}(\lambda t)^n}{n!} \tag{9.1}$$

for $t > 0$ and $n = \text{integer} \geq 0$

*Taken from Reference 5.

where: $P_N(n/\lambda)$ = Probability of having n events in time period t, given λ.

n = Number of events.

λ = Mean rate of occurrence per unit of time

A Bayesian approach is used so that historical data and subjective information can be effectively combined and used in the analysis. Assuming that the number of seismic events for a future time t follows a Poisson Law, there is still uncertainty about the parameter λ, the mean rate of occurrence in Eq. 9.1. Therefore, λ is treated as a random variable. The probabilistic information on λ can be obtained through historical data or from subjective knowledge of the analyst. The subjective probability distribution on λ is called the prior distribution. The concept of conjugate prior is used for analytical simplicity.

The prior distribution for the random variable λ is chosen as the gamma distribution with parameters λ' and υ'. The prior can thus be written as:

$$f'\Lambda(\lambda) = \frac{\lambda'(\lambda'\lambda)^{\upsilon'-1}e^{-\lambda'\lambda}}{\Gamma(\upsilon')} \qquad \lambda > 0;\ \lambda' > 0;\ \upsilon' > 0 \qquad (9.2)$$

where: $\Gamma(\upsilon') = \int_0^\infty e^{-u}u^{\upsilon'-1}du$

The sample likelihood function on λ is obtained by using the historical information available for the region. Since the event-generating process is assumed to be a Poisson process, the sample likelihood function on λ is given by

$$L(\lambda/N,T) = \frac{e^{-\lambda T}(\lambda T)^N}{N!} \qquad T > 0;\ N \geq 0 \qquad (9.3)$$

where: T = time of the data base

N = number of events greater than a fixed lower bound M observed during time period T

Combining the prior distribution and the sample likelihood function by means of Bayes' theorem, the posterior distribution on λ is obtained as:

$$f''_{\Lambda}(\lambda) = N_1 L(\lambda) f'_{\Lambda}(\lambda) \tag{9.4}$$

where: N_1 is a normalizing constant

Introducing N_1, $L(\lambda)$ and $f'(\lambda)$ in Eq. 9.4, the posterior distribution is written as:

$$f''_{\Lambda}(\lambda) = \frac{\lambda''(\lambda''\lambda)^{\upsilon''-1} e^{-\lambda''\lambda}}{\Gamma(\upsilon'')} \qquad \lambda \geq 0;\ \lambda'' > 0;\ \upsilon'' > 0 \tag{9.5}$$

where: $\lambda'' = \lambda' + T$

$\upsilon'' = \upsilon' + N$

In Eq. 9.1, the conditional probability on the number of events n is based on λ. The unconditional or the marginal distribution on n can be obtained by using Eq. 9.5 together with Eq. 9.1 and integrating over all λs. Thus,

$$P_N(n) = \frac{\Gamma(n + \upsilon'')}{n!\,\Gamma(\upsilon'')} \quad \frac{t^n \lambda''^{\upsilon''}}{(t + \lambda'')^{n+\upsilon''}} \tag{9.6}$$

for $n \geq 0$; $\upsilon'' > 0$; $\lambda'' > 0$ and $t > 0$

Equation 9.6 is called the Marginal Bayesian distribution of n and it gives the probability of the number of events above a predetermined lower bound M, in time period t.

Richter Magnitude

A Bernoulli trial is used to model information on magnitudes. Given that an event has occurred, the probability that it is of any given Richter Magnitude can be represented in terms of a Bernoulli trial. If the seismic event that has occurred is of the M under consideration, then the outcome of the Bernoulli trial is a success. Conversely, failure at each trial implies that the seismic event that has occurred is of M other than the one under consideration.

The available data on Richter Magnitude have been discretized every ¼ Richter unit (M_i). The number of different Mi's expected to occur is thus finite. This allows for the use of a discrete probability model.

If p_{M_i} = probability of success at each trial corresponding to M_i and $q_{Mi} = 1 - p_{M_i}$ = probability of failure at each trial, using the binomial law:

$$P_R(r_{Mi}/n, p_{M_i}) = C_n^{r_{M_i}} p_{M_i}^{r_{M_i}} (1 - p_{M_i})^{n-r_{M_i}} \tag{9.7}$$

for n integer > 0, r_{M_i} = integer; $0 \leq r_{M_i} \leq n$ and $0 \leq p_{M_i} \leq 1$

where: $P_R(r_{M_i}/n, p_{M_i})$ is the probability that r_{M_i} events of Magnitude M_i will occur out of a total of n events given that the probability of occurrence of M_i is p_{M_i} at each trial, and:

$$C_n^{r_{M_i}} = \frac{n!}{r_{M_i}!(n - r_{M_i})!}$$

Equation 9.7 represents the generating process for the number of events M_i. However, this information in conditional on the knowledge about p_{M_i} (the probability of success corresponding to M_i), to incorporate the historical as well as subjective information on p_{M_i}, this parameter is treated as a random variable and a Bayesian formulation is used.

The conjugate prior distribution on p_{M_i} is assumed to be Beta type and is given by:

$$f'_p(p_{M_i}) = \frac{1}{B'_{M_i}} p_{M_i}^{\varepsilon'_{M_i}-1} (1 - p_{M_i})^{\eta'_{M_i}-\varepsilon'_{M_i}-1} \qquad (9.8)$$

$$\text{For } 0 \le p_{M_i} \le 1,\ \varepsilon'_{M_i} \ge 0,\ \eta'_{M_i} - \varepsilon'_{M_i} \ge 0$$

$$\text{where: } B'_{M_i} = \frac{\Gamma(\varepsilon'_{M_i})\Gamma(\eta'_{M_i} - \varepsilon'_{M_i})}{\Gamma(\eta'_{M_i})}$$

and the parameters η'_{M_i} and ε'_{M_i} are obtained from the subjective information. A prior distribution of a similar form has to be assumed for each of the magnitudes considered.

Using historical information one can obtain the sample likelihood function on p_{M_i}. Noting that the generating process (Eq. 9.7) is a binomial process, the sample likelihood function on p_{M_i} is given by:

$$L(p_{M_i}/N, R_{M_i}) = p_{M_i}^{R_{M_i}} (1 - p_{M_i})^{N-R_{M_i}} \qquad (9.9)$$

This operation must be repeated for each of the different magnitudes considered and combined with the corresponding prior distributions to obtain the posterior distributions.

From Equations 9.8 and 9.9, the posterior distribution can be written as:

$$f''_p(p_{M_i}) = \frac{1}{B''_{M_i}} p_{M_i}^{\varepsilon''_{M_i}-1} (1 - p_{M_i})^{\eta''_{M_i}-\varepsilon''_{M_i}-1} \qquad (9.10)$$

$$\text{for } 0 \le p_{M_i} \le 1,\ \varepsilon''_{M_i} \ge 0,\ \eta''_{M_i} - \varepsilon''_{M_i} \ge 0$$

$$\text{where: } \varepsilon''_{M_i} = \varepsilon'_{M_i} + R_{M_i}$$

$$\eta''_{M_i} = \eta'_{M_i} + N$$

$$B''_{M_i} = \frac{\Gamma(\xi''_{M_i})\Gamma(\eta''_{M_i} - \xi''_{M_i})}{\Gamma(\eta''_{M_i})}$$

In Eq. 9.7, the conditional probability on the number of successes r_{M_i} is based on p_{M_i} and n. The condition on p_{M_i} can be removed using Eq. 9.10 and integrating over all the values of p_{M_i}. Thus,

$$P_R(r_{M_i}/n) = C_n^{r_{M_i}} \left\{ \frac{\Gamma(\eta''_{M_i})}{\Gamma(\xi''_{M_i})\Gamma(\eta''_{M_i} - \xi''_{M_i})} \cdot \frac{\Gamma(\alpha_{M_i})\Gamma(\beta_{M_i} - \alpha_{M_i})}{\Gamma(\beta_{M_i})} \right\} \qquad (9.11)$$

for n integer > 0, r_{M_i} integer, $0 \le r_{M_i} \le n$

where: $r_{M_i} + \xi''_{M_i} = \alpha_{M_i}$

$n + \eta''_{M_i} = \beta_{M_i}$

The above expression is the distribution on the number of earthquakes of a fixed M_i given that n earthquakes have occurred. There is a similar distribution for each M_i considered.

The distribution of the number of events of each magnitude independently of the number of trials is obtained by combining Eq. 9.11 and Eq. 9.6. Thus,

$$P_R(r_{M_i}) = \sum_{n=0}^{\infty} \left\{ C_n^{r_{M_i}} \frac{\Gamma(\eta''_{M_i})}{\Gamma(\xi''_{M_i})\Gamma(\eta''_{M_i} - \xi''_{M_i})} \cdot \frac{\Gamma(r_{M_i} + \xi''_{M_i})\Gamma(n + \eta''_{M_i} - r_{M_i} - \xi''_{M_i})}{\Gamma(n + \eta''_{M_i})} \cdot \frac{\Gamma(n + \upsilon'')t^n \lambda''^{\upsilon''}}{n!\Gamma(\upsilon'')(t+\lambda'')^{n+\upsilon''}} \right\} \qquad (9.12)$$

Seismic Sources Geometry

The present model considers two different types of sources to represent the seismicity of a given region. They are:

- Area Sources
- Line Sources

Area Sources

When past earthquake epicenters do not lie on a line (i.e., along a given fault line) but are scattered over a region, the seismic source is considered as an area source. The present model (unlike the Classical Model--Chapter VII, which considers only sources at constant depth under the surface of the ground) introduces the concept of dipping plane sources (trapezoids or triangles), allowing for the modelling of dipping faults. Planes can be vertical or dipping at an angle. If a change of direction or dip occurs within a source, a number of trapezoids can be combined to accomodate the geometry (see Figure 9-1). Area Sources as defined in the Classical Model (Chapter VII) can still be represented by near horizontal trapezoids.

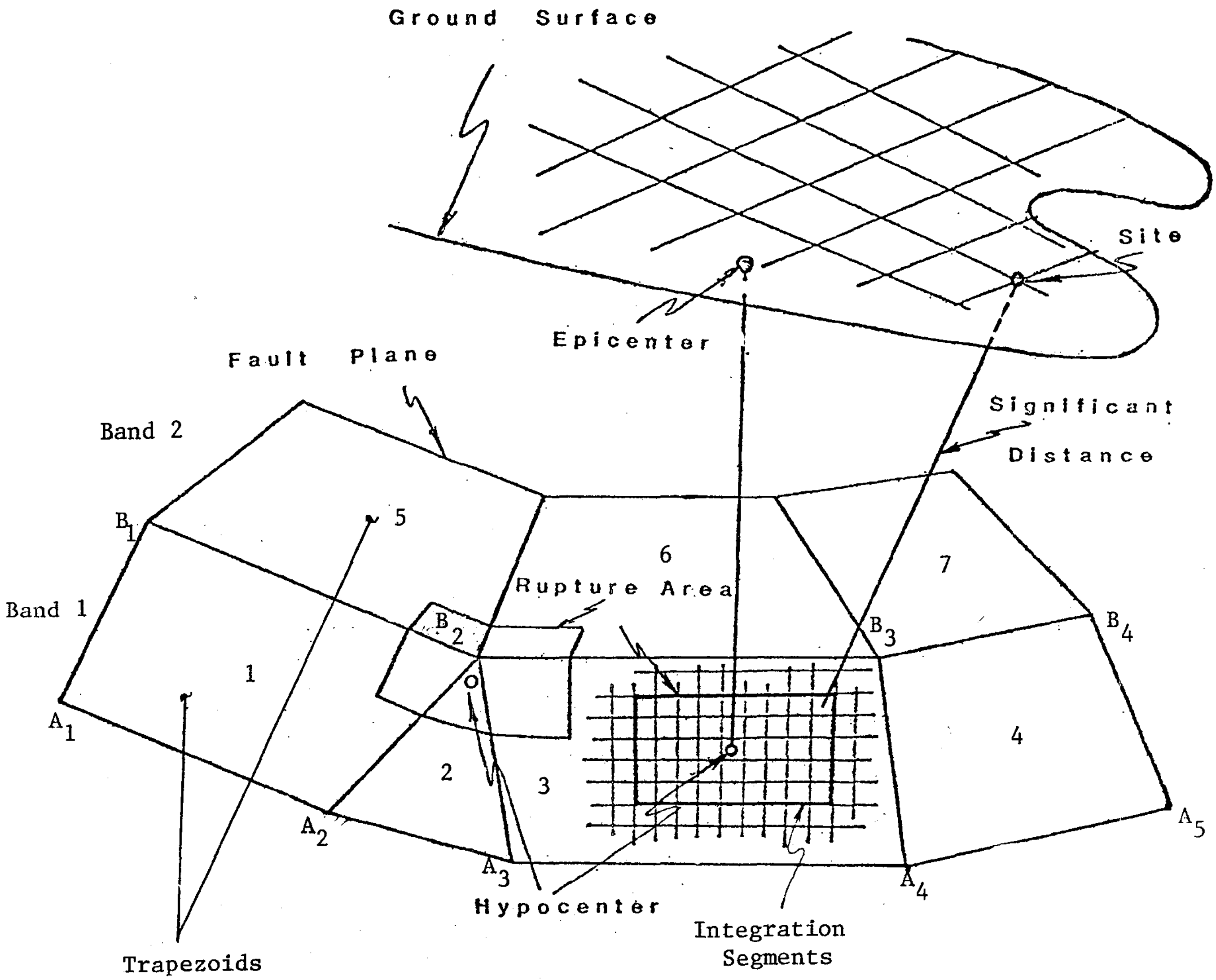
Line Sources

Line sources are used to model regions where recorded hypocenters lie fairly well along a line at constant depth. The source can be broken up in several segments to satisfy geometric constraints.

Tectonic Model and Travel Path

The present model incorporates the fault rupture concept first proposed by Ang (1974) and further developed by DerKiureghian and Ang (1975, 1977). The model is based on the assumption that an earthquake originates at the focus and propagates as an intermittant series of fault slips in the ruptured zone of the earth's crust. The maximum intensity of ground shaking at a site is determined by the slip that is closest to the site (Significant Distance, see Figure 9-1).

Figure 9-1 Typical Dipping Fault Surface



The length of rupture can be related to the total energy released. Several relationships have been presented (Krinitzsky, 1974; Patwardhan and others, 1975).

Specific boundary conditions are required to determine the rupture process near the extremities of the fault to satisfy geometric constraints (fault dimensions) as well as seismic ones (rupture areas).

The three possible boundary conditions are shown in Figure 9-2.

Strong Ground Motion Attenuation

The most commonly used attenuation relationships are of the form:

$$a = f(M, R) \tag{9.13}$$

where: a = ground motion parameter

M = Magnitude of event

R = distance from point of energy release to site

These relationships are based on regression analysis of the pertinent ground motion data. Confidence intervals for the least square fit are quite wide because of a considerable data scatter. Therefore there is a high degree of uncertainty associated with values as predicted by these relationships.

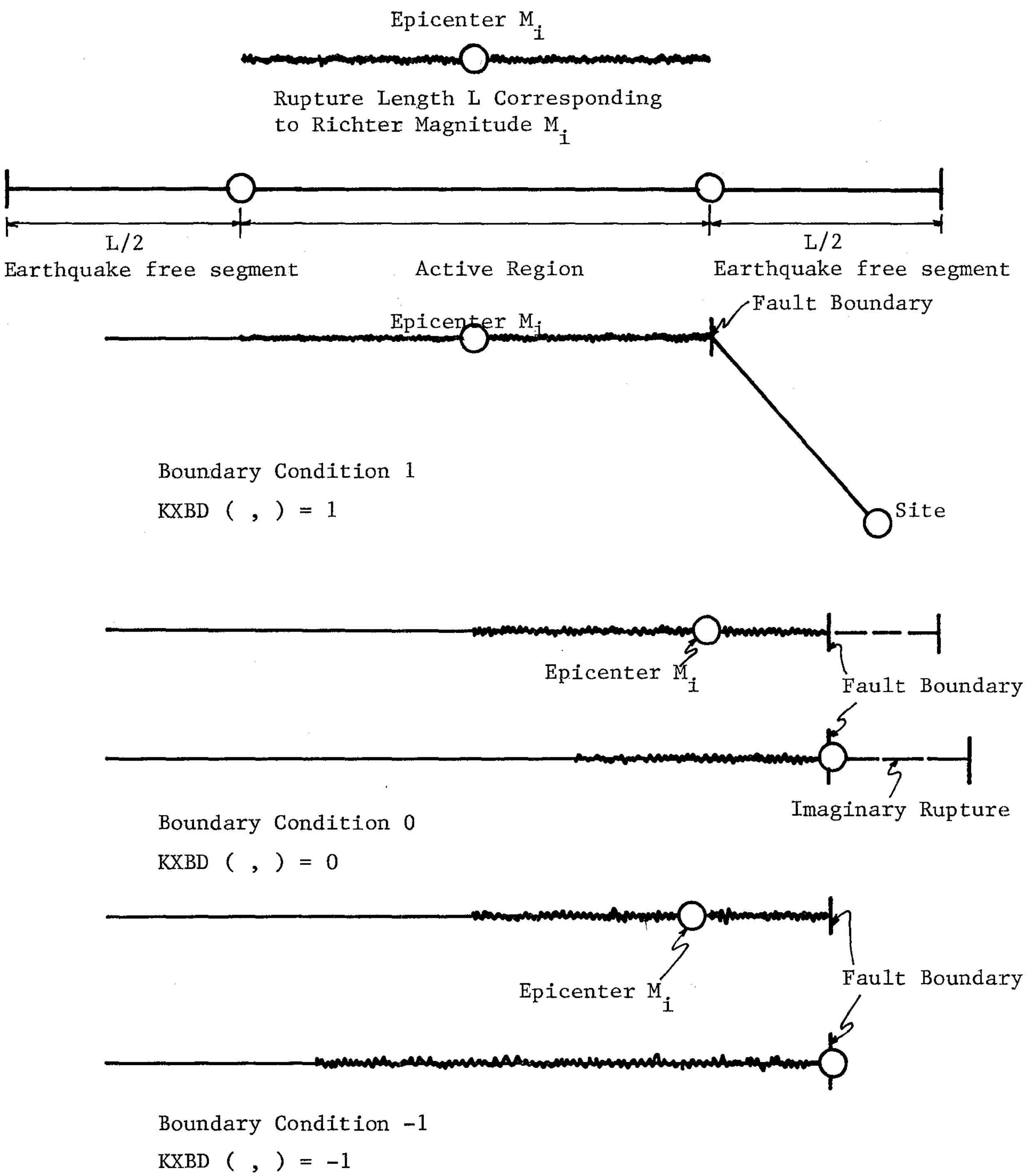
The present model uses this type of attenuations associated with a log-normal distribution in order to incorporate the uncertainty inherent in the use of such relations.

9.3 Description of Program SEISMIC.HAZARD

Program SEISMIC.HAZARD has been designed to compute the seismic exposure of a region. This is done by combining the effect of all seismic sources identified within the region to provide an estimate of the probability of occurrence of at least one event (assumed to be independent),

Figure 9-2

Boundary Conditions
Line Source Case Presented for Simplicity



with a given ground parameter level (e.g., PGA, PGV, etc.) within a future time period of interest "t." A cumulative distribution function (CDF) or a complementary cumulative distribution function (1 - CDF) for a ground parameter of interest is developed at a site. By choosing a large number of sites at the nodes of a grid covering a region (Figure 9-9), seismic exposure within the region can be described.

The present version can handle line sources at constant depth, modeled by one or a series of straight line segments, area sources at constant depth, modeled by near horizontal trapezoids and sources having one or several dipping planes, modeled by bands (each band subdivided into one or more elements (trapezoids)). In order to describe the source geometry properly, the analyst is required to input the coordinates (in degrees of latitutde and longitude) of the segment's endpoints (or nodes) for line sources, and for the vertices (or nodes) of each trapezoid describing constant depth area sources or describing the different bands in dipping plane sources (see Figure 9-3). The program will automatically transform the nodal coordinates (longitude-positive for east, latitude-positive for north) to kilometers taking into consideration the geographic location of the region (e.g., north or south of the Equator, east or west of Greenwich).

Since the significant distance is a parameter in the attenuation relationships considered by the program (Eq. 9.13), the area and line sources are divided in small segments in order to take into consideration the distance variation to the site(s) from different parts of a source. The analyst is required to input the segment size. Usually the size of the segments is chosen small enough (e.g., 10 km) such that the approximation from a continuous to discrete computation is acceptable. The seismicity within a source remains the same from segment to segment.

The quantities M (magnitude) and the ground parameter(s) of interest (e.g., PGA, PGV, etc.) are discretized to equal step increments. Hence, integration in the equations presented in Section 9.2, can be replaced by summations.

The fault rupture for area sources is considered as an area (a rectangle of height equal to half its length, see Figure 9-1). The length is taken from the available relationships for length of fault rupture. The analyst is required to input the rupture length for each magnitude considered in the run. The specific boundary conditions (shown in Figure 9-2) required to determine the rupture process near the extremities of the fault(s) (or seismic sources) are also specified by setting KXBD (,) equal to -1, 0, or 1 (see Section 9.5). If the point model (total energy released during an earthquake is radiated from the hypocenter) instead of the fault rupture model is desired, setting the rupture lengths equal to zero in the input data deck will automatically indicate the program to use the point source model.

Information on the values of attenuation coefficients is included as part of the input data deck. The parameter XSIG (number of standard deviations on each side of the mean, see Section 9.5) will indicate the program if whether to consider the attenuation probabilistically or deterministically. Setting XSIG equal to 0 will automatically indicate the program to treat attenuation deterministically.

A fixed format table (discussed in detail in Section 9.5) is recommended for the input of the parameters for the Poisson and Bernoulli models discussed in Section 9.2.

In its present form, program SEISMIC.HAZARD has been divided into a main routine and thirteen subprograms. It contains 1966 executable FORTRAN statements. The space requirements are approximately 251812 bytes. The actual array dimensions can accomodate up to 30 seismic sources, 210 nodes, 54 elements (trapezoids) and analyze 13 parameters (e.g., PGA, PGV, etc.) in one run. There is practically no limitation with respect to the number of grids considered per run and the number of sites or nodal points chosen per grid.

9.4 Description of Input Data

Input data for program SEISMIC.HAZARD will consist of thirteen sets of cards. The organization of data on each card, along with a description of the items, is given in the following paragraphs.

I. Run Identification--(20A4)--Two cards

Col.	1-80	HED1	(Identification Label)--Card One
	1-80	HED2	(Identification Label)--Card Two

II. Lambert Projection--(4F10.0)--One card

Col.	1-10	STLT1	(Standard Latitude 1)*
	11-20	STLT2	(Standard Latitude 2; input as zero if only one standard latitude is used)
	21-30	STLN	(Standard longitude)*
	31-40	SCAL	(Not used in the program, Scale to be used for future seismic exposure maps (i.e., program PLOT.ISO, Chapter XI)*

III. Frame Description**--(6F10.0)--One Card

Col.	1-10	XXOR	(X-coordinate of origin, in degrees)
	11-20	YYOR	(Y-coordinate of origin, in degrees)

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*These parameters depend on the maps available to the analyst as obtained from an atlas or any other source (see reference 10).

**These parameters will be used when plotting seismic exposure maps (i.e., program PLOT.ISO in Chapter XI).

Col.	21-30	XXRT	(X-coordinate of right bottom corner)
	31-40	YYRT	(Y-coordinate of right bottom corner)
	41-50	XXUP	(X-coordinate of left top corner)
	51-60	YYUP	(Y-coordinate of left top corner)

IV. Problem Description--(16I5)--One card

Col.	1-5	NOAR	(Number of area sources)	See Fig. 9-3
	6-10	NOLN	(Number of line sources)	See Fig. 9-3
	11-15	NOND	(Number of nodes)	See Fig. 9-3
	16-20	NOEL	(Number of elements)	See Fig. 9-3
	21-25	NOGD	(Number of grids)	See Fig. 9-3
	26-30	NOVB	(Number of parameters to be studied (e.g., PGA, PGV, etc.))	
	31-35	NOAT*	(Number of attenuations per parameter--Program allows for two relationships/parameter; use 2)	
	36-40	IWPT	(First logical unit for print, DF = 6)	
	41-45	SADT	(Save plot file ? 0 = NO)	

V. Time Period and Magnitude--(3F10.0)--One card

Col.	1-10	TM	(Time period of interest, i.e., 10, 20, 50, 100 yrs, etc.)
	11-20	DLMG	(Magnitude increment, i.e., 0.25)
	21-30	STMG	(Smallest magnitude of interest, i.e., RM = 3.00)

VI. Nodal Coordinates--(NOND Cards, see IV)--(I5,4F10.0)

Col.	1-5	IXWC	(Node index, i.e., 1, 2, 3, etc.)
	6-15	XXIN	(X-coordinate of node, in degrees)

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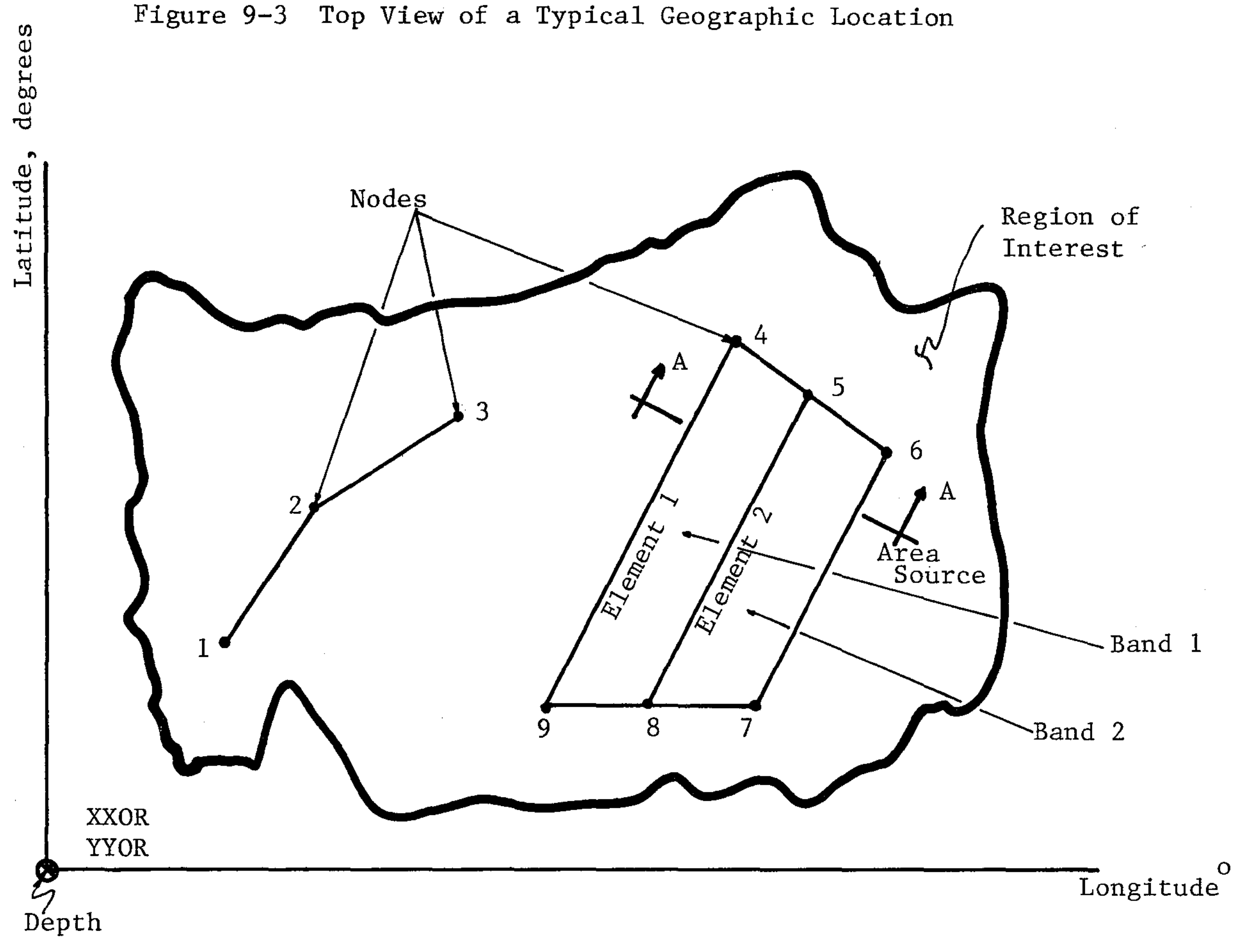
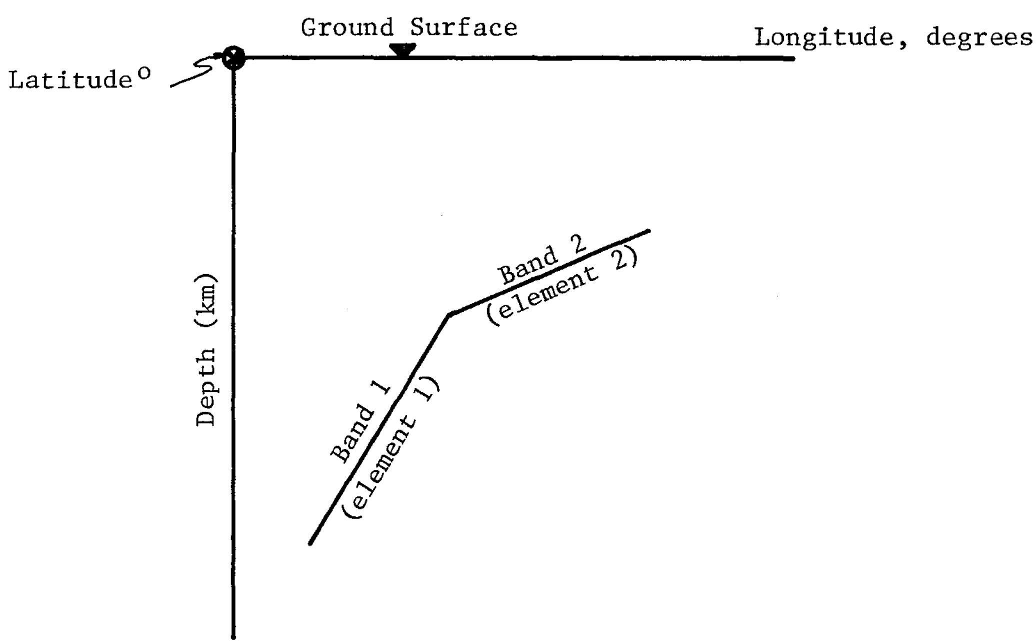
*See Data Set X and Figure 9-8.

Figure 9-3 Top View of a Typical Geographic Location





Note: For this particular case:

NOAR = 1
NOLN = 1
NOND = 9
NOEL = 2

Sec A-A (Area Source)

Col. 16-25 YYIN (Y-coordinate of node, in degrees)

26-35 ZZIN (Depth-negative kilometers, see Fig. 9-3)

VII. Elements' Description--(4I5)--(NOEL Cards, see IV)

Col.	1-5	IXTP(1)	(Index of node I)	See Figure 9-4
	6-10	IXTP(2)	(Index of node J)	
	11-15	IXTP(3)	(Index of node K)	
	16-20	IXTP(4)	(Index of node L)	

VIII. Area Sources' Properties--(At least five cards per source)

Card 1--(19A4, I4)

Col. 1-75 HED2 (Area source identification)

76-80 NB (Number of different magnitudes)

Card 2--Geometric Description and Boundary Conditions--(5I5)

Col. 1-5 NOBD (Number of bands)

6-10 KXBD(IX,1) (Boundary Condition 1--Deep)

11-15 KXBD(IX,2) (Boundary Condition 2--Shallow)

16-20 KXBD(IX,3) (Boundary Condition 3--corresponding to side I, J of first element in source

21-25 KXBD(IX,4) (Boundary Condition 4--corresponding to side K, L of last element in source

Card 3--Number of Elements in Bands--(16I5)

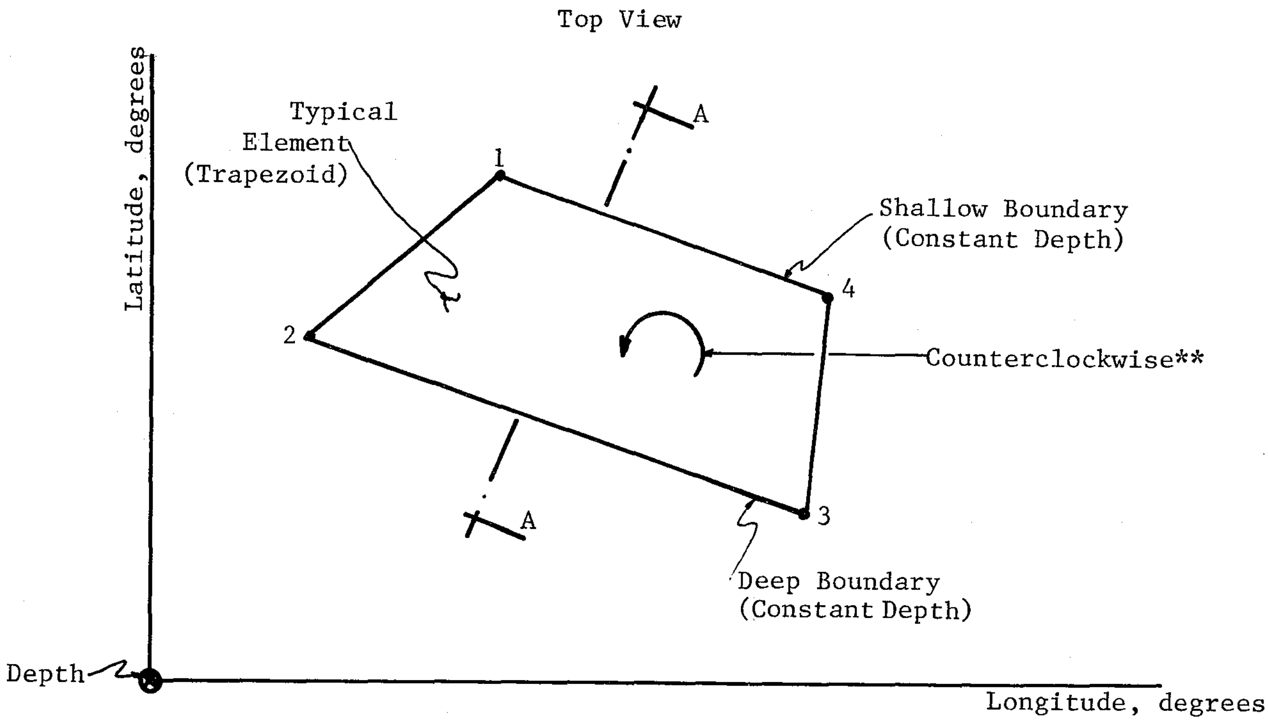
Col. 1-5 NBELBD(1) (Number of elements in band 1--deep)

6-10 NBELBD(2) (Number of elements in band 2)

⋮ NBELBD(NOBD) (Number of elements in band NOBD--shallowest)

Note: for a given area source, the number of elements in each band are read in starting with the deepest band and moving up to the shallowest. For example, refer to Fig. 9-5: The area source shown conatins two bands (band 1--deepest, and

Figure 9-4 Input Convention for Element's Nodes



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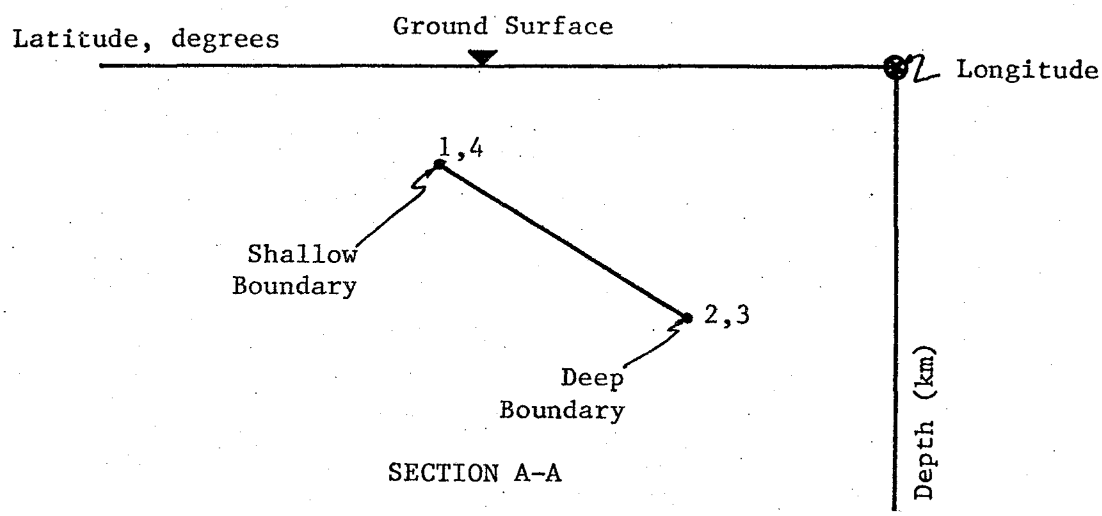
*Note: If area sources at constant depth are considered within a given region, because of program's algorithm, the analyst has to consider a small slope within the source in order for the program to identify a shallow and deep boundary. If the difference in depth between the opposite boundaries is given small enough, the effect on overall analysis is negligible. Also, as a general rule, all trapezoids must have the parallel sides each at a constant depth.

**When inputting a source from left to right, the element's nodal indexes are always read in, following a counter-clockwise sense and the node indexes are input in such a way that the shallow nodes occupy positions 1 and 4 of vector IXTP and deep nodes positions 2 and 3, and boundary conditions 3 and 4 correspond to west and east, respectively.

Figure 9-4 (Continued)



SECTION A-A

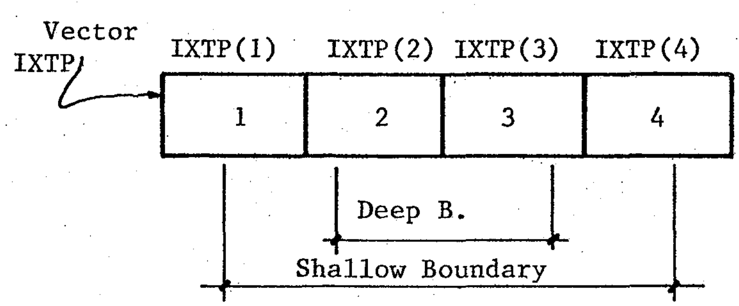
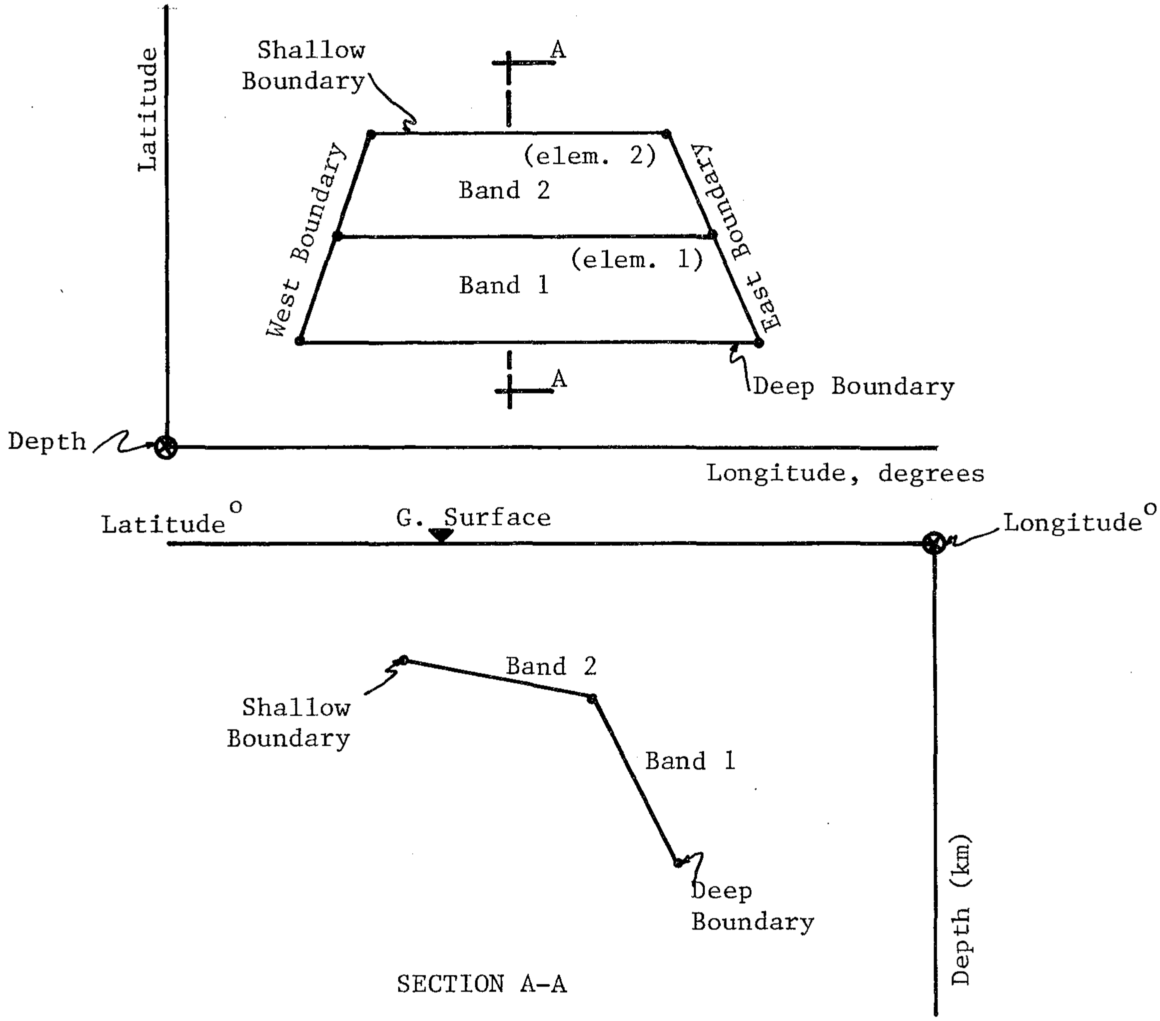


Figure 9-5 Typical Dipping Fault Plane (Area Source)



For each boundary (e.g., deep, shallow, west, or east), the variable KXBD(,) can take one of three possible values:

If KXBD(,) = -1, the edge of the rupture area coincides with the edge of the source but the center of energy release is not fixed at the centroid of rupture area, see Fig. 9-2.

If KXBD(,) = 0, the center of energy release coincides with the centroid of the rupture area but half the rupture may extend beyond the source boundary, see Fig. 9-2.

If KXBD(,) = 1, the edge of the rupture zone coincides with the edge of the source but does not extend beyond it, see Fig. 9-2.

band 2--shallowest), each band is formed of only one element (trapezoid), therefore for this particular case: NOBD = 2 and hence, NBELB (1) = 1 and NBELBD(2) = 1

Card 4--Section of Source** --(8F10.0)

Col. 1-10	XXSC(1)	(Horizontal distance to deepest boundary measured from local coordinate system, input always as zero)	See Fig. 9-6
11-20	ZZSC(1)	(Depth of deepest boundary in km-negative)	
. . .			
. . .	XXSC(NOBD+1)	(Horizontal distance from XXSC(1) in km-positive)	
. . .	ZZSC(NOBD+1)	(Depth of shallowest boundary in km-negative)	

**Coordinates measured from a local reference system as shown in Fig. 9-6

Card 5--Parameters of Poisson and Bernoulli Model*--(8F10.0)

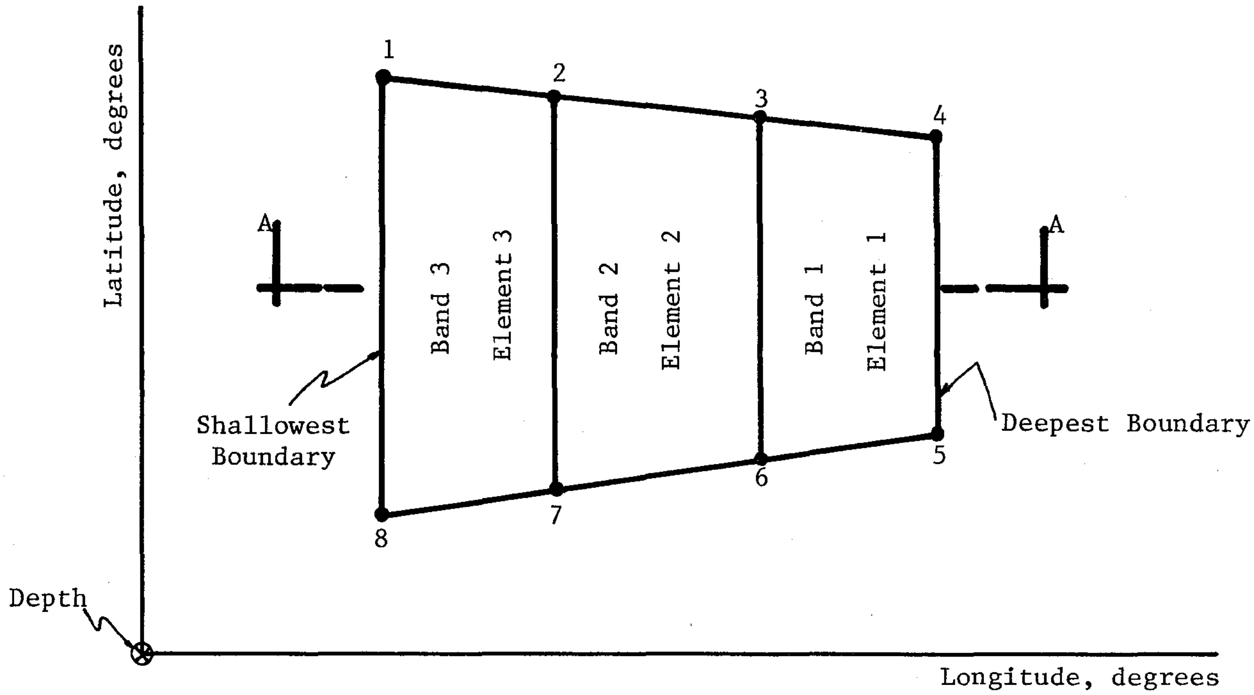
Col. 1-10	TMDA(IXSC)	(Time data base)
11-20	XNBDA(IXSC)	(Number of events greater than STMG; smallest magnitude of interest)
21-30	XNBMG(IXSC,1)	(Number of successes for RM = STMG)
31-40	XNBMG(IXSC,2)	(Number of successes for RM = (STMG + DLMG)
. . .	XNBMG(IXSC, NB)	(Number of successes for largest RM on this source)

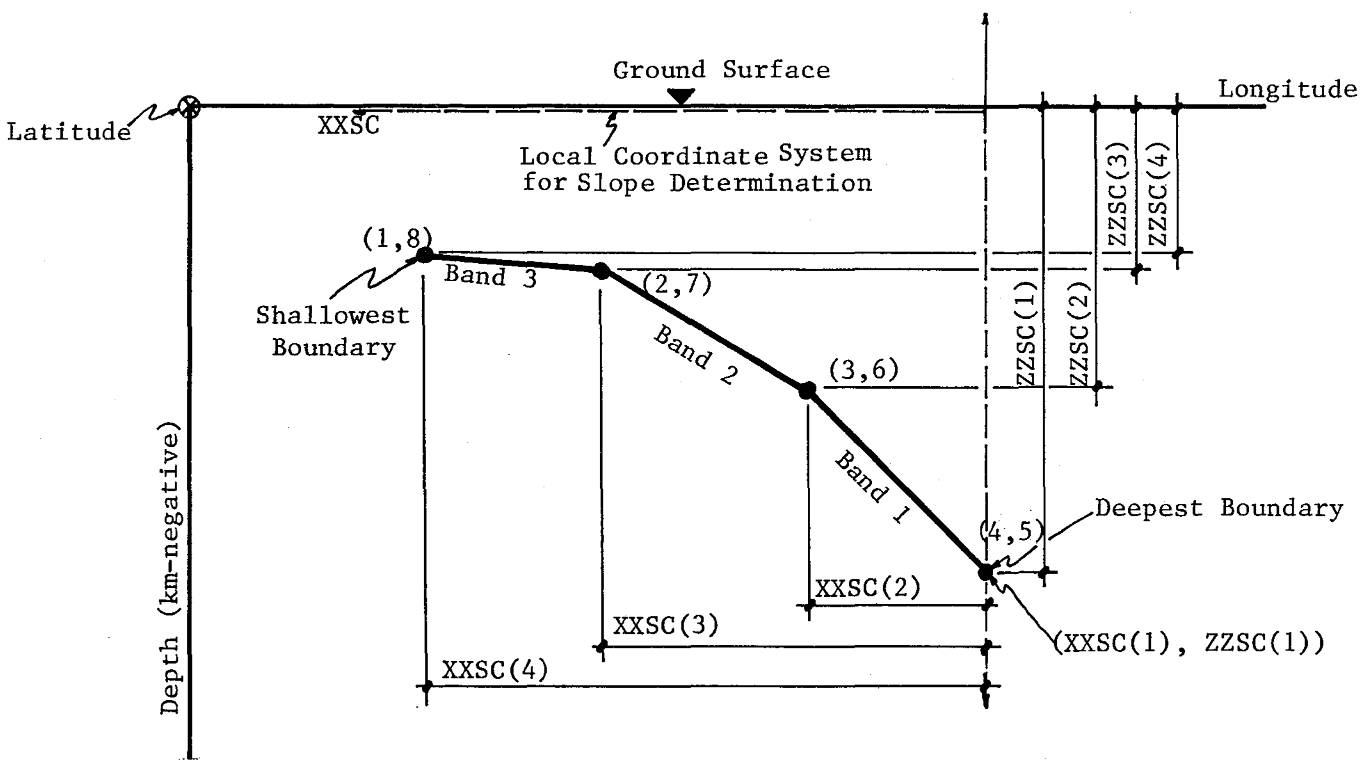
Note that IXSC is the index of the iteration control statement for the total number of sources in this run. NB = number of different magnitudes in this source.

*Detailed explanation will be deferred until Section 9.5.

Figure 9-6

Top View of Typical Dipping Plane Source





SECTION A-A

IX. Line Sources' Properties--(At least 3 cards per source)

Card 1--(19A4, I4)

Col.	1-75	HED2	(Line source identification)
	76-80	NB	(Number of different magnitudes)

Card 2--Geometric Description and Boundary Conditions--(5I5)

Col.	1-5	NOSG	(Number of sigments)	See Fig. 9-7
	6-10	NBELBD( )	(Index of first node)	
	11-15	KXBD(IX,3)	(Boundary condition 1--first node)	
	16-20	KXBD(IX,4)	(Boundary condition 2--last node)	

Card 3--Parameters of Poisson and Bernoulli Model*--(8F10.0)

Col.	1-10	TMDA(IXSC)	(Time data base)
	11-20	XNBDA(IXSC)	(Number of events greater than STMG)
	21-30	XNBMG(IXSC,1)	(Number of successes for RM = STMG)
	31-40	XNBMG(IXSC,2)	(Number of successes for RM = STMG + DLMG)
	. . .	XNBMG(IXSC,NB)	(Number of successes for largest RM on this source)

X. Attenuation Information--(NOVB sets of 2 or 3 cards)

Card 1--Identification--(5A4, 3F10.0)

Col.	1-20	HEDVB(, IXVB)	(Attenuation identification)
	21-30	DLVBEX(IXVB)	(Increment for parameter in this iteration, i.e., if parameter is PGA then the increment could be taken as 0.02G)
	31-40	DNVBEX(IXVB)	(Smallest value of interest of parameter in this iteration)
	41-50	UPVBEX(IXVB)	(Largest value of interest of parameter in this iteration)

Note: IXVB is the index of the iteration control statement on the number of ground parameters in this run.

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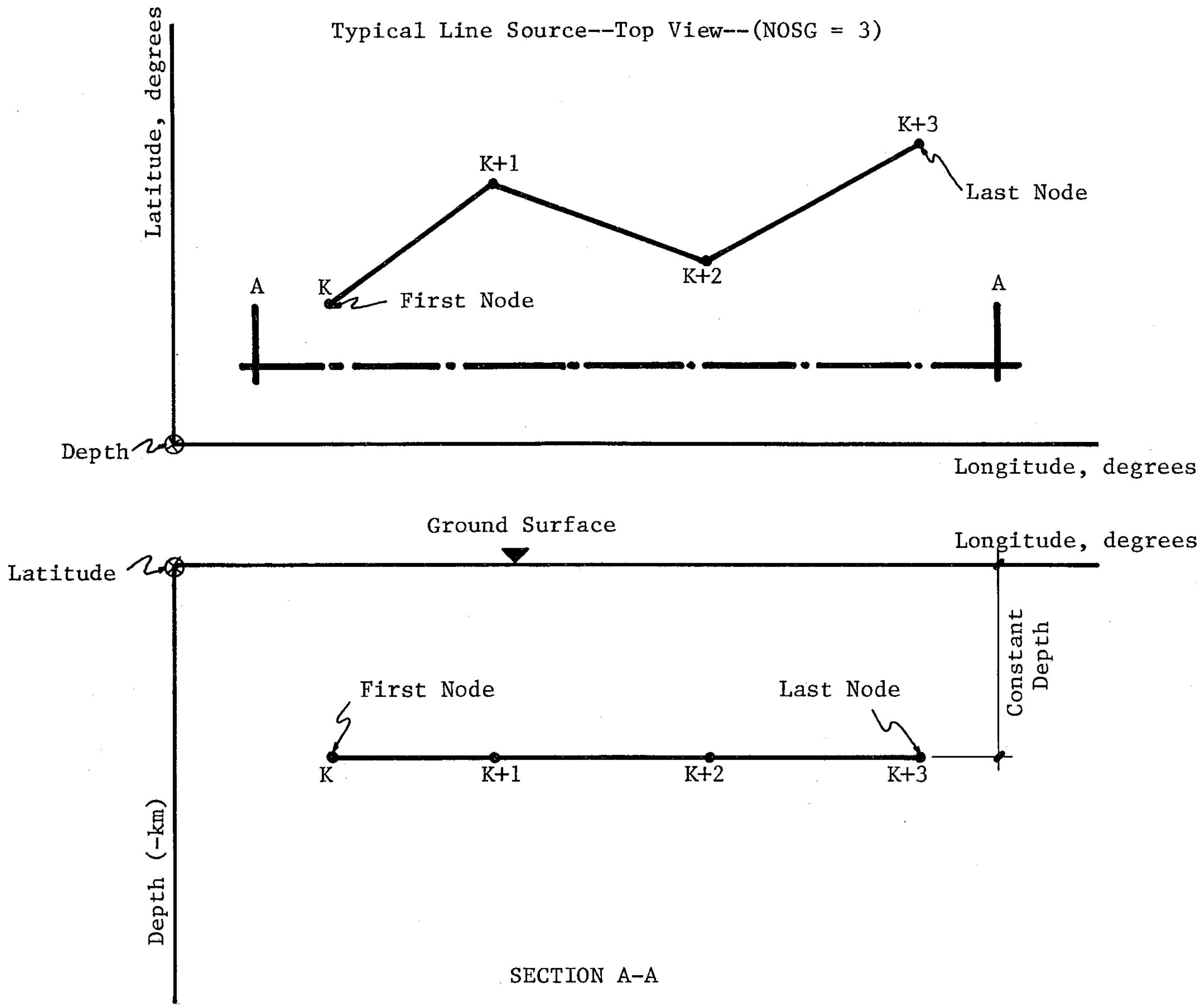
*Detailed explanation will be deferred until Section 9.5; see Fig. 9-11.

Figure 9-7



Note: In contrast to area sources (where nodal indexes can be numbered in any arbitrary order), for line sources the nodal indexes <u>have</u> to be numbered in sequential order, starting with the first node. The boundary conditions KXBD(,) can take one of the three possible values, that is, -1, 0, or 1 (see Fig. 9-2). Depth of all nodes in the source has to be constant.

Card 2--Attenuation Coefficients for Magnitude Smaller than XMX--(8F10.0)

where XMX is the maximum M value for which the coefficients in attenuation relationships of the form:

$$\text{GROUND PARAMETER} = \frac{b_1 e^{b_2 M}}{(R + b_3)^{b_4}} \quad \text{are valid.}$$

Col.	1-10	B1(IXTT)	(Coefficient b_1)
	11-20	B2(IXTT)	(Coefficient b_2)
	21-30	B3(IXTT)	(Coefficient b_3)
	31-40	B4(IXTT)	(Coefficient b_4)
	41-50	SIGLN(IXTT)	(Standard deviation of log-normal distribution associated to attenuation; input in log-scale)
	51-60	XMX	(Maximum magnitude for which coefficients above are valid--if XMS is input as zero, the coefficient is valid for all magnitudes)

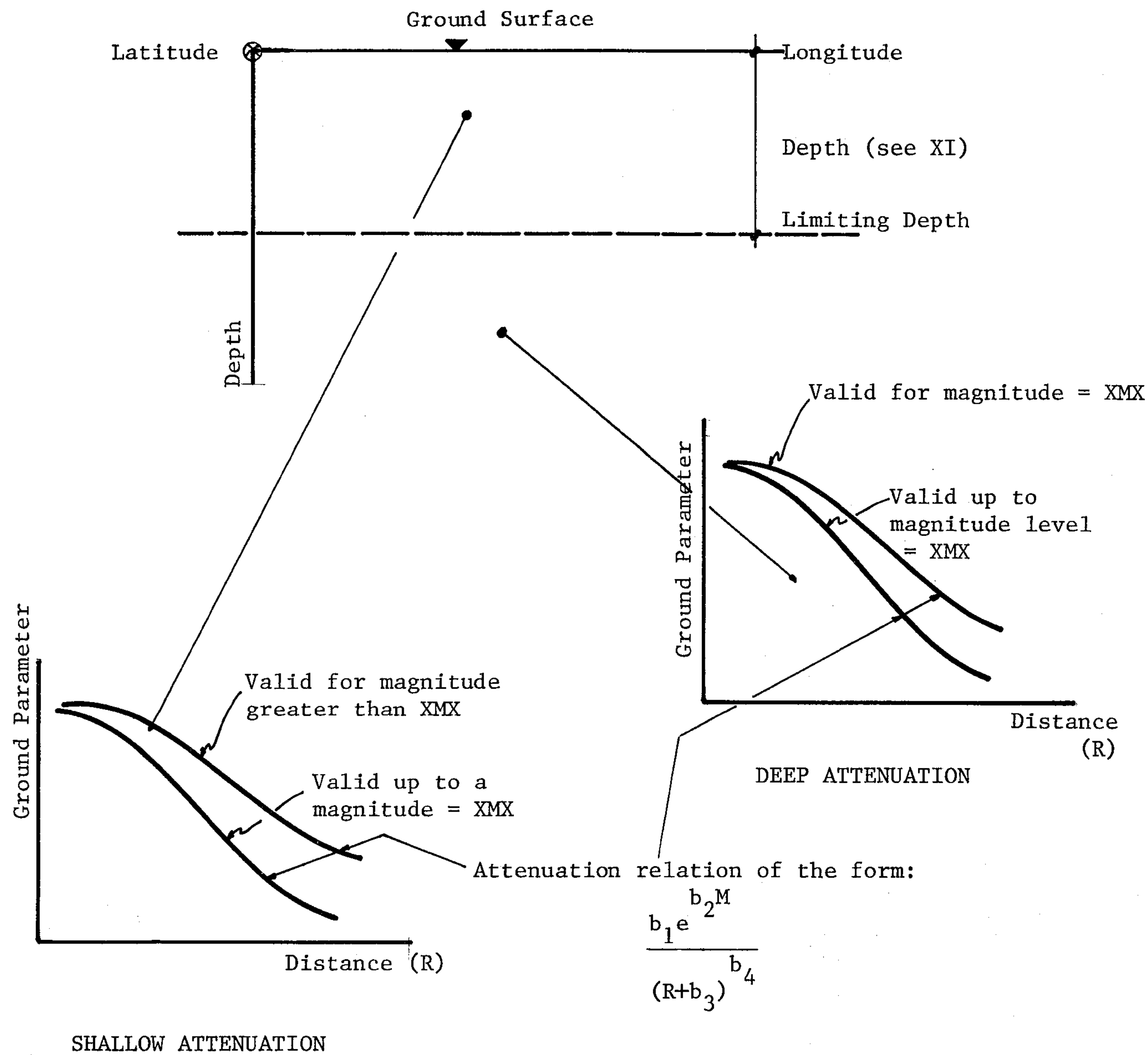
Card 3--Input only is XMX is different from zero--(8F10.0)

Col.	1-10	B1(IXTT)	(Coefficient b_1, linear scale)
	11-20	B2(IXTT)	(Coefficient b_2, linear scale)

XI. Information on Distribution Associated to Attenuation Relation--(I10,7F10.0)

Col.	1-10	MXDTIC	(Number of steps in distribution; use 85)
	11-20	XSIG	(Number of standard deviations on each side of the mean--if XSIG = 0, the median curve is used)
	21-30	DEPTH	(Depth to establish the limit between different attenuation relationships--see Fig. 9-8; this value is irrelevant if the same attenuation is input twice)

Figure 9-8



Note: The program handles two attenuation relationships/ground parameter (i.e., NOAT = 1 or 2, see IV). The parameter Detph in Data Set XI establishes the depth limit between the two relationships. Also the program allows considering validity of the Attenuation Relationships for magnitude ranges (e.g., valid between RM = 3.00 and RM = 6.00, etc.)

Two attenuation laws have to be input for each loading parameter studied. If only one attenuation law is available, it should be repeated.

Col. 31-40 C1 (Coefficient C_1 used to determine b_3; see Eq. below)

41-50 C2 (Coefficient C_2 used to determine b_3; see Eq. below)

$$\text{Ground parameter} = \frac{b_1 e^{b_2 M}}{(R + b_3)^{b_4}}$$

$$\text{where:} \quad b_3 = C_1 e^{C_2 M}$$

51-60 RPICVR (Vertical integration step in km; if input as zero, DEFAULT = 10 km)

61-70 RPICHZ (Horizontal integration step in km; if input as zero, DEFAULT = 10 km)

71-80 EPS (Parameter used for horizontal and parallel checks, use 0.10 km)

XII. Rupture Length*--(8F10.0)--(At least two cards)

Col. 1-10 RUPTUR(1) (Horizontal rupture length corresponding to STMG--smallest magnitude of interest in km)

11-20 RUPTUR(2) (Horizontal rupture length corresponding to STMG + DLMG)

. . . RUPTUR(MGMX)** (Horizontal rupture length corresponding to MGMX--largest magnitude of interest)

Note: The program will compute the vertical rupture length as one-half the horizontal.

---

*Taken from relationships presented by Krinitzsky (1974), or Patwardhan et al. (1975).

**If rupture (MGMX) is read in as zero, the point source model is used instead of the rupture model.

XIII. Grid Description--(2 Cards per grid)

Card 1--Identification--(20A4)

Col. 1-80 HED2 (Grid identification label)

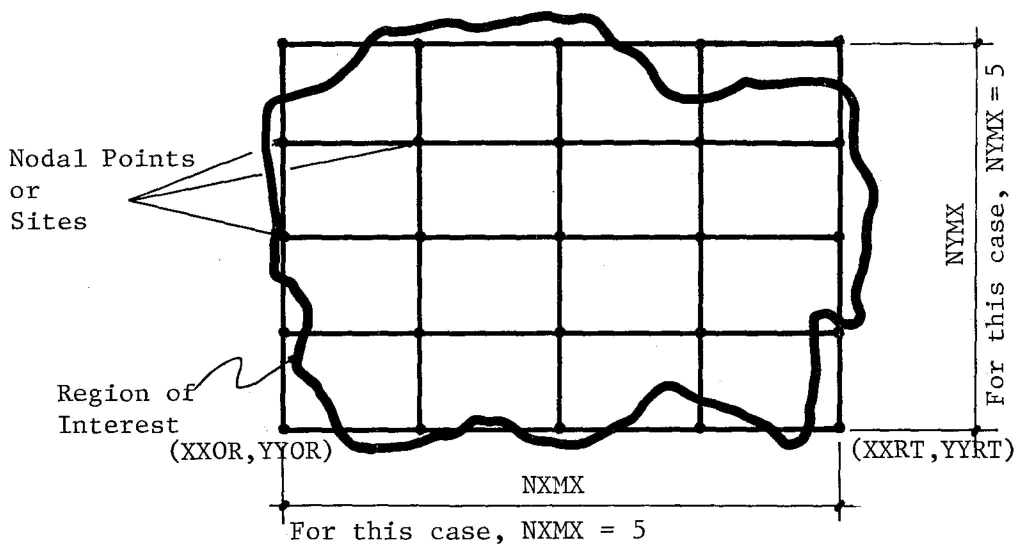
Card 2--Grid Coordinates--(7F10.0, 2I5)

Col. 1-10	XXOR	(X-coordinate of origin, degrees)	See Fig. 9-9
11-20	YYOR	(Y-coordinate of origin--degrees)	
21-30	XXRT	(X-coordinate of right bottom corner)	
31-40	YYRT	(Y-coordinate of right bottom corner)	
41-50	XXUP	(X-coordinate of left top corner, degrees)	
51-60	YYUP	(Y-coordinate of left top corner)	
61-70	ZZSITE	(Depth of site (km)--DEFAULT = 0)	
71-75	NXMX*	(Number of points in X-direction)	
76-80	NYMX*	(Number of points in Y-direction)	

Note: If (NXMX = 0) and (NYMX = 0), only one site with coordinates XXOR and YYOR will be studied.

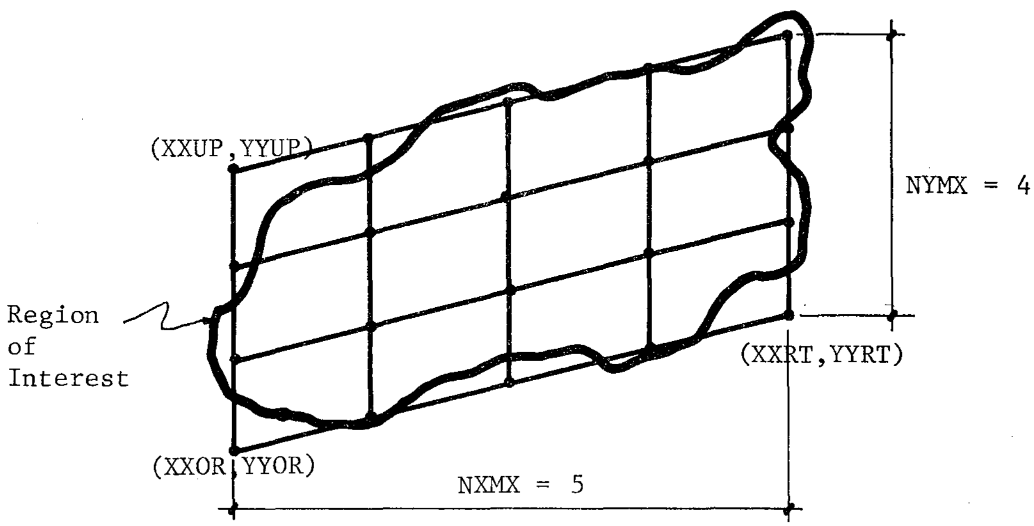
*Note: Assumed equally spaced--See Fig. 9-9.

Figure 9-9 Typical Grids



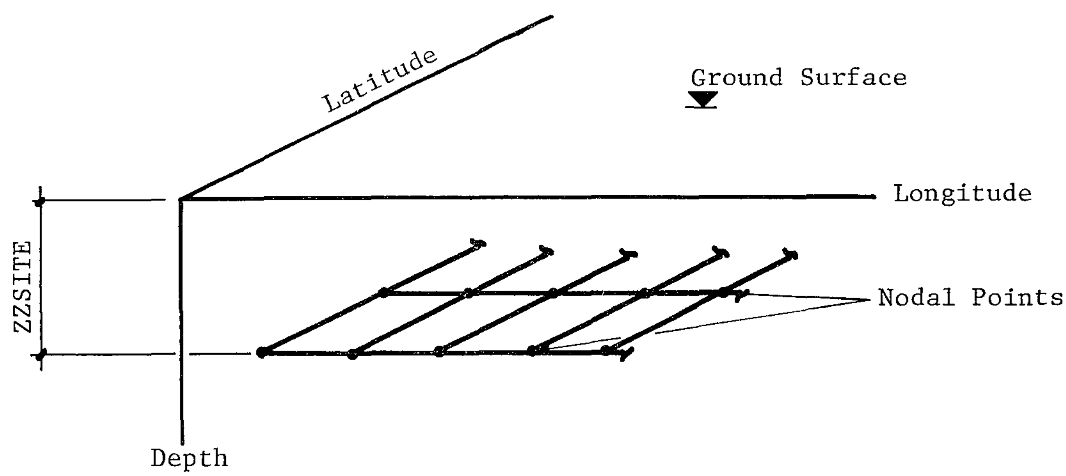
Plan View of Conventional (Orthogonal) Grid

Figure 9-9 (Continued)



Plan View of Non-Orthogonal Grid

Note: The program allows for grids making an angle with the horizontal. The flexibility when covering a given region is increased with this option.



Side View of Typical Grid

Note: ZZSITE is given in kilometers (negative) if zero, nodal points or sites are assumed at ground surface.

9.4.1 Recommendations

A number of recommendations regarding the input and uses of the program are summarized in the following paragraphs:

- The relationship between distances in degrees (input) and in kilometers (used in the analysis) is obtained using Lambert conformal projections (see Ref. 10). The parameters needed to define the projection are:
  - ---One or two standard latitudes: parallels at the contact or at intersections between the cone and the earth.
  - ---The standard longitude plotted vertically on the maps available.
  - ---One point of reference from which the distances are computed. All distances should be positive, therefore this point should be chosen at the left bottom corner of the area of interest. The exact location of this point is irrelevant (XXOR, YYOR).
  - ---The coordinate sign convention is as follows: North and east are positive. Hence, in the example of Figure 9-10, the site and sources are located in the northeast quadrangle.
- A number of loading parameters (PGA, PGV, etc.) can be studied in one run (NOVB). They each require two attenuation relationships -- A shallow one and a deep one. If only one attenuation is available, it should be input twice and the value of the parameter DEPTH (coordinate X_1) is irrelevant.
- The output of the program can be saved on disk in the standard line printer format (SAUT = 1) and in a condensed version for plotting purpose (SADT = 1). The output for the first leading parameter studied is directed to logical unit IWPT (line printer, default = 6) and, if required, to logical units IWUT and IWDT, respectively, for theline printer copy and the condensed version. The program increments by one of these logical units for any additional loading parameter and creates a different file for each

of them. Therefore, if, for example, three parameters are studied and all outputs are required, nine files will be created.

- The coordinates of all nodes are input sequentially. Their input order is irrelevant. The elements (trapezoids or triangles) are described by their node indices. The elements are input in the order they are selected in the area sources (ie., the element of the first source first and so on).

- The area sources are input first, followed by the line sources.

- When inputting an area source (Figure 9-1):

---The lines defining the bands must be horizontal (i.e., A_1, A_2, A_3, A_4, A_5 are at the same depth, similarly B_1, B_2, B_3, B_4 are at the same depth.

---The slope of each trapezoid or triangle in a same band must be constant.

---The order of indexing of element nodes is irrelevant since they are explicitly input in cards VII (i.e., B_1, A_1, A_2, B_2 could be 10, 7, 3, 1).

---The indexing of the elements must be sequential in each band (either from left to right or right to left) starting with the deepest band and moving upwards.

---A triangle is input by repeating the first and last node (i.e., B_2, A_2, A_3, B_2). See convention in Figure 9-4.

---If necessary, a rupture area will spread over several elements within a source, but will not extend from a source to another even if they are adjacent (see boundary conditions)

---The four boundary conditions are input in the following order: Deep, shallow, side of the first element in the source, side of the last element in the source. In the example, sources are input from left to right; therefore, the two last boundary conditions are west and east.

---The seismicity is treated as homogeneous over the whole source.

- When inputting a line source (Figure 9-7) :

---All the nodes must be at constant depth.

---The nodes must be numbered sequentially along the line either from left to right or right to left.

---If necessary, the rupture length will spread over several segments, but will not extend to another line source.

---The first boundary condition applies to the side of the line with the smaller node index. In the example the line sources are input from left to right (west to east).

---The seismicity is treated as homogeneous over the whole line.

9.5 Program's Organization

9.5.1 Description of Subroutines

The program SEISMIC.HAZARD has been divided into a main routine plus a series of subroutines. A brief description of the function of each is given in the following paragraphs.

Input: Reads all the data sets discussed in Section 9.4, except for Data Set XII and XIII.

LMBRT and Function CONFRM: Transformation of nodal coordinates from degrees longitude and latitude to kilometers.

Initia: Reads fault rupture lengths, generates magnitudes for output purposes, computes coefficient "C" in attenuation relationship(s). Checks whether point source model or rupture model is required and whether attenuation is to be considered probabilistically or deterministically.

Function Gauss: Evaluates the integral of the normal distribution $f_X(x)$ over the limits $-\infty$ to x.

Bernui: Computes the geometry of each seismic source (i.e., area, length, etc.), computes probability distributions given by Eqs. 9.6 and 9.11 for each source.

Output: Selects both the output to be listed on the line printer and to be saved on disk for plotting purposes.

INTGAR: Obtains shortest distance from site(s) to area sources. Checks if the perpendicular from site(s) to source falls within or outside the source.

EDGECK: Computes the shortest distance from site(s) to sources' edges.

INTGHZ: Computes the contribution to site's loading from each segment in which a line source has been subdivided. Considers area sources to be composed of a series of line sources subdivided in small segments and computes the contribution of each segment to the loading of a site(s).

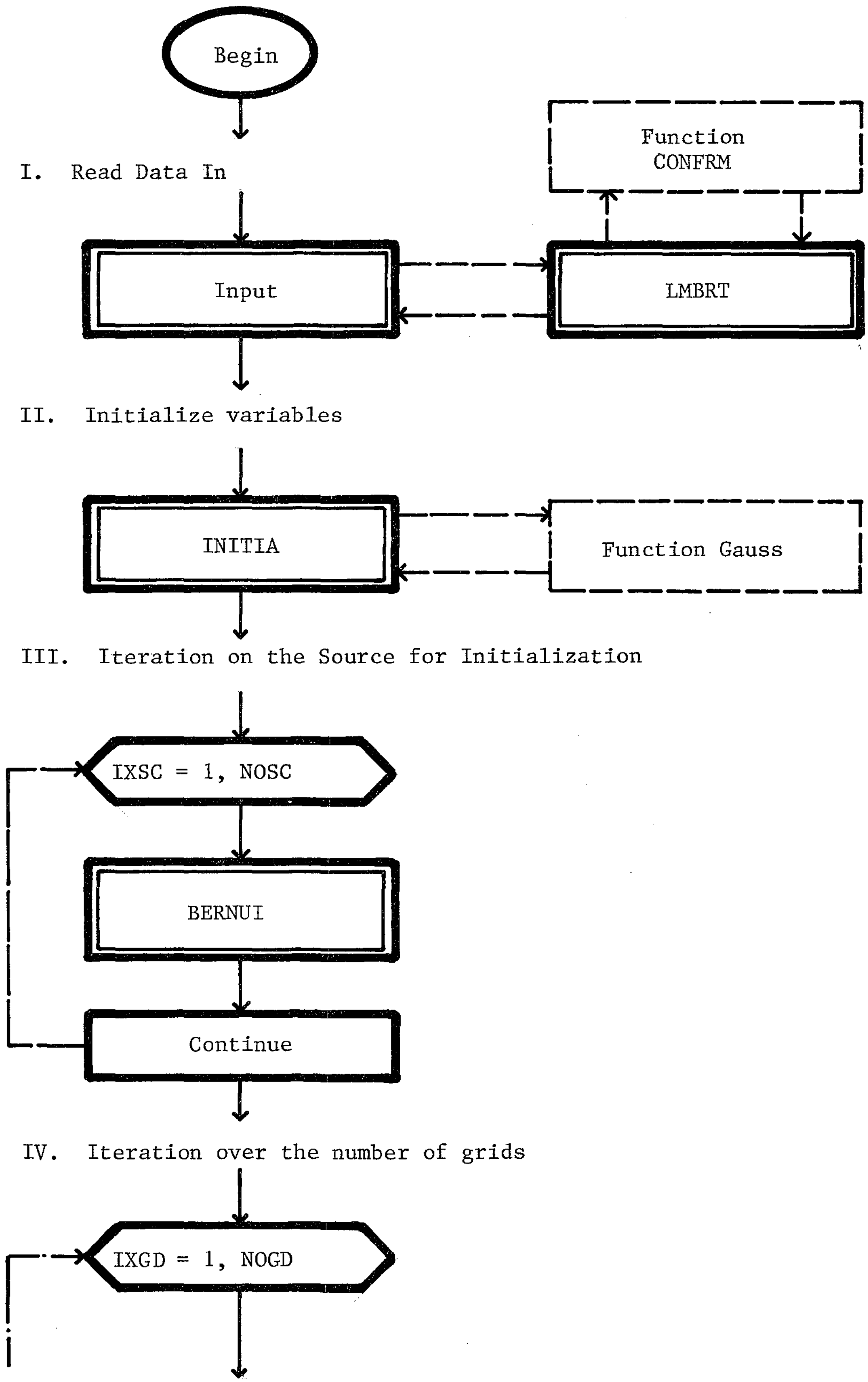
PBPDF, PWPDF: Computes the contribution of the last segment considered to each ground parameter.

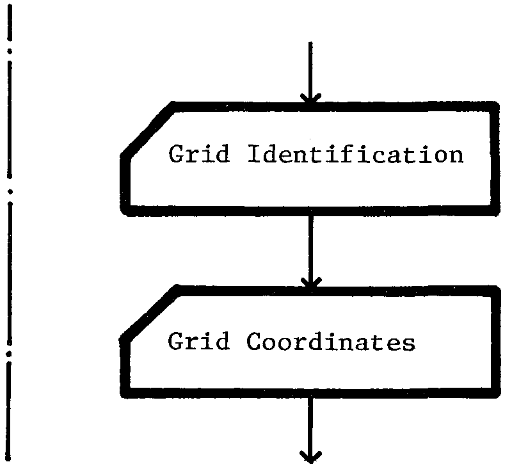
SUMQ: Computes the term $P\{A \leq a_i\}$ for each seismic source.

9.5.2 Macro Flow Chart

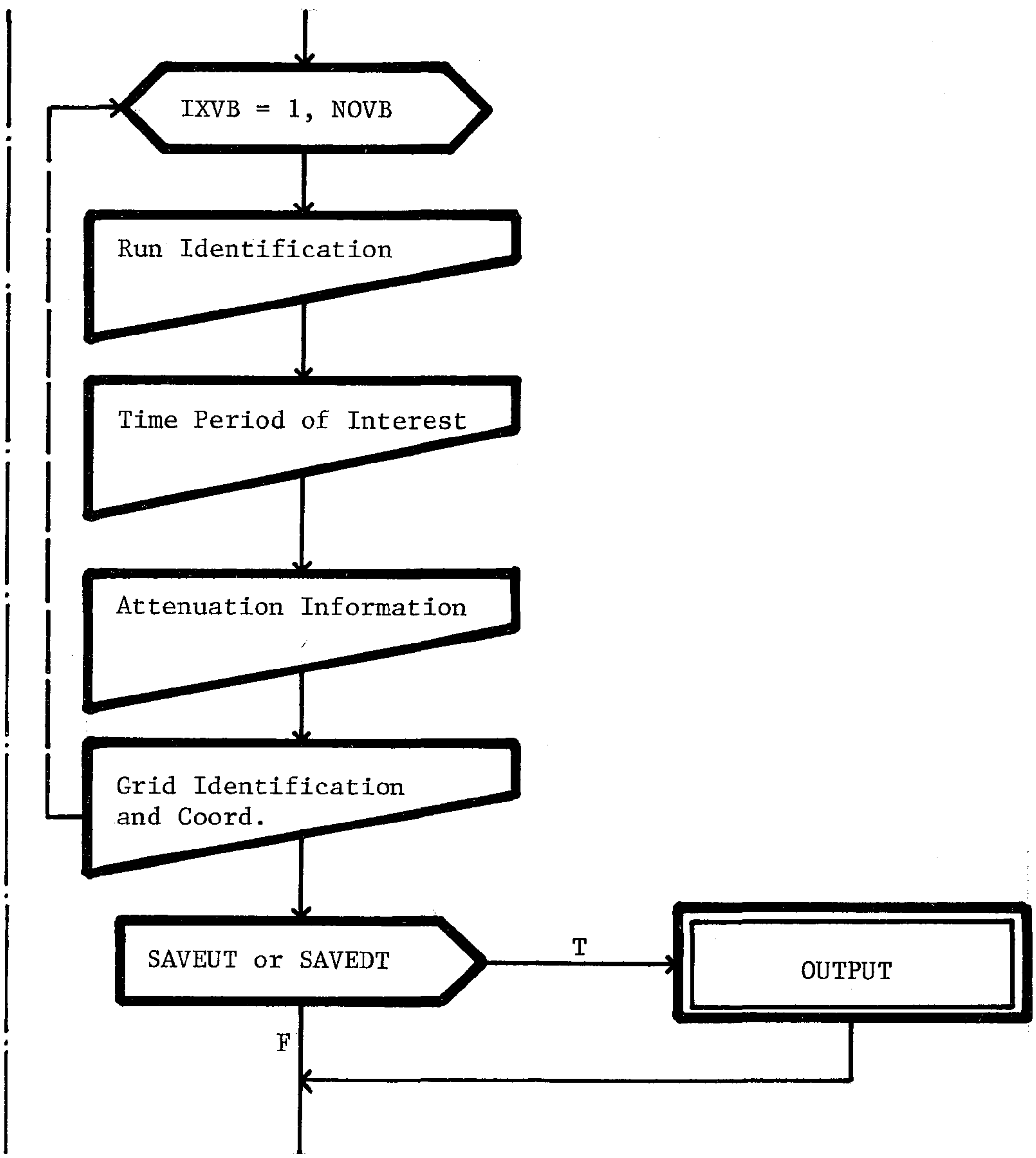
A Macro flow chart of program SEISMIC.HAZARD is presented in order to show its overall logic. The flow chart follows.

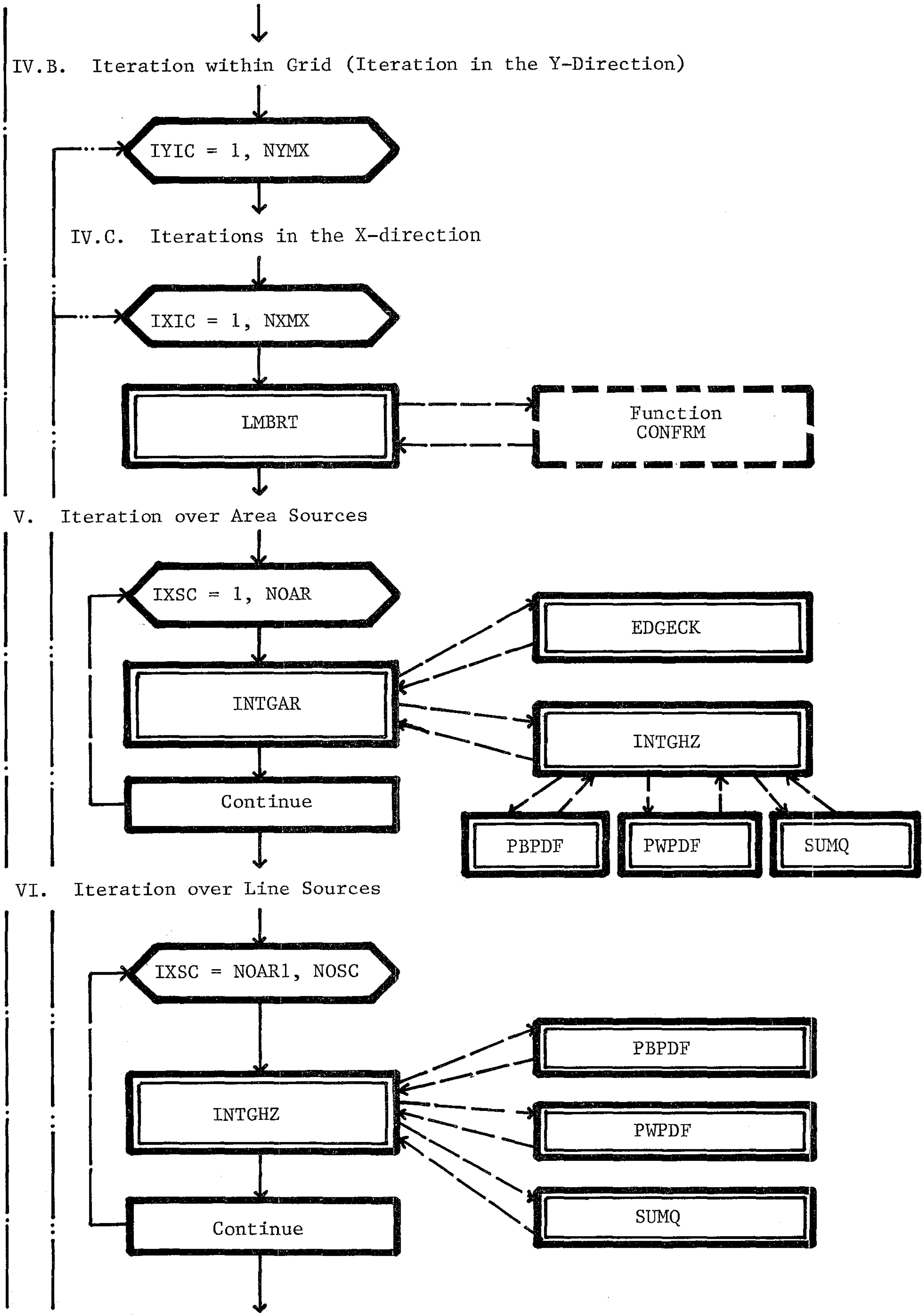
Macro Flow Chart For Program SEISMIC.HAZARD



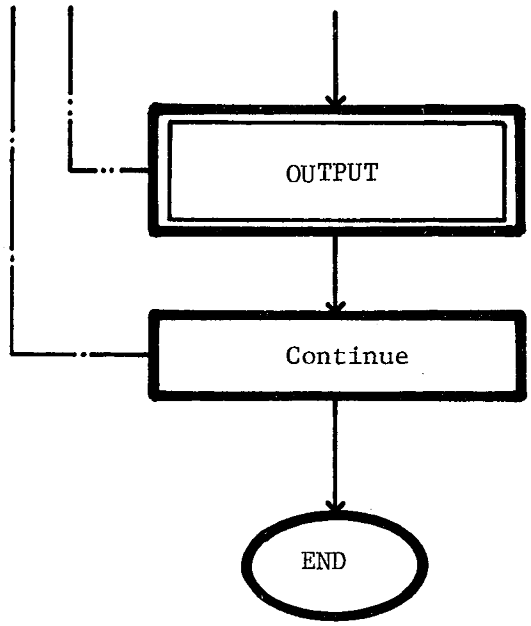


IV.A. Iteration on the Number of Parameters to be Studied



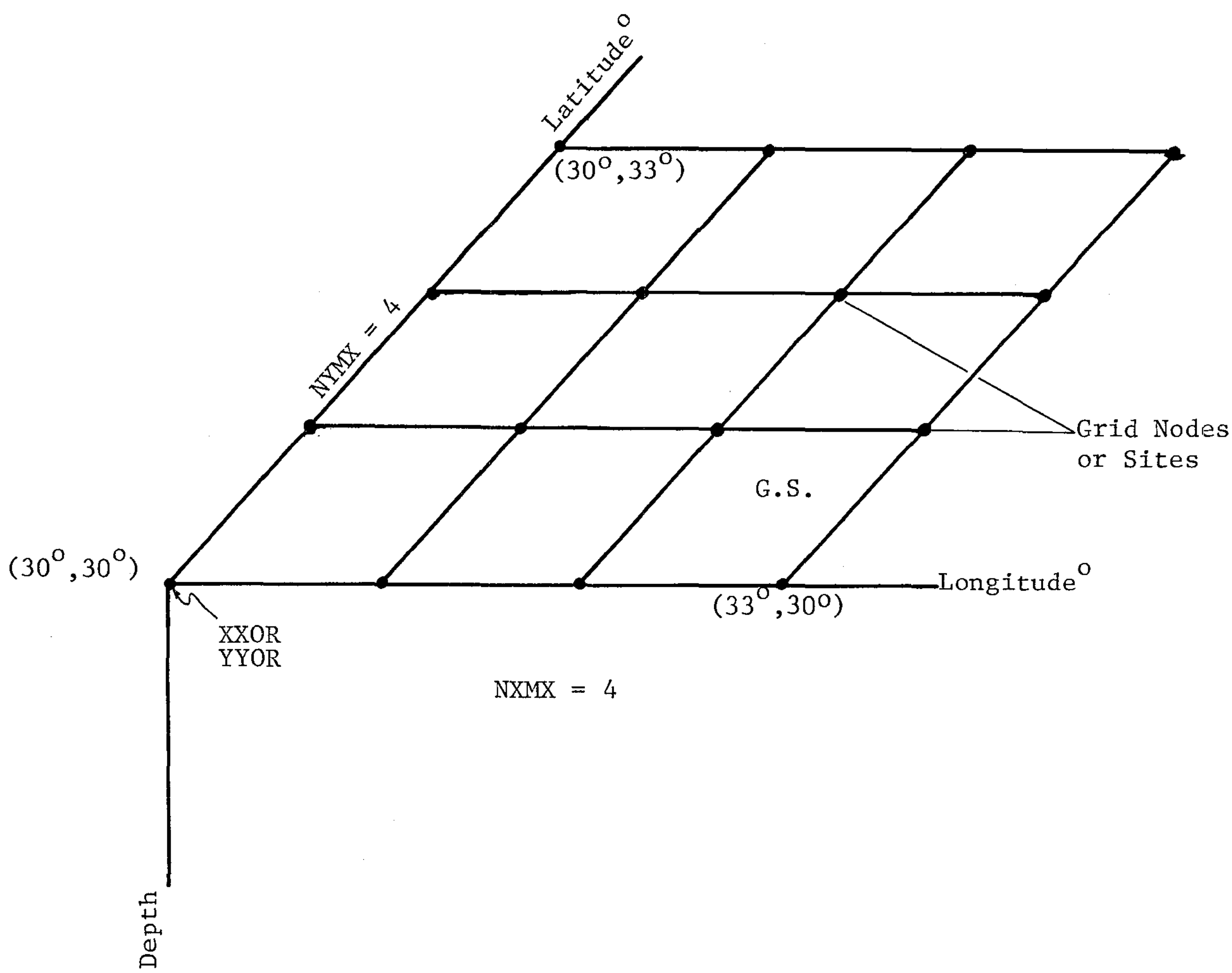


IV.B. Iteration within Grid (Iteration in the Y-Direction)
IYIC = 1, NYMX
IV.C. Iterations in the X-direction
IXIC = 1, NXMX
LMBRT
Function CONFRM
V. Iteration over Area Sources
IXSC = 1, NOAR
EDGECK
INTGAR
INTGHZ
Continue
PBPDF
PWPDF
SUMQ
VI. Iteration over Line Sources
IXSC = NOAR1, NOSC
PBPDF
INTGHZ
PWPDF
SUMQ
Continue


OUTPUT
Continue
END

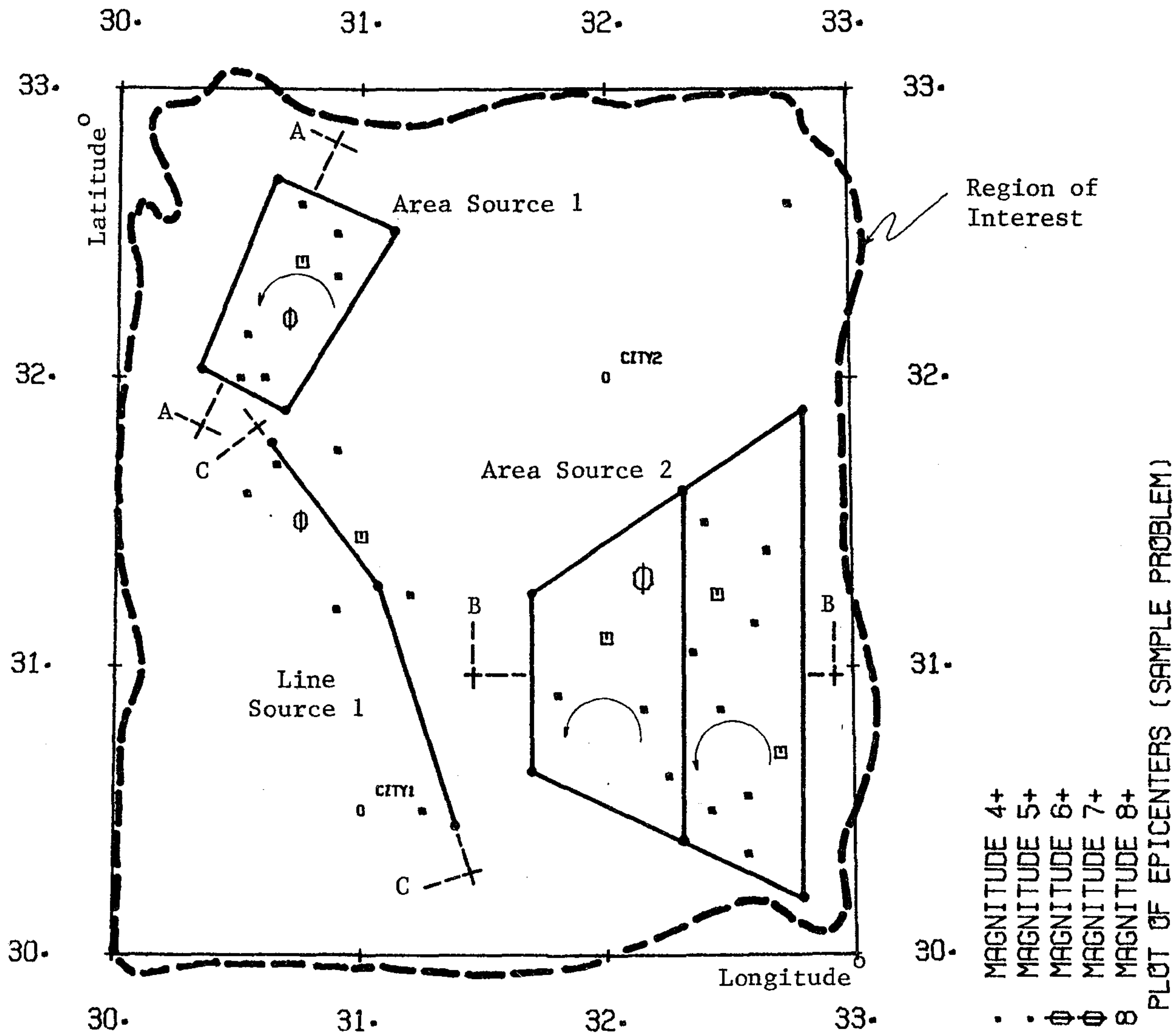
9.6 Sample Problem

Suppose the analyst has obtained the epicentral map shown in Figure 9-10 for a given region* (shown with dotted lines), and that three seismic sources (one line source composed of two segments, one area source (trapezoid) at constant depth, and one area source with dipping planes) have been identified after associating past events to major fault systems in the region. The future seismic exposure (PGA-Peak Ground Acceleration in this example) for the grid shown below and a time period of 50 years is required.



*This implies that Stages I and II (see Fig. 1-2) have been completed.

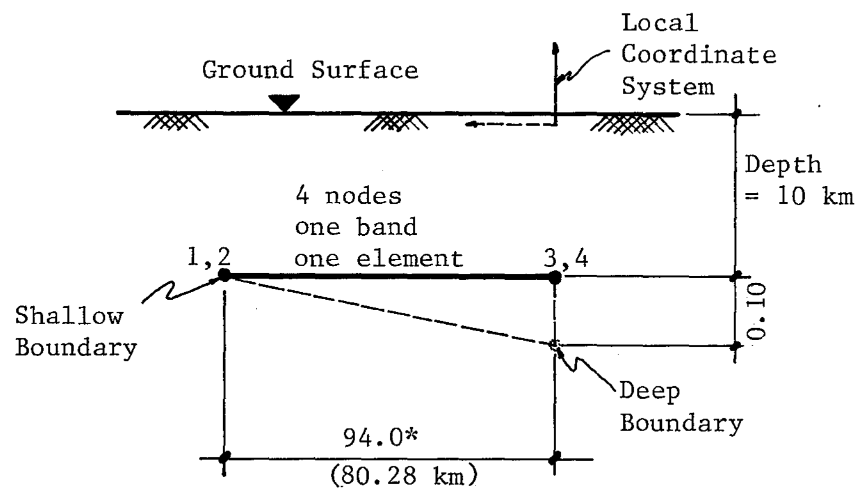
Figure 9-10



30.
31.
32.
33.
Latitude°
A
Area Source 1
Region of Interest
CITY2
A
C
Area Source 2
B
B
Line Source 1
CITY1
C
Longitude°
MAGNITUDE 4+
MAGNITUDE 5+
MAGNITUDE 6+
MAGNITUDE 7+
MAGNITUDE 8+
PLOT OF EPICENTERS (SAMPLE PROBLEM)

Figure 9-10 (Continued)

Area Source 1 (Sec. A-A)



Boundary Conditions: KXBD(IX,1) = 0
KXBD(IX,2) = 0
KXBD(IX,3) = 0
KXBD(IX,4) = 0

See Data Set VIII, Card 2

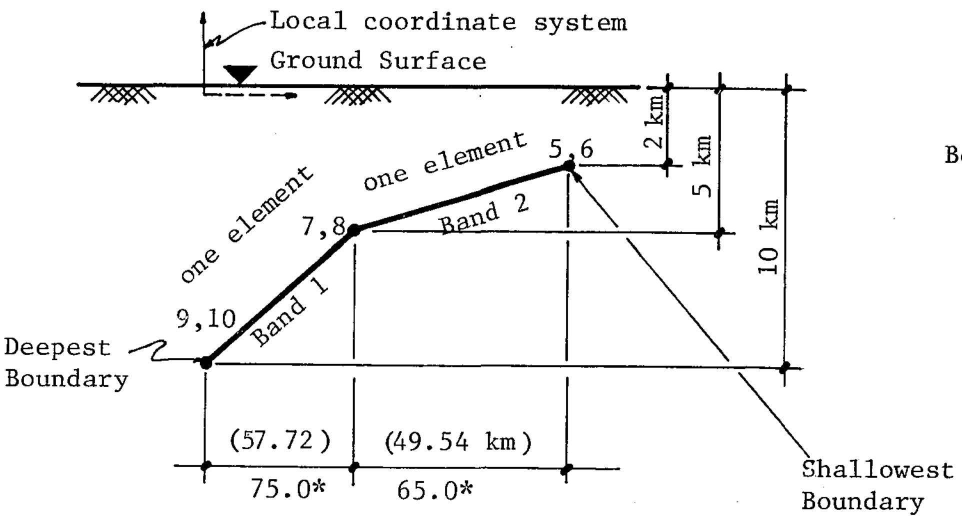
Note: Even though the area source is considered at constant depth, due to computer algorithm, a difference in height of 0.10 km between opposite parallel boundaries is given by the analyst.

---

*Note: Distances in parentheses are "exact," as computed by program PLOT.DATA (Appendix B). In the present example, the "approximate" distances were used instead of the "exact" ones. Normally, a second run would be necessary.

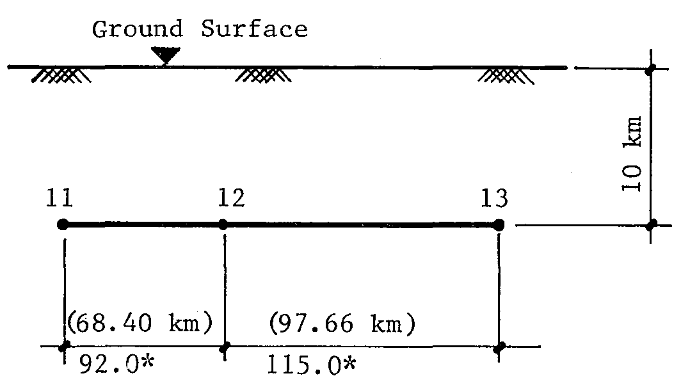
Figure 9-10 (Continued)

Area Source 2 (Sec. B-B)



Boundary Conditions:
KXBD(IX,1) = 0
KXBD(IX,2) = 0
KXBD(IX,3) = 0
KXBD(IX,4) = 1

Line Source 1 (Sec. C-C)



Boundary Conditions:

KXBD(IX,3) = 1 See Data
KXBD(IX,4) = 1 Set IX,
Card 2

Note: Line Source 1 is formed of two segments.

---

*Note: Distances in parentheses are "exact," as computed by program PLOT.DATA(Appendix B). In the present example, the "approximate" distances were used instead of the "exact" ones. Normally, a second run would be necessary.

Tables 2, 3, and 4 show the seismic parameters for each source (1, 2, and 3, respectively). A detailed explanation of the parameters is given in Table 2.

As mentioned previously, the Richter magnitude is treated as a discrete variable. Its values are rounded off to the closest multiple of .25 on the Richter magnitude scale. These rounded off values are referred thereafter as M_i's (3.5; 3.75; 4.0; 4.25, etc.). Events of M_i smaller than 3.5 are not considered in the model (although they are used in obtaining the subjective information on occurrences). Events of M_i smaller than 3.0 are totally disregarded.

The data is analyzed in two steps. In the first step information is obtained to determine the rate of occurrence of events independently of magnitude. This is used as an input to the Poisson-gamma model. In the second step information is gathered about the distribution of magnitudes of these events. For each M_i the probability of success given one trial is determined. A trial is defined as the occurrence of an earthquake. A success is defined as the earthquake being of the M_i considered while a failure is defined as the earthquake being of any other magnitude. This is used as the input to the Bernoulli-Beta model.

The analysis is based on two sources of information: the available data and the sujective input introduced through Bayesian analysis.

Poisson Model

The generating process for the number of occurrences is the Poisson model with uncertain mean rate of occurrence λ (Eq. 9.1). The parameter λ is treated as a random variable and Bayesian statistics are applied to it.

The sample likelihood function on λ (Eq. 9.3) is derived from the generating Poisson model. The parameters T and N of the sample likelihood function are determined from the available data. T represents the time base for which the data is available: 125 years for Area Sources 1 and 2, and 50 years for Line Source 1. N represents the total number of occurrences observed on the source considered during this time period.

The gamma prior distribution on λ (Eq. 9.2) is based on the subjective input of the analyst. The numerical values of the parameters λ' and ν' are obtained from this subjective input. For this example, it is assumed that the values of λ' and ν' are respectively equal to T and N of the corresponding source. The implication of this assumption is that the subjective information of the expert is similar to the available data. In other words, the analyst has as much confidence in his subjective input as he has in the data.

Based on the values of λ', ν', T and N, the parameters λ'' and ν'' of the posterior distribution on λ (Eq. 9.5) can be calculated for each source. It should be pointed out that in the absence of any subjective information (diffuse prior), the analysis can be carried out with objective data alone and in the absence of any objective data, the analysis can be carried out with subjective information alone. Knowledge of λ'' and ν'' completely defines--in a posterior sense--the probability function for the mean rate of occurrence λ for the source considered during a future time t.

Convolving the conditional Poisson generating process for the number of occurrences with the posterior distribution on λ, the marginal distribution for the number of occurrences (Eq. 9.6) is derived for each source considered. This distribution does not give any information on the magnitude of the occurrences. The next step is to obtain the posterior conditional distribution on magnitudes.

Bernoulli Trials

The generating process for the number r_{M_i} of events of any specific M_i given that a total of n events have occurred is the binomial model. However, the probability of success p_{M_i} for each trial has been assumed to be uncertain. The parameter p_{M_i} is treated as a random variable and Bayesian statistics is applied to it.

The sample likelihood function on p_{M_i} (Eq. 9.9) is derived from the generating binomial process. From the available data, the parameters N and R_{M_i} of the sample likelihood function can be determined. N represents the total number of events recorded on the source under consideration and R_{M_i} represents the number of earthquakes of magnitude M_i (successes) recorded on the same source. R_{M_i} must be determined for each source and each M_i.

Using the conjugate beta prior (Eq. 9.8) for the distribution on p_{M_i}, the parameters η'_{M_i} and ξ'_{M_i} are determined from the analyst's subjective input. For this example, it is assumed that the analytical recurrence relationship fitted to the data for each source constitutes the subjective input. For each individual source, the analytical relationship describing the recurrence of various M_i events is given by the following log-linear relationship (refer to Chapter VI).

$$\ln N(M) = \alpha + \beta M$$

where: N(M) = Number of events above magnitude M

M = Richter magnitude

α and β are regression constants.

The prior η'_{M_i} represents the subjective knowledge about the number of events for a source above the fixed lower bound ($M_i = 3.5$). As an example, consider the line source 1. From Figure 9-11 the η'_{M_i} corresponding to this source is 16. ε'_{M_i} represents the number of earthquakes of magnitude M_i. Again from Figure 9.11, for M = 3.50, Nc = 16 and for M = 3.75, Nc = 14, thus, for M_i = 3.50, ξ'_{M_i} is equal to 16 - 14 = 2. Because of the definition of the prior, within each source, η'_{M_i} is constant for all M_i's. If the prior had been input differently such as in the form of a distribution for each M_i, different η'_{M_i} could have been obtained.

Having determined the parameters of the sample likelihood function as well as the ones of the prior distribution, the posterior parameters η''_{M_i} and ξ''_{M_i} (Eq. 9.10) can be obtained by using the concept of conjugate distribution. The knowledge of η''_{M_i} and ξ''_{M_i} completely defines--in the posterior sense--the probability distribution of the probability of success p_{M_i} of magnitude M_i on the source considered.

The marginal distribution on the number of successes M_i's (Eq. 9.11) is obtained by convolving the posterior distribution on p_{M_i} and the conditional generating process of r_{M_i}. However, this marginal distribution is still conditional on the number of events n.

Combining the distribution of r_{M_i} for given n (Eq. 9.11), with the distribution on n (Eq. 9.6) gives the marginal Bayesian distribution on r_{M_i} (Eq. 9.12). This information completes the description of seismicity for a given source.

To obtain the probabilistic information on the peak ground acceleration at the site, the above information on the seismicity of various sources must be combined with an attenuation relationship.

The attenuation relationship used in this example is the empirical relation derived by Idriss et al. (1977) from a data base of shallow earthquakes recorded on stiff soil. The relation is given by:

$$A = \frac{190.67e^{0.823M}}{(R + b_3)^{1.561}} \quad \text{(See Data Set XI, Section 9.4)}$$

with standard deviation $\sigma_{\ln A} = 0.568$ and $b_3 = 0.864e^{0.463M}$

where: A = PGA (Ground parameter of interest in this example)

It will be assumed in this example that the relation given above is valid for the magnitude range (3.5, 8.00).

The Horizontal Rupture lengths associated to each Richter Magnitude level (discretized to 0.25) are summarized in the table below.

Table 1

Richter Magnitude	3.50	3.75	4.00	4.25	4.50	4.75
Horizontal Rupture Length (km)	0.00	0.00	0.00	0.00	0.00	5.00
Richter Magnitude	5.00	5.25	5.50	5.75	6.00	6.25
Horizontal Rupture Length (km)	6.00	7.60	9.20	12.00	15.00	18.00
Richter Magnitude	6.50	6.75	7.00	7.25	7.50	7.75
Horizontal Rupture Length (km)	26.00	45.00	80.00	135.00	230.00	400.00

Figure 9-12 shows the listing of the input data deck. Each data set as described in Section 9.4 is indicated with the corresponding item number. It is important to note that in Data Set X (Fig. 9-12) the cards containing information on the attenuation coefficients (Card 2 and Card 3, respectively) are identical. This is because only one attenuation is available, the limiting depth between both relationships (parameter DEPTH in Data Set XI) read in as (-15.000 km, see XI in Fig. 9-12) is irrelevant.

Figure 9-11 Recurrence Relationship for Line Source 1

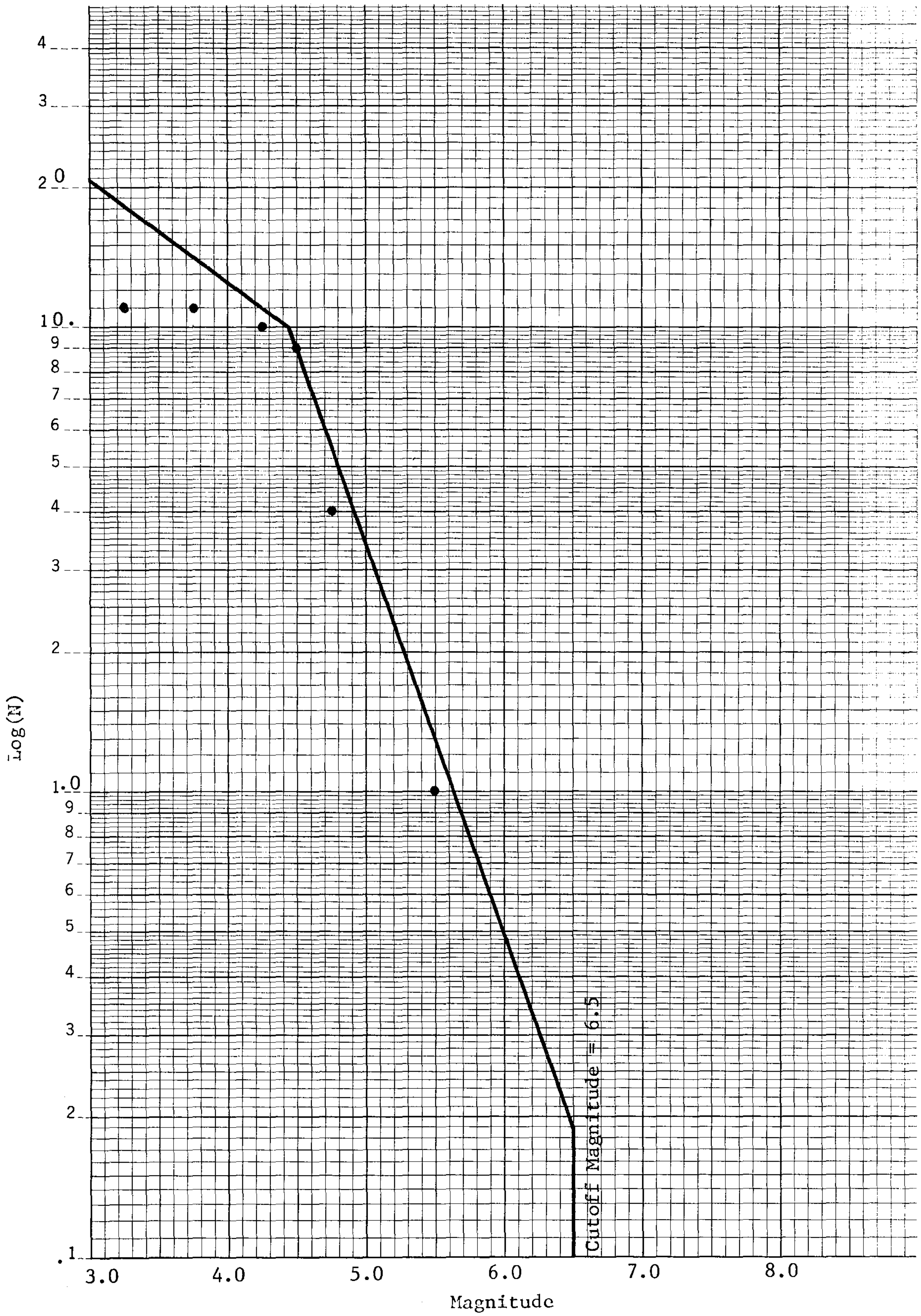


Figure 9-12

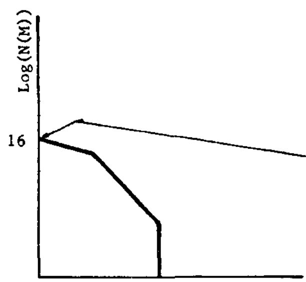
INPUT DATA FOR PROGRAM SEISMIC.HAZARD (SAMPLE PROBLEM)

```
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM) ---------------------------------- I
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM) ----------------------------------
30.00      0.000      31.000    2000000. --------------------------------- II
30.000     30.00      33.000    30.000     30.000    33.00 --------------- III
   2    1   13    3    1    1    2    0    1   12    1   10    0    0   18 --- IV
 50.00     0.25       3.50 ----------------------------------------------- V
   1  30.686    31.854    -10.000 ---------------------------------------+
   2  30.343    32.024    -10.000                                        |
   3  30.657    32.705    -10.100                                        |
   4  31.070    32.500    -10.100                                        |
   5  32.800    31.878     -2.000                                        |
   6  32.800    30.195     -2.000                                        |
   7  32.286    30.390     -5.000                                        | VI
   8  32.286    31.573     -5.000                                        |
   9  31.686    30.634    -10.000                                        |
  10  31.686    31.207    -10.000                                        |
  11  30.629    31.780    -10.000                                        |
  12  31.029    31.268    -10.000                                        |
  13  31.371    30.439    -10.000 ---------------------------------------+
   1    4    3    2 -----------------------------------------------------+
   8   10    9    7                                                      | VII
   5    8    7    6 -----------------------------------------------------+
AREA SOURCE 1                                                      12 ---+
   1    0    0    0    0                                                 |
   1                                                                     |
 0.000      -10.100   94.000    -10.000                                  | VIII
 250.00     15.000    2.400     2.600     1.500     2.100     0.800     1.600 |
   1.500     0.400    1.250     0.210     0.150     0.110     0.370 -----+
AREA SOURCE 2                                                      12 ---+
   2    0    0    0    1                                                 |
   1    1                                                                | VIII
 0.000      -10.000   75.000     -5.000  140.000    -2.000               |
   250.00   38.500    4.500     2.500     4.500     5.000     4.500     1.400 |
   6.800    4.100     4.050     .280      0.150     0.150 ---------------+
LINE SOURCE 1                                                      13 ---+
   2   11    1    1                                                      |
   100.0    28.000    3.000     2.500     1.500     4.000     5.600     3.000 | IX
     2.3     2.800    2.500     0.300     0.190     0.110     0.20 ------+
ACCELERATION PGA      20.00      50.000    1500.00 ----------------------+
 190.67   0.823308    0.000     1.561272  0.568      0.00                | X
 190.67   0.823308    0.000     1.561272  0.568      0.00 ---------------+
        85   3.000    -15.000    0.8643    0.4626    10.00     10.00     0.100 --- XI
 0.00       0.00      0.00      0.00      0.00       5.00      6.00      7.600 ---+
 9.20      12.00      15.00     18.00     26.00     45.00     80.00    135.00    | XII
230.00    400.00 --------------------------------------------------------------+
GRID FOR SAMPLE PROBLEM (PROGRAM SEISMIC HAZARD) ------------------------------+
 30.00     30.00      33.00     30.00     30.00     33.00      0.00       4    4 ---+ XIII
```

As obtained from historical information (see Fig. 1-2, Chapter I)

υ" is a parameter of the posterior distribution λ (See Eq. 9.5)

υ" corresponds to XNBDA(IXSC)* in Data Set VIII, card 5 and Data Set IX, card 3.



Recurrence Relationship (See Fig. 9-11)

Table 2

SEISMIC PARAMETERS FOR LINE SOURCE 1

Time Data Base (T) : 50
Number of Recorded Events (N) : 12
υ' from log-linear fit : 16
$\lambda'' = \lambda' + T = 50 + 50 = 100$
$\upsilon'' = \upsilon' + N = 16 + 12 = 28$
$n''_{M_i} = n'_{M_i} + N = 16 + 12 = 28$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 9.11) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
3.50	1	16.0	2.0	3.0
3.75	1	14.0	1.5	2.5
4.0	0	12.5	1.5	1.5
4.25	1	11.0	3.0	4.0
4.50	3	9.0	2.6	5.6
4.75	1	5.4	2.0	3.0
5.0	1	3.4	1.3	2.3
5.25	2	2.1	0.8	2.8
5.50	2	1.3	0.5	2.5
5.75	0	0.8	0.3	0.3
6.0		0.5	0.19	0.19
6.25		0.31	0.11	0.11
6.50		0.20	0.20	0.20
6.75				
7.0				
7.25				
7.50				
7.75				

NB (number of different magnitudes) = 13 (see Data Sets VIII and IX).

Cutoff magnitude for source obtained from geologic information

Difference between successive M_i bands

Parameter of the prior distribution on P_{M_i} (Eq. 9.8).

Parameter of the posterior distribution on P_{M_i} (see Eq. 9.10)

ξ''_{M_i} corresponds to XNBMG(IXSC), in Data Set VIII, Card 5, and Data Set IX, Card 3.**

Obtained by adding Columns 2 and 4

υ' is a parameter of the prior distribution on λ (Eq. 9.2) and is the total number of earthquakes greater or equal to magnitude 3.5 (in this case) expected to occur on the source.

λ" is a parameter of the posterior distribution on λ (see Eq. 9.5)
λ' is a parameter of the prior distribution on λ (see Eq. 9.7). Note that in this particular case, λ' = T = 50 yrs, implying that the subjective information of the analyst has the same weight as the available data.

λ" corresponds to TMDA(IXSC)* in Data Set VIII, card 5, and Data Set IX, Card 3

As obtained using program SORT.MAGNITUDE (Chapter VIII). R_{M_i} is used to obtain sample likelihood function on P_{M_i} (See Eq. 9.9).

As read from Recurrence Relationship (Fig. 9-11)

*Parameters of Poisson Model

**Parameter of Bernoulli Model

Table 3 Seismic Parameters for Area Source 1

Time Data Base (T) : 125
Number of Recorded Events (N) : 5
ν' from log-linear fit : 10
$\lambda'' = \lambda' + T = 125 + 125 = 250$
$\nu'' = \nu' + N = 10 + 5 = 15$
$\eta''_{M_i} = \eta'_{M_i} + N = 10 + 5 = 15$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
3.50	0	10.0	2.4	2.4
3.75	1	7.6	1.6	2.6
4.0	0	6.0	1.5	1.5
4.25	1	4.5	1.10	2.1
4.50	0	3.4	0.80	0.8
4.75	1	2.6	0.60	1.6
5.0	1	2.0	0.50	1.5
5.25	0	1.5	0.40	0.4
5.50	1	1.10	0.25	1.25
5.75		0.85	0.21	0.21
6.0		0.64	0.16	0.15
6.25		0.48	0.11	0.11
6.50		0.37	0.37	0.37
6.75				
7.0				
7.25				
7.50				
7.75				

Table 4 Seismic Parameters for Area Source 2

Time Data Base (T) : 125
Number of Recorded Events (N) : 17
ν' from log-linear fit : 21.5
$\lambda'' = \lambda' + T = 125 + 125 = 250$
$\nu'' = \nu' + N = 21.5 + 17 = 38.5$
$\eta''_{M_i} = \eta'_{M_i} + N = 21.5 + 17 = 38.5$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
3.50	1	21.5	3.5	4.5
3.75	0	18.0	2.5	2.5
4.0	2	15.5	2.5	4.5
4.25	3	13.0	2.0	5.0
4.50	3	11.0	1.5	4.5
4.75	0	9.5	1.4	1.4
5.0	3	8.1	3.8	6.8
5.25	2	4.3	2.1	4.1
5.50	3	2.2	1.05	4.05
5.75	0	0.58	0.28	0.28
6.0	0	0.30	0.15	0.15
6.25		0.15	0.15	0.15
6.50				
6.75				
7.0				
7.25				
7.50				
7.75				

9.7 Output for Program SEISMIC.HAZARD

Figure 9-13 shows the output for the sample problem as obtained in the line printer (i.e., logical unit equals 6). In general, the output is self-explanatory; however, comments have been included next to some of the items.

Figure 9-14 shows the output for the sample problem as saved on disk (i.e., LU* number = 10; see Data Set IV in Fig. 9-12).

Figure 9-15 shows the output saved on disk for plotting purposes (i.e., LU* number = 12; see Data Set IV in Figure 9-12) and to be used later as part of the input data for program CONST.PROB. (Chapter X).

---

*Proper control cards must be included in the job card list (JCL) when saving data on disk. For this particular example and for Stanford's Computer Center, the job control cards used are as follows:

```
//GO.FT10F001 DD  UNIT=DISK,DSN=WYL.??$???.FILENAME,
        DISP=(,KEEP),DCB=PRINT,SPACE=(TRK,(2,1),RLSE),
        VOL=SER=PUBØØ5
//GO.FT12F001 DD  . . . . . . . . . . .
```

Figure 9-13

OUTPUT FOR PROGRAM SEISMIC.HAZARD (SAMPLE PROBLEM)-AS OBTAINED ON LINE PRINTER-

```
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
STANDARD LATITUDE 1         30.0000
STANDARD LATITUDE 2          0.0000
STANDARD LONGITUDE          31.0000
NUMBER OF AREA SOURCES            2
NUMBER OF LINE SOURCES            1
NUMBER OF NODES                  13
NUMBER OF ELEMENTS                3
NUMBER OF GRIDS                   1
NUMBER OF VARIABLES               1
NUMBER OF ATT/VARIABLE            2
LINES PRINTED PER SITE            4
MAX NO. OF MAG                   18
SAVE RESULTS ON DISK (PLOTTING FORMAT)   40  VALUES PER SITE

SAVE COPY OF OUTPUT ON DISK    4  LINES PER SITE

TIME PERIOD   MAG INC   SMALLEST MAG
     50.00      0.25      3.50
NODAL COORDINATES   (  13  NODES)
```

INDEX	WCC INDEX	X COORD	Y COORD	Z (KM)	X (KM)	Y (KM)
1	1	30.686	31.854	-10.000	66.808	205.394
2	2	30.343	32.024	-10.000	34.405	224.409
3	3	30.657	32.705	-10.100	64.340	299.938
4	4	31.070	32.500	-10.100	103.162	277.113
5	5	32.800	31.878	-2.000	267.133	209.351
6	6	32.800	30.195	-2.000	270.052	22.574
7	7	32.286	30.390	-5.000	220.274	43.545
8	8	32.286	31.573	-5.000	218.808	174.835
9	9	31.686	30.634	-10.000	162.398	70.125
10	10	31.686	31.207	-10.000	162.020	133.717
11	11	30.629	31.780	-10.000	61.378	197.193
12	12	31.029	31.268	-10.000	99.335	140.295
13	13	31.371	30.439	-10.000	132.241	48.348

* (last two columns)

ELEMENTS DESCRIPTION (3 ELEMENTS)

INDEX	I	J	K	L	RENUMBERED	I	J	K	L
1	1	4	3	2		1	4	3	2
2	8	10	9	7		8	10	9	7
3	5	8	7	6		5	8	7	6

```
AREA SOURCE 1
NUMBER OF BANDS      1    BOUNDARY COND       0     0     0     0
NUMBER OF ELEMENT IN EACH BAND STARTING WITH DEEPEST ONE    1
SOURCE SECTION IN X AND Z TERMS
            X       0.000       94.000
            Z     -10.100      -10.000
TIME DATA BASE                 250.000
NO OF OCC                       15.000
NO OF DIFF MAG.                 12.000
TOTAL NO OF MAG.                14.620
DISTRIBUTION OF MAG.
       3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500  5.750
       2.400      2.600      1.500      2.100      0.800      1.600      1.500      0.400      1.250  0.210
       6.000      6.250
       0.150      0.110
AREA SOURCE 2
NUMBER OF BANDS      2    BOUNDARY COND       0     0     0     1
```

*Last two columns: X and Y coordinates of each node have been transformed from degrees (longitude, latitude) to kilometers by subroutine LMBRT.

Figure 9-13 (Continued)

```
NUMBER OF ELEMENT IN EACH BAND STARTING WITH DEEPEST ONE     1     1
SOURCE SECTION IN X AND Z TERMS
          X       0.000       75.000       140.000
          Z     -10.000       -5.000        -2.000
TIME DATA BASE               250.000
NO OF OCC                     38.500
NO OF DIFF MAG.               12.000
TOTAL NO OF MAG.              37.930
DISTRIBUTION OF MAG.
       3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500      5.750
       4.500      2.500      4.500      5.000      4.500      1.400      6.800      4.100      4.050      0.280
       6.000      6.250
       0.150      0.150
LINE SOURCE     1
LINE SOURCE 1
   2  SEGMENTS   BOUNDARY CONDITION    1    1  STARTING AT NODE   11   RENUMBERED   11
TIME DATA BASE               100.000
NO OF OCC                     28.000
NO OF DIFF MAG.               13.000
TOTAL NO OF MAG.              28.000
DISTRIBUTION OF MAG.
       3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500      5.750
       3.000      2.500      1.500      4.000      5.600      3.000      2.300      2.800      2.500      0.300
       6.000      6.250      6.500
       0.190      0.110      0.200
ATTENUATION RELATIONSHIPS
ACCELERATION PGA        IC=    20.000      MN=    50.000      MX=  1500.000
          B1          B2         B3          B4      LN SIG      MG MX
     190.670       0.823      0.000       1.561      0.568      0.000
     190.670       0.823      0.000       1.561      0.568      0.000
C1                 0.864
C2                 0.463
DEPTH            -15.000
LOG-NORMAL DISTRIBUTION ON ATTENUATION
NO OF SIG ON EACH SIDE OF MEAN       3.0
NO OF INCREMENTS IN DIST              85
INTG. STEP VERT. (KM)             10.000
INTG. STEP HOR.  (KM)             10.000
EPSILON          (KM)              0.100
HORIZONTAL RUPTURE LENGTHS (KM)(VERTICAL=HORIZONTAL/2)
       3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500      5.750
       0.000      0.000      0.000      0.000      0.000      5.000      6.000      7.600      9.200     12.000
       6.000      6.250      6.500      6.750      7.000      7.250      7.500      7.750
      15.000     18.000     26.000     45.000     80.000    135.000    230.000    400.000
NO INCREMENTS VERT      0      0      0      0      0      0      0      0      0      0      0      0
NO INCREMENTS VERT      0      2      4      6     10     20
NO INCREMRNTS HOR       0      0      0      0      0      0      0      0      0      0      0      0
NO INCREMRNTS HOR       2      4      8     12     22     40
   4.3635      4.8984      5.4990      6.1732      6.9300      7.7797      8.7335      9.8042     11.006
   13.870      15.571      17.480      19.623      22.029      24.730      27.762      31.166
ACCELERATION PGA      LOG - LINEAR CORRELATION
    1    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
    2    2    2    2    2    2    2    2    3    3    3    3    3    3    3    3    3    3    3    3
    3    4    4    4    4    4    4    4    4    5    5    5    5    5    5    6    6    6    6    6
    7    7    7    7    8    8    8    8    9    9    9   10   10   10   11   11   12   12   12   13
   13   14   15   15   16   16   17   18   18   19   20   20   21   22   23   24   25   26   27   28
   29   30   31   33   34   35   37   38   40   41   43   45   47   49   50   53   55   57   59   62
   64   67   69   72   75   78
    1    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
    2    2    2    2    2    2    2    2    3    3    3    3    3    3    3    3    3    3    3    3
```

Figure 9-13

```
    3     4     4     4     4     4     4     4     4     5     5     5     5     5     5     6     6     6     6     6
    7     7     7     7     8     8     8     8     9     9     9    10    10    10    11    11    12    12    12    13
   13    14    15    15    16    16    17    18    18    19    20    20    21    22    23    24    25    26    27    23
   29    30    31    33    34    35    37    38    40    41    43    45    47    49    50    53    55    57    59    62
   64    67    69    72    75    78
PROB   0.00135    0.00170    0.00214    0.00267    0.00332    0.00411    0.00506    0.00621    0.00758    0.00921
PROB   0.01114    0.01340    0.01606    0.01916    0.02275    0.02689    0.03165    0.03707    0.04324    0.05021
PROB   0.05804    0.06681    0.07656    0.08737    0.09927    0.11232    0.12553    0.14199    0.15865    0.17655
PROB   0.19568    0.21602    0.23752    0.26016    0.28365    0.30854    0.33412    0.36049    0.38755    0.41516
PROB   0.44320    0.47153    0.50000    0.52847    0.55680    0.58484    0.61245    0.63951    0.66588    0.69146
PROB   0.71615    0.73984    0.76248    0.78393    0.80432    0.82344    0.84135    0.85801    0.87345    0.88768
PROB   0.90073    0.91263    0.92344    0.93319    0.94196    0.94979    0.95676    0.96293    0.96835    0.97311
PROB   0.97725    0.98084    0.98394    0.98660    0.98886    0.99079    0.99242    0.99379    0.99494    0.99569
PROB   0.99668    0.99733    0.99786    0.99830    0.99865
ATTENUATION COEFFICIENTS
   5.2505      0.82331      1.5613      0.86430      0.46260
   8.1321       8.3379      8.5438       8.7496       8.9554      9.1613      9.3671      9.5729      9.7787
   10.190       10.396      10.602       10.808       11.014      11.220      11.425      11.631
ATTENUATION COEFFICIENTS
   5.2505      0.82331      1.5613      0.86430      0.46260
   8.1321       8.3379      8.5438       8.7496       8.9554      9.1613      9.3671      9.5729      9.7787
   10.190       10.396      10.602       10.808       11.014      11.220      11.425      11.631
PROB OF NO OCC OF EACH MAG PER INC, SOURCE    1
0.987682657 0.986678562 0.992242239 0.989194748 0.995837491 0.991732149 0.992242239 0.997911491 0.993521293 0.998901686
0.999215059 0.999424155
PROB OF NO OCC OF EACH MAG PER INC, SOURCE    2
0.994917943 0.997159229 0.994917943 0.994361873 0.994917943 0.998403685 0.992373886 0.995364016 0.995419852 0.999679464
0.999828119 0.999328119
PROB OF NO OCC OF EACH MAG PER INC, SOURCE    3
0.917264957 0.930314590 0.957275729 0.891987926 0.853697880 0.917264957 0.935613661 0.922451172 0.930314590 0.991226334
0.994429586 0.996769113 0.994137742
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
******  P R O B A B I L I T Y   O F   A T   L E A S T   O N E   E X C E E D E N C E   I N   50.00   Y E A R S   ******

ACCELERATION PGA     VB INC =     20.000 VB MIN =     50.000 VB MAX =   1500.000
GRID FOR SAMPLE PROBLEM (PROGRAM SEISMIC HAZARD)                                 NXMX =          4   NYMX =          4
   XXOR =     30.000   YYOR =     30.000   XXRT =     33.000   YYRT =     30.000   XXUP =     30.000   YYUP =     33.000
SITE COORDINATES X,Y,Z            30.000     30.000      0.000      0.000      0.000
     0.00000    20.00000    40.00000    60.00000    80.00000   100.00000   120.00000   140.00000   160.00000   180.00000
     1.00000     0.06969     0.00868     0.00102     0.00014     0.00000     0.00000     0.00000     0.00000     0.00000
        0.00      532.61     5733.07    49234.36        0.00        0.00        0.00        0.00        0.00        0.00
   200.00000   220.00000   240.00000   260.00000   280.00000   300.00000   320.00000   340.00000   360.00000   380.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00
   400.00000   420.00000   440.00000   460.00000   480.00000   500.00000   520.00000   540.00000   560.00000   580.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00
   600.00000   620.00000   640.00000   660.00000   680.00000   700.00000   720.00000   740.00000   760.00000   780.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00
SITE COORDINATES X,Y,Z            31.000     30.000      0.000     96.570     -0.419
     0.00000    20.00000    40.00000    60.00000    80.00000   100.00000   120.00000   140.00000   160.00000   180.00000
     1.00000     0.73244     0.18429     0.03942     0.01119     0.00375     0.00134     0.00054     0.00022     0.00011
        0.00       38.43      245.96     1243.69     4444.90    13319.42    37375.07        0.00        0.00        0.00
   200.00000   220.00000   240.00000   260.00000   280.00000   300.00000   320.00000   340.00000   360.00000   380.00000
     0.00004     0.00003     0.00001     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00        0.00
   400.00000   420.00000   440.00000   460.00000   480.00000   500.00000   520.00000   540.00000   560.00000   580.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
```

Annotations (margin notes, top to bottom):

- (Log_{10} of attenuation coefficients for relationship No. 1)
- Value of the term $b_1 e^{b_2 M}$ for each magnitude level.
- $P_R(r_{M_1} = 0)$ See Eq. 9.12
- PGA levels in cm/sec^2
- Values of complementary distribution function (1 - CDF)
- Return Period in years for each PGA-level (if $P\{A \geq a\} = 0$, return period is printed as zero)
- First three values are the site coordinates X, Y, Z in degrees (longitude, latitude). The last two values are the site coordinates X, Y in kilometers as computed by subroutine LMBRT.
- Note: Output for the remaining 14 sites is not shown since the form is the same.

Figure 9-14

OUTPUT FOR PROGRAM SEISMIC.HAZARD (SAMPLE PROBLEM) AS SAVED ON DISK

```
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
******  P R O B A B I L I T Y   O F   A T   L E A S T   O N E   E X C E E D E N C E   I N   50.00   Y E A R S   ******
ACCELERATION PGA      VB INC =     20.000 VB MIN =      50.000 VB MAX =   1500.000
GRID FOR SAMPLE PROBLEM (PROGRAM SEISMIC HAZARD)                                     NXMX =          4   NYMX =          4
   XXOR =      30.000   YYOR =      30.000    XXRT =      33.000    YYRT =      30.000   XXUP =      30.000   YYUP =      33.000
NUMBER OF INCREMENTS         40
SITE COORDINATES X,Y,Z                   30.000      30.000       0.000       0.000       0.000
     0.00000     20.00000     40.00000     60.00000     80.00000    100.00000    120.00000    140.00000    160.00000    180.00000
     1.00000      0.08969      0.00868      0.00102      0.00014      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00       532.61      5733.07     49234.36         0.00         0.00         0.00         0.00         0.00         0.00
   200.00000    220.00000    240.00000    260.00000    280.00000    300.00000    320.00000    340.00000    360.00000    380.00000
     0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
   400.00000    420.00000    440.00000    460.00000    480.00000    500.00000    520.00000    540.00000    560.00000    580.00000
     0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
   600.00000    620.00000    640.00000    660.00000    680.00000    700.00000    720.00000    740.00000    760.00000    780.00000
     0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
SITE COORDINATES X,Y,Z                   31.000      30.000       0.000      96.570      -0.419
     0.00000     20.00000     40.00000     60.00000     80.00000    100.00000    120.00000    140.00000    160.00000    180.00000
     1.00000      0.73244      0.18429      0.03942      0.01119      0.00375      0.00134      0.00054      0.00022      0.00011
        0.00        38.43       245.96      1243.69      4444.90     13319.42     37375.07         0.00         0.00         0.00
   200.00000    220.00000    240.00000    260.00000    280.00000    300.00000    320.00000    340.00000    360.00000    380.00000
     0.00004      0.00003      0.00001      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
   400.00000    420.00000    440.00000    460.00000    480.00000    500.00000    520.00000    540.00000    560.00000    580.00000
     0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
   600.00000    620.00000    640.00000    660.00000    680.00000    700.00000    720.00000    740.00000    760.00000    780.00000
     0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
SITE COORDINATES X,Y,Z                   32.000      30.000       0.000     193.139       0.000
     0.00000     20.00000     40.00000     60.00000     80.00000    100.00000    120.00000    140.00000    160.00000    180.00000
     1.00000      0.75177      0.17427      0.03273      0.00809      0.00229      0.00072      0.00025      0.00007      0.00003
        0.00        36.39       261.62      1502.83      6152.54     21831.50         0.00         0.00         0.00         0.00
   200.00000    220.00000    240.00000    260.00000    280.00000    300.00000    320.00000    340.00000    360.00000    380.00000
     0.00001      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
   400.00000    420.00000    440.00000    460.00000    480.00000    500.00000    520.00000    540.00000    560.00000    580.00000
     0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
   600.00000    620.00000    640.00000    660.00000    680.00000    700.00000    720.00000    740.00000    760.00000    780.00000
     0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
SITE COORDINATES X,Y,Z                   33.000      30.000       0.000     289.702       1.258
     0.00000     20.00000     40.00000     60.00000     80.00000    100.00000    120.00000    140.00000    160.00000    180.00000
     1.00000      0.48748      0.11490      0.02861      0.00942      0.00363      0.00150      0.00069      0.00030      0.00014
        0.00        75.30       410.14      1723.19      5284.39     13737.91     33222.92         0.00         0.00         0.00
   200.00000    220.00000    240.00000    260.00000    280.00000    300.00000    320.00000    340.00000    360.00000    380.00000
     0.00007      0.00004      0.00002      0.00001      0.00001      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
   400.00000    420.00000    440.00000    460.00000    480.00000    500.00000    520.00000    540.00000    560.00000    580.00000
     0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
        0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00
   600.00000    620.00000    640.00000    660.00000    680.00000    700.00000    720.00000    740.00000    760.00000    780.00000
```

PGA levels in cm/sec^2

Values of probability of exceedance (1-CDF) or $P\{A \geq a\}$

Return period in years for each PGA level (if $P\{A \geq a\} = 0$, RP is printed as zero.

Note: Output for the remaining 12 sites or nodal points is not shown since the form is the same.

Figure 9-15

OUTPUT FOR PROGRAM SEISMIC.HAZARD (SAMPLE PROBLEM)-AS STORED ON DISK FOR PLOTTING PURPOSES

```
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
ACCELERATION PGA         20.000    50.000  1500.000    50.000
GRID FOR SAMPLE PROBLEM (PROGRAM SEISMIC HAZARD)
       4          4    30.000    30.000    33.000    30.000    30.000    33.000
      40
 1.00000 0.08969 0.00868 0.00102 0.00014 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.73244 0.18429 0.03942 0.01119 0.00375 0.00134 0.00054 0.00022 0.00011
 0.00004 0.00003 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.75177 0.17427 0.03273 0.00809 0.00229 0.00072 0.00025 0.00007 0.00003
 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.48748 0.11490 0.02861 0.00942 0.00363 0.00150 0.00069 0.00030 0.00014
 0.00007 0.00004 0.00002 0.00001 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.61883 0.09821 0.01559 0.00306 0.00090 0.00026 0.00008 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.99993 0.98972 0.90660 0.74962 0.57322 0.41335 0.29582 0.19809 0.14037
 0.09637 0.07307 0.04726 0.03466 0.02956 0.02073 0.01484 0.01210 0.00837 0.00683
 0.00449 0.00372 0.00305 0.00225 0.00186 0.00152 0.00106 0.00078 0.00064 0.00051
 0.00032 0.00029 0.00026 0.00020 0.00014 0.00013 0.00011 0.00009 0.00007 0.00006
 1.00000 0.99812 0.89555 0.65153 0.45501 0.31705 0.22032 0.15764 0.10837 0.07959
 0.05705 0.04507 0.03097 0.02380 0.02071 0.01562 0.01158 0.00996 0.00730 0.00614
 0.00440 0.00373 0.00307 0.00256 0.00215 0.00177 0.00143 0.00119 0.00098 0.00076
 0.00063 0.00056 0.00051 0.00040 0.00030 0.00027 0.00024 0.00019 0.00015 0.00014
 1.00000 0.92996 0.49566 0.19849 0.08917 0.04364 0.02226 0.01230 0.00646 0.00382
 0.00221 0.00148 0.00080 0.00052 0.00041 0.00025 0.00014 0.00011 0.00007 0.00005
 0.00002 0.00001 0.00001 0.00001 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.81212 0.25418 0.06394 0.02059 0.00779 0.00309 0.00142 0.00061 0.00030
 0.00014 0.00008 0.00003 0.00002 0.00001 0.00001 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.99254 0.73347 0.33817 0.15346 0.07355 0.03638 0.01959 0.01002 0.00573
 0.00322 0.00213 0.00114 0.00072 0.00057 0.00035 0.00021 0.00016 0.00008 0.00006
 0.00003 0.00002 0.00001 0.00001 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.63920 0.12634 0.02193 0.00505 0.00135 0.00035 0.00012 0.00003 0.00001
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.50293 0.13698 0.03942 0.01470 0.00627 0.00285 0.00142 0.00067 0.00037
 0.00019 0.00013 0.00005 0.00003 0.00002 0.00002 0.00001 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.22690 0.02904 0.00440 0.00089 0.00021 0.00005 0.00001 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.45687 0.10805 0.02619 0.00832 0.00308 0.00121 0.00052 0.00021 0.00009
 0.00004 0.00002 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.04675 0.00360 0.00039 0.00004 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.00214 0.00015 0.00002 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
```

Ground parameter increment

Minimum value of G.P. of interest

Maximum value of G.P. of interest

Time prd. of interest

Grid's description

(1-CDF) for each site (NXMX*NXMY number of sites)

CHAPTER X

Program CONST.PROB

10.1 Introduction

At this point of the analysis (see Fig. 1-2, Item III-5), the probabilities of exceedance for a given ground motion parameter(s) and for a given time period of interest "t," have been determined through the use of one of the two available main programs (program ACC.LINE.AREA, incorporating the theory behind the "Classical" seismic hazard model, or program SEISMIC.HAZARD, incorporating the theory behind the "Bayesian" seismic hazard model). The probabilities of exceedance have been obtained in the form of cumulative distribution function(s) (CDF) or complementary cumulative distribution function(s) (1-CDF) by both programs. This has been done for one or several sites (or nodal points) within a given region, depending on the interests and needs of the analyst.

The next step consists of selecting the value(s) of the ground motion parameter(s) which correspond to a given probability of non-exceedance (risk level taken by the analyst--see Chapter VII). Program CONST.PROB has been designed for this purpose.

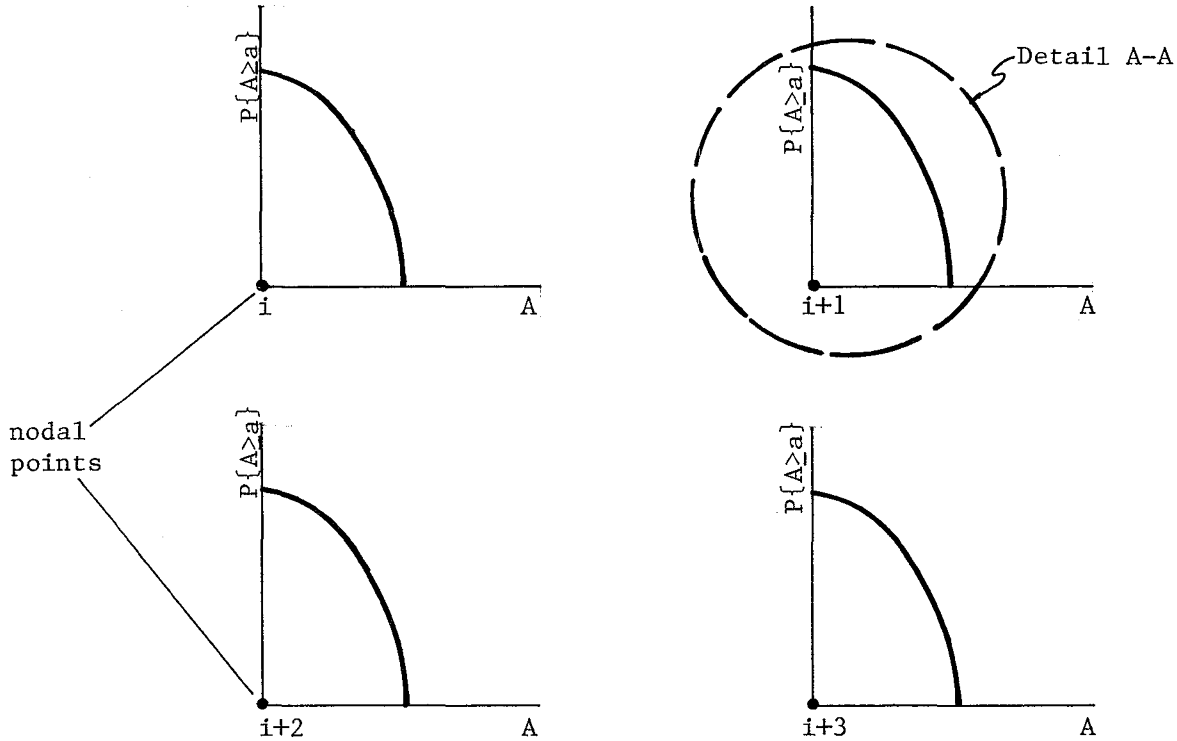
10.2 Description of the Program

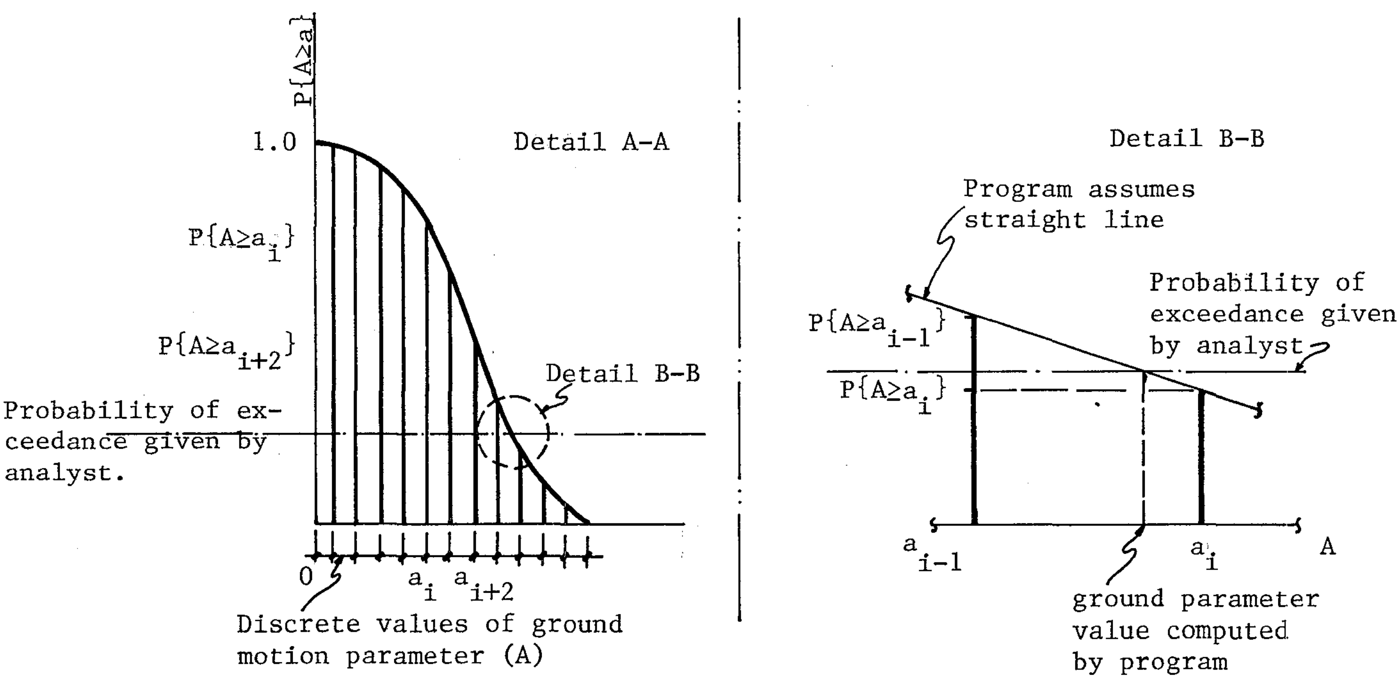
Program CONST.PROB computes the value of a specific ground motion parameter (e.g., PGA, PGV, etc.) given a probability of exceedance (1 - probability of non-exceedance) and a (1 - CDF) as obtained from one of the two main programs discussed in Chapters VII and IX.

Using the discretized (1 - CDF) at a site (or sites) and linear interpolation, the program determines the ground motion parameter value

Figure 10-1

(1 - CDFs), as computed by program ACC.LINE.AREA or by program SEISMIC.HAZARD for a given grid, ground motion parameter (A) and time period of interest "t."





corresponding to the level of exceedance chosen by the analyst. Figure 10-1 summarizes the procedure.

In its present form Program CONST.PROB has been organized in a main routine. It contains 67 executable FORTRAN statements and the space requirements is approximately 71100 bytes. The actual version can handle up to 300 nodal points (or sites) and 7 levels of exceedance in one run.

10.3 Description of Input Data

Input data for program CONST.PROB consists of nine sets of cards. The organization of data on each card, along with a description of the items, is given in the following paragraphs.

I. Lambert Projection*--(4F10.0)--1 card

Col.	1-10	STL1	(Standard latitude 1)
	11-20	STL2	(Standard Latitude 2)
	21-30	STLN	(Standard Longitude)
	31-40	SCAL	(Scale)

II. Label Description**--(7F10.0)--1 card

Col.	1-10	DXCR	(X-distance between marks (degrees))
	11-20	DYCR	(Y-distance between marks (degrees))
	21-30	DXLB	(X-distance between labels (degrees))
	31-40	DYLB	(Y-distance between labels (degrees))
	41-50	DCLV	Increments between contours
	51-60	XMDC	Label every XMDC contour
	61-70	CRCR	Marks inside grid. If 0 = NO.

---

*Same parameters as in Data Set II (Program SEISMIC HAZARD, Chapter IX).

**Parameters used for plotting purposes (to be discussed in Chapter XI).

III. General Information--(2I5, 7F10.0)--One card

Col.	1-5	NOPD	(Number of data sets required)
	6-10	NDLV	(Number of levels of exceedance in each run--7 maximum/run)
	11-20	PBLV(1)	(First level of exceedance)
	21-30	PBLV(2)	(Second level of exceedance)
	⋮		
	71-80	PBLV(7)	(Seventh level of exceedance)

IV. Run Identification*--(20A4)--2 cards

Card 1

Col.	1-80	HED1	(Identification)

Card 2

Col.	1-80	HED1	(Identification)

V. Variable Identification--(5A4,4F10.0)--One card

Col.	1-20	HED2	(Variable identification, e.g., PGA, PGV, etc.)
	21-30	VBPR	(Variable increment: 4 values, namely:

1. Parameter's step increment, e.g., 20 cm/sec^2 if PGA)
2. Minimum ground parameter's level of interest.
3. Maximum ground parameter's level of interest.
4. Time of interest "t."

VI. Grid Identification--(20A4)--One card

Col.	1-80	HED3	(Grid identification label)

---

*Note that Data Sets IV-IX inclusive can be read from Unit IIN (see Macro Flow Chart) as created by program SEISMIC.HAZARD.

VII. Grid Description*--(2I5, 6F10.0)--One card

Col.	1-5	NXMX	(Number of points in the X direction)
	6-10	NYMX	(Number of points in the Y direction)
	11-20	XXOR	(X-coordinate of origin)
	21-30	YYOR	(Y-coordinate of origin)
	31-40	XXRT	(X-coordinate of bottom right corner)
	41-50	YYRT	(Y-coordinate of bottom right corner)
	51-60	XXUP	(X-coordinate of top left corner)
	61-70	YYUP	(Y-coordinate of top left corner)

VIII. Number of Values in (1 - CDF)--(I5)--One card

Col.	1-5	NOVB	(Number of values in (1 - CDF) used to describe (1 - CDF), i.e., 40)

IX. Levels of exceedance in (1 - CDF)s--(10F8.0)--(NXMX*NYMX) cards or sets of cards

Col.	1-10	PB(1)	(Probability of exceedance corresponding to the smallest ground parameter level)
	. . .	PB( )	
	. . .	PB(NOVB)	(Probability of exceedance corresponding to the largest ground parameter level)

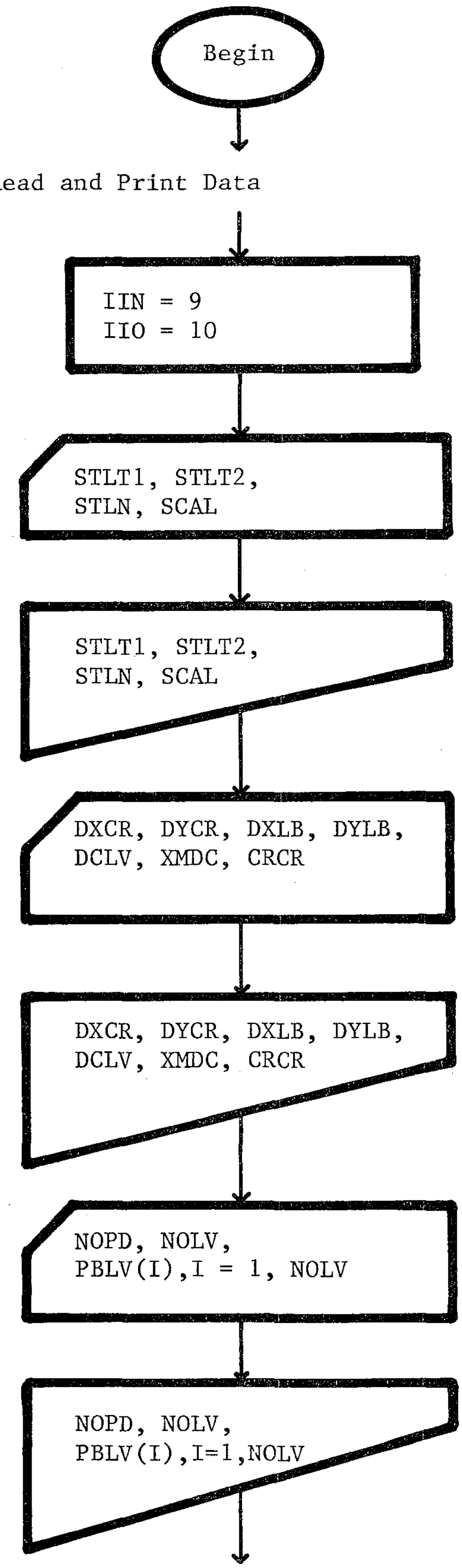
Note: Do-Loop on NOPD (number of runs required) starts at card 4.

*Refer to Figure 9-9.

10.4 Macro Flow Chart for Program CONST.PROB

* Unit = 5 Card reader and Unit = 6 Line Printer

I. Read and Print Data



Define input and output units on disk (Supply appropriate JCL)

Read and Print: {Unit=5 and Unit=6}*

1. Standard latitude 1
2. Standard latitude 2
3. Standard longitude
4. Map scale

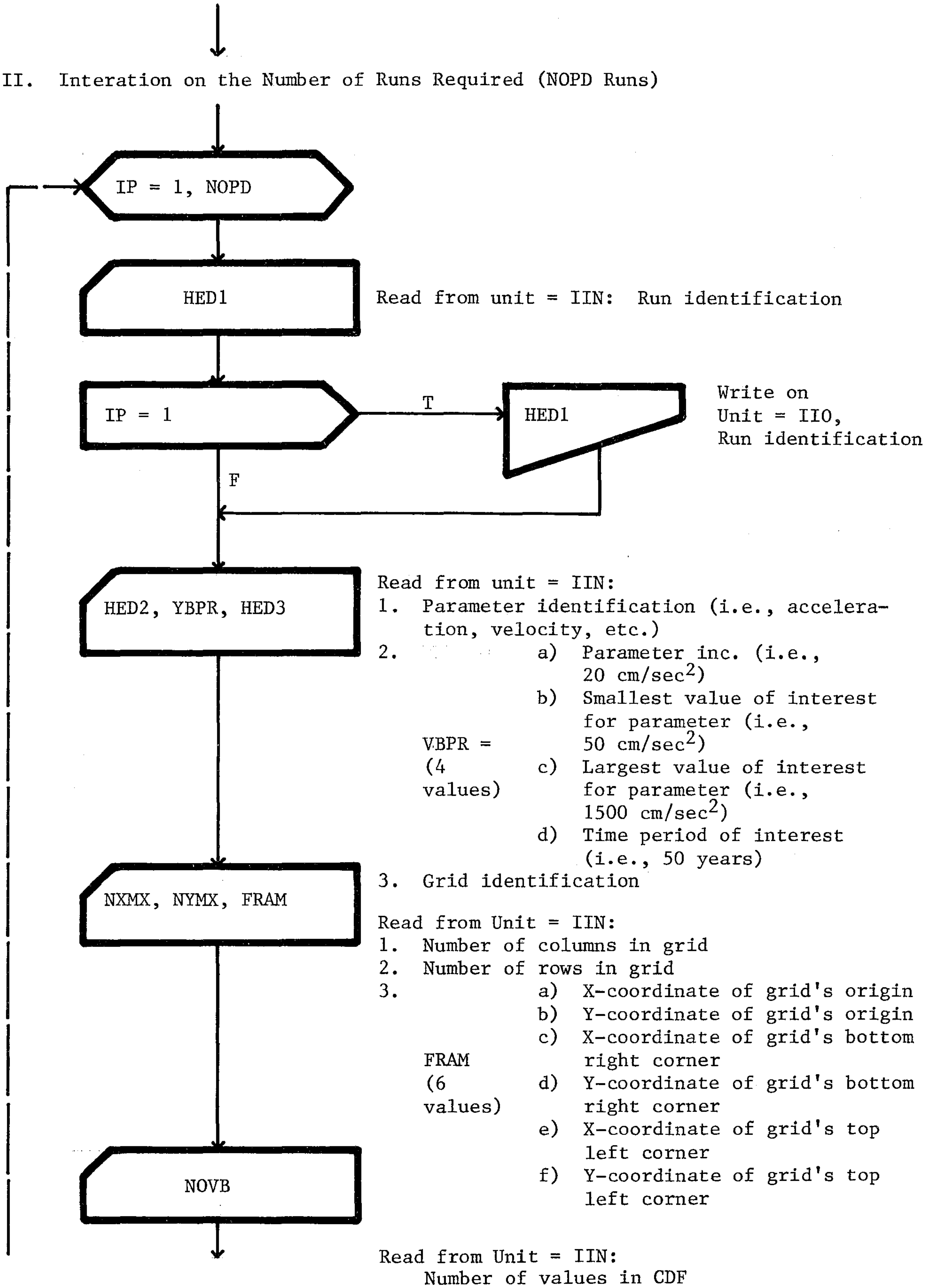
Read and Print: {Unit=5 and Unit=6}*

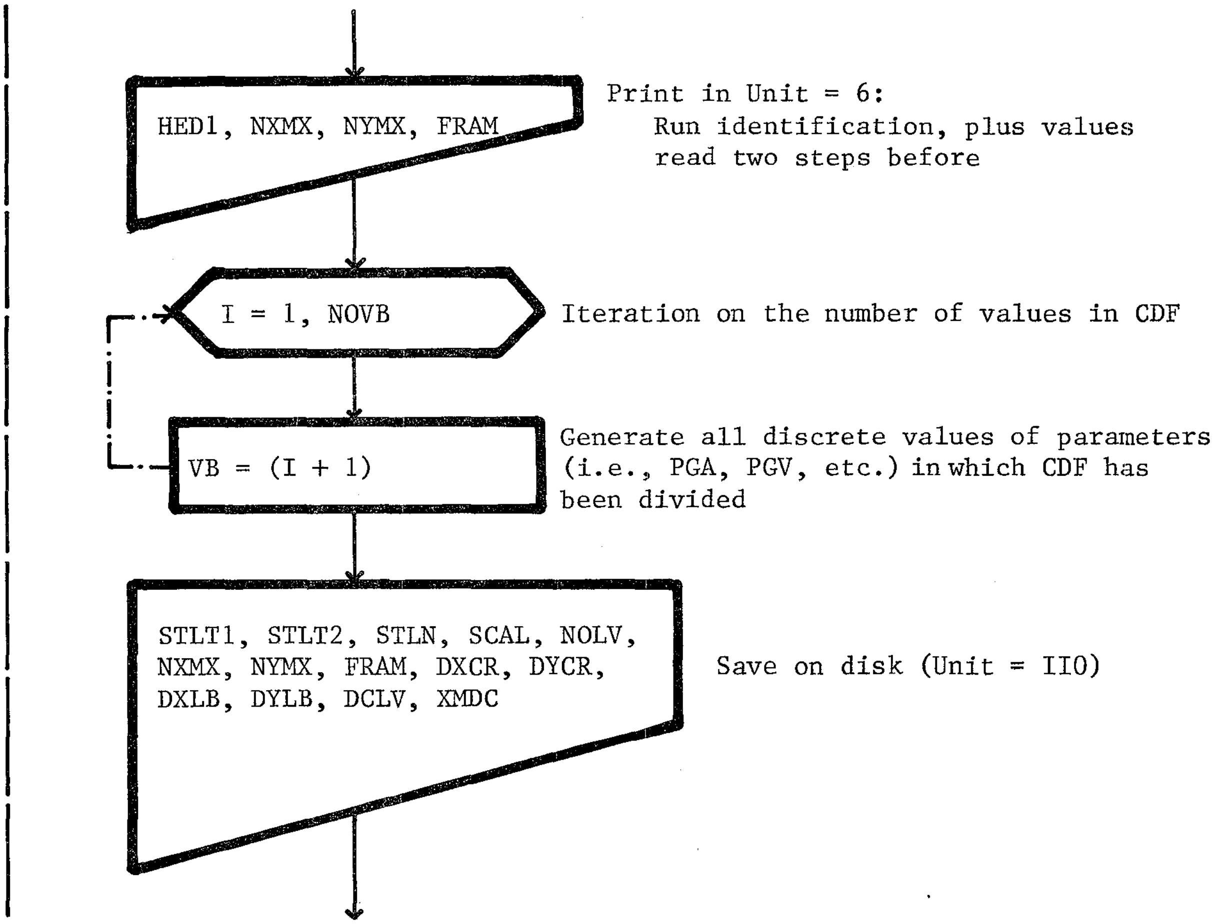
1. X-distance between marks
2. Y-distance between marks
3. X-distance between labels
4. Y-distance between labels
5. Increments between contours
6. Label every "XMDC" contour
7. Marks inside grid? 0 = NO

Read and Print: {Unit=5 and Unit=6}*

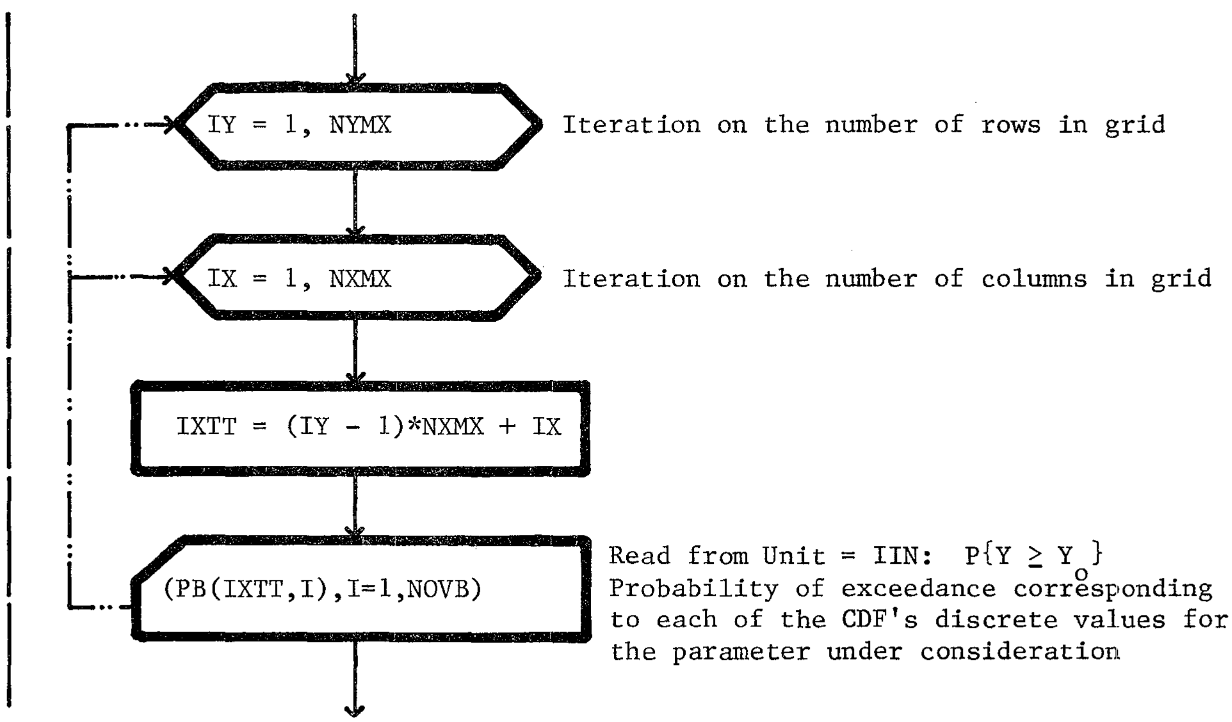
1. Number of runs required
2. Number of levels of exceedance in each run
3. Level I of exceedance where I = 1 up to 7 per run

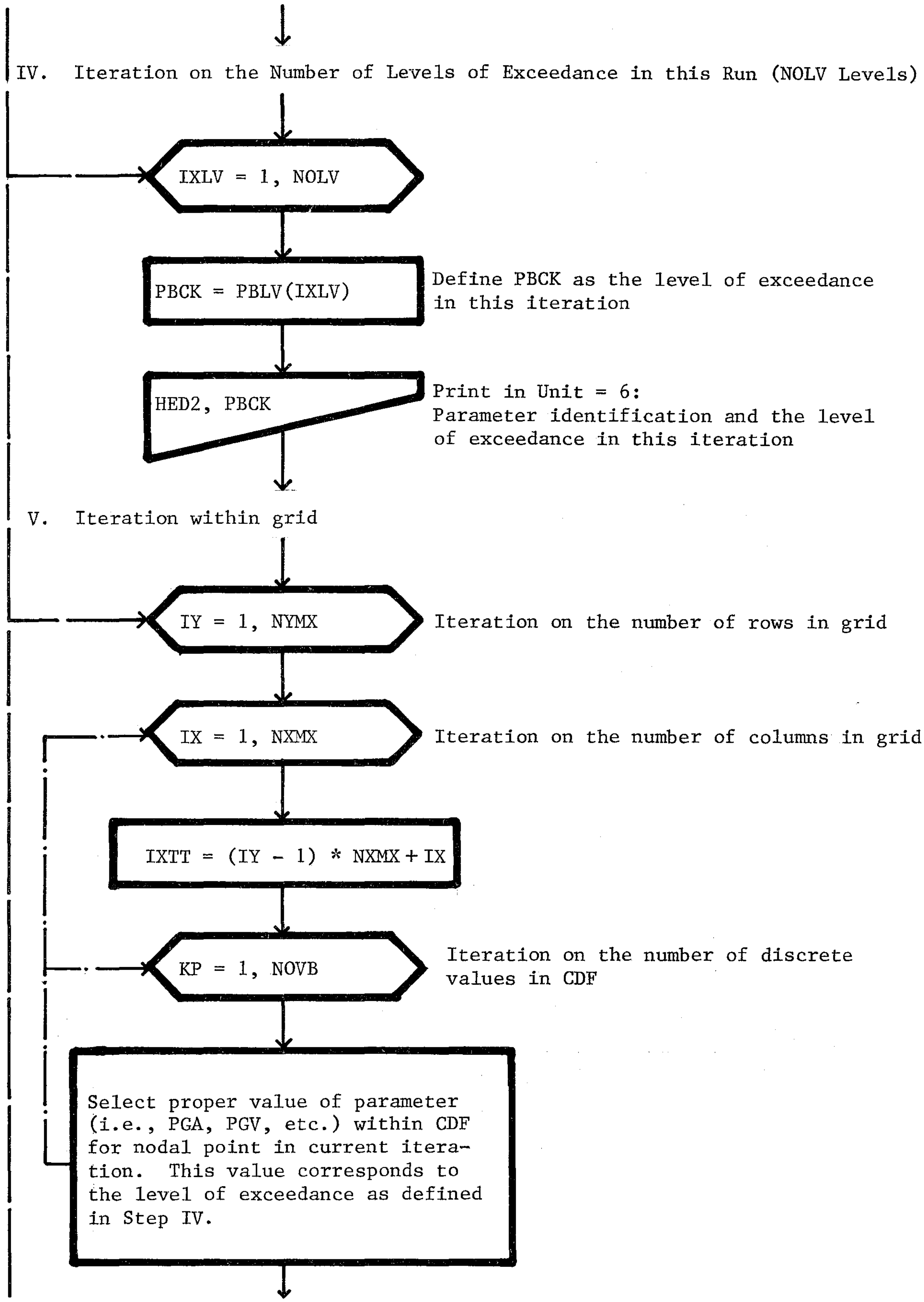
II. Interation on the Number of Runs Required (NOPD Runs)

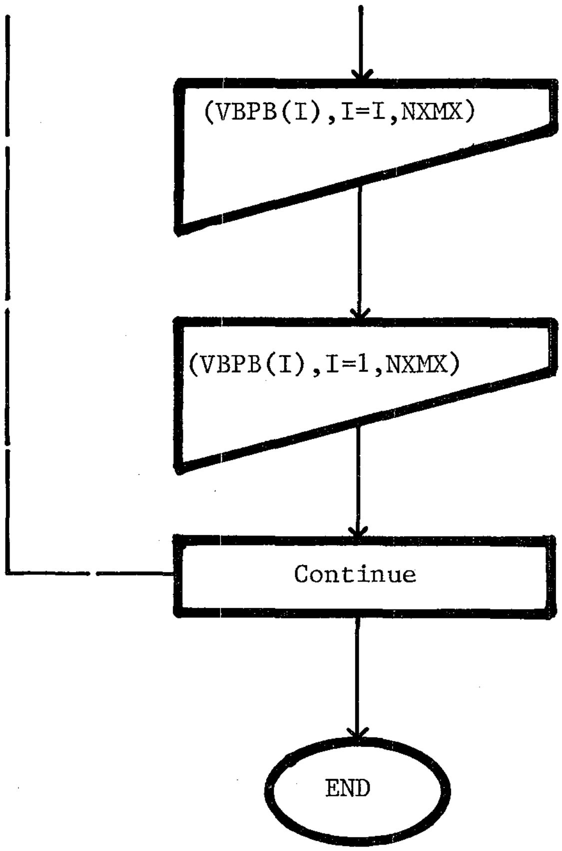




III. Iteration within Grid




IV. Iteration on the Number of Levels of Exceedance in this Run (NOLV Levels)
IXLV = 1, NOLV
PBCK = PBLV(IXLV)
Define PBCK as the level of exceedance in this iteration
HED2, PBCK
Print in Unit = 6: Parameter identification and the level of exceedance in this iteration
V. Iteration within grid
IY = 1, NYMX
Iteration on the number of rows in grid
IX = 1, NXMX
Iteration on the number of columns in grid
IXTT = (IY - 1) * NXMX + IX
KP = 1, NOVB
Iteration on the number of discrete values in CDF
Select proper value of parameter (i.e., PGA, PGV, etc.) within CDF for nodal point in current itera- tion. This value corresponds to the level of exceedance as defined in Step IV.



Print in Unit = 6,
The values of the parameter (i.e., PGA, PGV, etc.) for all grid nodes, row-wise.

Save results on disk, unit = IIO.

10.5 Sample Problem

Using the output for the sample problem in Chapter IX (see Figures 9-10 and 9-17), assume that the analyst is interested in knowing the ground motion parameter values (PGA in this case) at each nodal point or site of the grid shown on page and corresponding to a probability of exceedance of 5 percent or a probability of non-exceedance of 95 percent.

Figure 10-2 shows the listing of the input data deck. Each data set as described in Section 10.3 is indicated with the corresponding item number.

Figures 10-3 and 10-4 show the output for program CONST.PROB as obtained on the line printer and disk.

Figure 10-2

INPUT DATA FOR PROGRAM CONST.PROB (SAMPLE PROBLEM)

```
 30.000    0.000     31.000  2000000. ---------------------------------------- I
 1.00      1.000     1.000     1.0000    1.0000    1.0000 -------------------- II
   1    1    0.050 ------------------------------------------------------------ III
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM) ---------------------------------------- IV
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM) ---------------------------------------- IV
ACCELERATION PGA          20.000    50.000  1500.000    50.000 ----------------- V
GRID FOR SAMPLE PROBLEM (PROGRAM SEISMIC HAZARD) ------------------------------- VI
          4          4    30.000    30.000    33.000    30.000    30.000    33.000 ---- VII
         40 ------------------------------------------------------------------- VIII
 1.00000 0.08969 0.00868 0.00102 0.00014 0.00000 0.00000 0.00000 0.00000 0.00000 ---- IX
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.73244 0.18429 0.03942 0.01119 0.00375 0.00134 0.00054 0.00022 0.00011
 0.00004 0.00003 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.75177 0.17427 0.03273 0.00809 0.00229 0.00072 0.00025 0.00007 0.00003
 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.48748 0.11490 0.02861 0.00942 0.00363 0.00150 0.00069 0.00030 0.00014
 0.00007 0.00004 0.00002 0.00001 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.61883 0.09821 0.01559 0.00306 0.00090 0.00026 0.00008 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.99993 0.98972 0.90660 0.74962 0.57322 0.41335 0.29582 0.19809 0.14037
 0.09637 0.07307 0.04726 0.03466 0.02956 0.02073 0.01484 0.01210 0.00837 0.00683
 0.00449 0.00372 0.00305 0.00225 0.00186 0.00152 0.00106 0.00078 0.00064 0.00051
 0.00032 0.00029 0.00026 0.00020 0.00014 0.00013 0.00011 0.00009 0.00007 0.00006
 1.00000 0.99812 0.89555 0.65153 0.45501 0.31705 0.22032 0.15764 0.10837 0.07959
 0.05705 0.04507 0.03097 0.02380 0.02071 0.01562 0.01158 0.00996 0.00730 0.00614
 0.00440 0.00373 0.00307 0.00256 0.00215 0.00177 0.00143 0.00119 0.00098 0.00076
 0.00063 0.00056 0.00051 0.00040 0.00030 0.00027 0.00024 0.00019 0.00015 0.00014
 1.00000 0.92996 0.49566 0.19849 0.08917 0.04364 0.02226 0.01230 0.00646 0.00382
 0.00221 0.00148 0.00080 0.00052 0.00041 0.00025 0.00014 0.00011 0.00007 0.00005
 0.00002 0.00001 0.00001 0.00001 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.81212 0.25418 0.06394 0.02059 0.00779 0.00309 0.00142 0.00061 0.00030
 0.00014 0.00008 0.00003 0.00002 0.00001 0.00001 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.99254 0.73347 0.33817 0.15346 0.07355 0.03638 0.01959 0.01002 0.00573
 0.00322 0.00213 0.00114 0.00072 0.00057 0.00035 0.00021 0.00016 0.00008 0.00006
 0.00003 0.00002 0.00001 0.00001 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.63920 0.12634 0.02193 0.00505 0.00135 0.00035 0.00012 0.00003 0.00001
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.50293 0.13698 0.03942 0.01470 0.00627 0.00285 0.00142 0.00067 0.00037
 0.00019 0.00013 0.00005 0.00003 0.00002 0.00002 0.00001 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.22690 0.02904 0.00440 0.00089 0.00021 0.00005 0.00001 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.45687 0.10805 0.02619 0.00832 0.00308 0.00121 0.00052 0.00021 0.00009
 0.00004 0.00002 0.00001 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.04675 0.00360 0.00039 0.00004 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1.00000 0.00214 0.00015 0.00002 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 ----
```

Figure 10-3

```
OUTPUT FOR PROGRAM CONST.PROB (SAMPLE PROBLEM)

STANDARD LATITUDE 1         30.0000
STANDARD LATITUDE 2          0.0000
STANDARD LONGITUDE          31.0000
SCALE              1   TO  2000000.0
X MARK  EVERY                1.0000
Y MARK  EVERY                1.0000
X LABEL EVERY                1.0000
Y LABEL EVERY                1.0000
CONTOUR LINE  EVERY         30.0000
CONTOUR LABEL EVERY             1.0  LINES
CROSSES INSIDE? 0=NO            0.0
NUMBER OF GRIDS                   1
NUMBER OF PROB LEVELS             1
PROBABILITY LEVELS            0.050
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)                                          NXMX =          4   NYMX =          4
   XXOR =     30.000   YYOR =     30.000   XXRT =     33.000   YYRT =     30.000  XXUP =     30.000   YYUP =     33.000
ACCELERATION PGA          PROBABILITY OF NON-EXCEEDENCE       0.950
    29.799    58.539    57.560    55.042
    51.670   237.877   211.770    97.206
    66.431   112.671    54.623    57.831
    37.881    54.183    19.932    19.041
```

Figure 10-4

OUTPUT FOR PROGRAM CONST.PROB (SAMPLE PROBLEM)--AS SAVED ON DISK

```
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
  30.00000   0.00000  31.00000  2000000.
    1    4    4
    30.000    30.000    33.000    30.000    30.000    33.000
     1.000     1.000     1.000     1.000     1.000     1.000
PROB. OF EXCEED.= 0.050
    29.799    58.539    57.560    55.042
    51.670   237.877   211.770    97.206
    66.431   112.671    54.623    57.831
    37.881    54.183    19.932    19.041
```

CHAPTER XI

Program PLOT.ISO

11.1 Introduction

This chapter concludes the presentation of the seismic hazard methodology currently used at Stanford, by discussing the last step in the analysis, namely the preparation of an exposure map (see Figure 1-1, Item II-6). Program PLOT.ISO is discussed and implemented in the remaining sections of this chapter.

11.2 Description of the Program

Once a complementary distribution function (1 - CDF) has been established for each nodal point or site of a grid covering a given region (program SEISMIC.HAZARD or program ACC.LINE.AREA), a seismic exposure map can be prepared for any desired probability of non-exceedance. Program CONST.PROB selects the ground parameter values at each nodal point for a given probability of exceedance (1 - probability of non-exceedance) and for a given time period of interest, thus producing the necessary information to be used by program PLOT.ISO. This program selects the minimum and maximum values of the specific ground motion parameter of interest (i.e., PGA, PGV, etc.) from the data obtained by program CONST.PROB, and computes the number of contours to be plotted based on the parameter "DCLV" (increment between contours) given by the analyst in the input data deck. A second order polynomial is used to interpolate between the parameter's values at the grid's nodes in order to establish the locus of points corresponding to each contour. A file containing contour information is created on tape and plotted on the 11 or 33 inch Calcomp plotter. A conformal Lambert projection is used.

The program has the optional capability of transforming the ground parameter (PGA) into intensity using Richter-Gutenberg's relation $\{I = 3(LOG(PGA) + 0.5)\}$. This option can be specified by setting the parameter "SKIPAC" different from zero in the input data deck. (If a different intensity vs PGA relation is required, Line 781 (see program's listing in Appendix C) should be modified accordingly.)

Program PLOT.ISO is system dependent. Its use is limited to Stanford's Computer Center since it uses plotting routines which are system oriented. The present dimensions allow for a maximum of 1600 levels for the ground motion parameter per grid (i.e., a grid having 40 rows and 40 columns or 1600 sites). The program handles any number of different grids per run.

11.3 Description of Input Data

Input data for program PLOT.ISO consists of eight sets of cards. The organization of data on each card, along with a description of the items, is given in the following sections.

I. Identification Card--(3I5, 16A4)--One card

Col.	1-5	NOTP	(Number of plot types (i.e., different grids))
	6-10	ICAL	(Plotter size: If = 3, 11 inch size (default), If = 4, 33 inch size)
	11-15	NN	(Flag for Lambert Projection, 0 = 0/180°, 1 = 0/360°)
	16-80	HED1	(Run identification)

II. Lambert Projection--(5F10.0)--One card

Col.	1-10	STLT1	(Standard latitude° 1)
	11-20	STLT2	(Standard latitude° 2; if read as zero, only one standard latitude° used)

Col.	21-30	STLN	(Standard longitude°)
	31-40	SCAL	(Scale (1/SCAL))
	41-50	DTLB	(Distance between grid and label-default = 0.5 inch)

III. Plot Flags--(6F10.0)--One card

Col.	1-5	NOPL	(Number of plots with same parameters)
	6-10	NXMX	(Number of points in X-direction; i.e., number of columns in grid)
	11-15	NYMX	(Number of points in Y-direction; i.e., number of rows in grid)
	16-20	PLFR	(Plot frame ?, if 0 = NO)
	21-25	SKIPAC	(Transformation from acceleration to intensity ? If 0 = NO)

IV. Grid Description--(6F10.0)--One card (see Fig. 9-9)

Col.	1-10	XXOR	(X-coordinate° of origin)
	11-20	YYOR	(Y-coordinate° of origin)
	21-30	XXRT	(X-coordinate° of right bottom corner)
	31-40	YYRT	(Y-coordinate° of right bottom corner)
	41-50	XXUP	(X-coordinate° of left top corner)
	51-60	YYUP	(Y-coordinate° of left top corner)

V. Label description--(7F10.0)--One card

Col.	1-10	DXCR	(X-distance between marks, degrees)
	11-20	DYCR	(Y-distance between marks, degrees)
	21-30	DXLB	(X-distance between labels, degrees)
	31-40	DYLB	(Y-distance between labels, degrees)
	41-50	DCLV	(Increments between contours)
	51-60	XMDC	(Label every "XMDC" contour)
	61-70	CRCR	(Degree marks inside grid? If 0 = NO)

VI. Plot Identification--(75A1, I5)--One card

Col.	1-75	HED2	(Title of plot)
	76-80	NOMD	(Number of modifications in fourpt)

VII. Calls Needing Modifications*--(16I5)--16 Values per card,

Input only if NOMD $\neq$ 0

Col.	1-5	NBCL(1)	(First fourpt call needing modification)
	6-10	NBCL(2)	(Second fourpt call needing modification)
	. . .		
		NBCL(NOMD)	(Last fourpt call needing modification)

VIII. Ground Parameter's Values at Grid's Nodes**--(8F10.0)--8 values/card

Col.	1-10	AA(1,1)	(Ground parameter value at grid's origin)
	11-20	AA(1,2)	(Ground parameter value at right of origin)
	. . .	AA(1,NXMX)	(Ground parameter value at XXRT, YYRT)

Repeat "NYMX" times, read data in by rows, see Fig. 9-9.

Do-Loop on NOTP starts at Data Set V

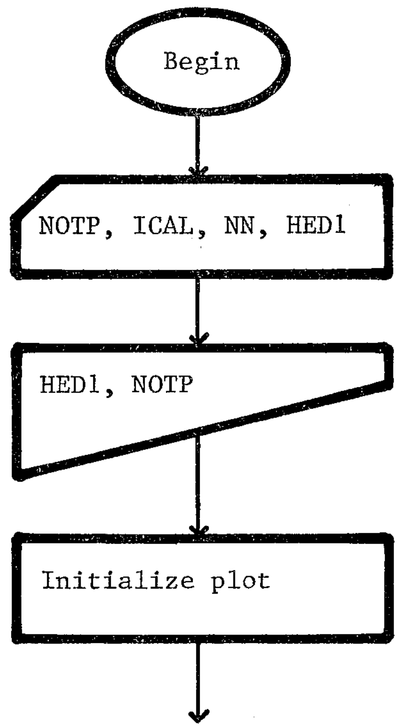
If "DCLV" is different between two plots, the do-loop has to be done on NOTP, starting at Data Set II.

---

*See explanatory note, page

**These values correspond to the output produced by Program CONST.PROB. (i.e., ground parameter's values obtained for a given probability of exceedance (1 - P{non-exceedance}) and time period t for a whole set of nodal points or sites).

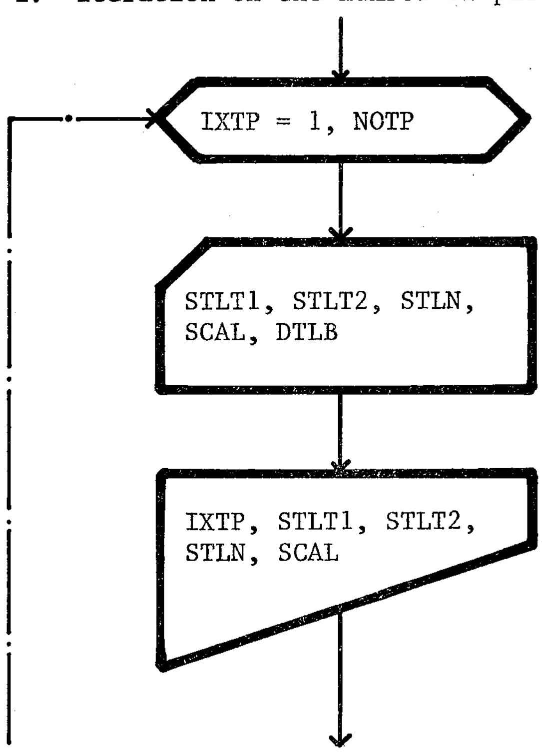
11.4 Macro Flow Chart for Program PLOT.ISO



Read: 1. Number of plot types (different grids)
2. Plotter size
3. Flag for Lambert projection
4. Run identification

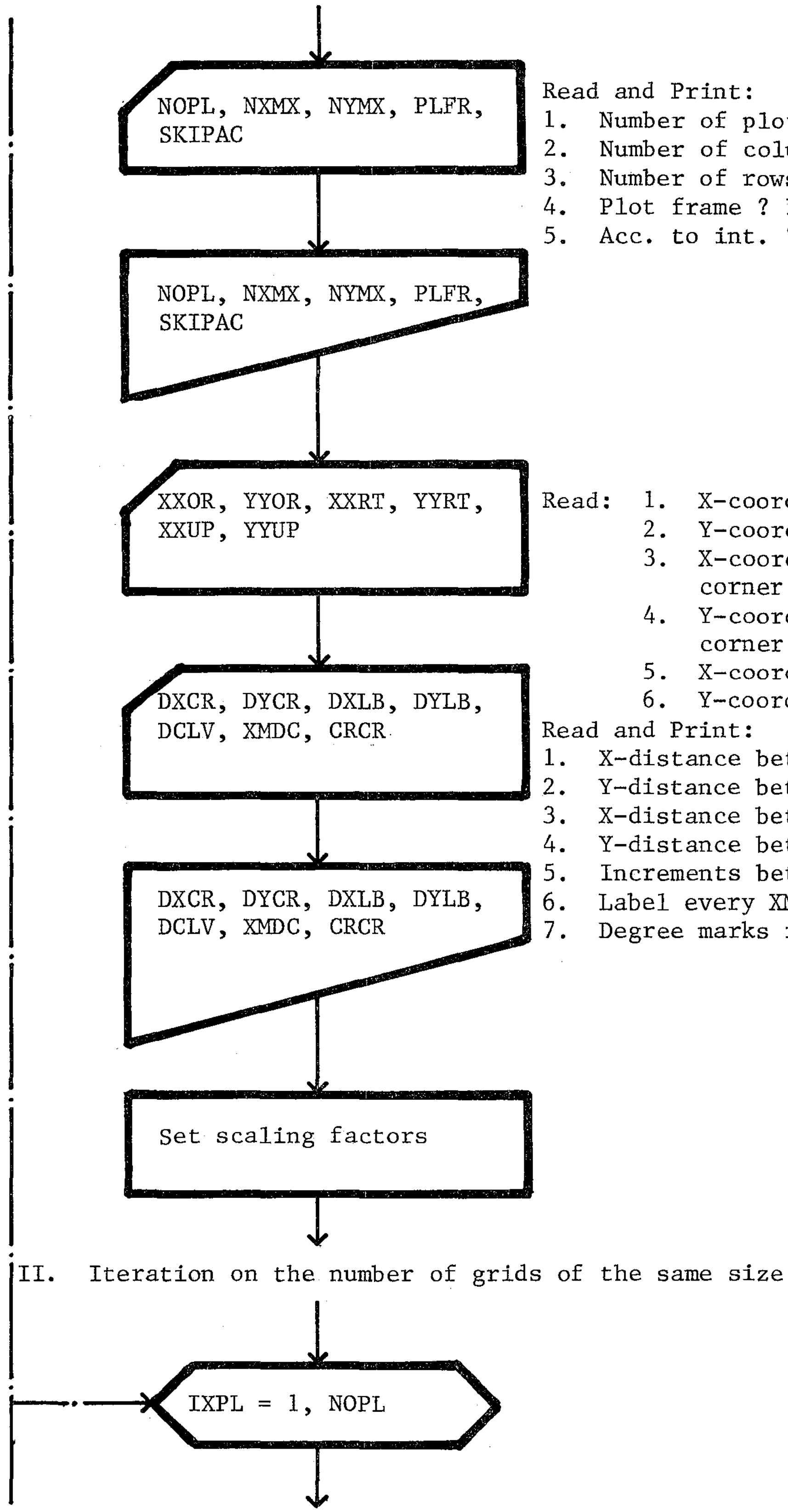
Print: Run identification and number of plot types

I. Iteration on the number of plot types in this run (NOTP types)



Read: 1. Standard latitude 1
2. Standard latitude 2
3. Standard longitude
4. Map scale
5. Distance between grid and label

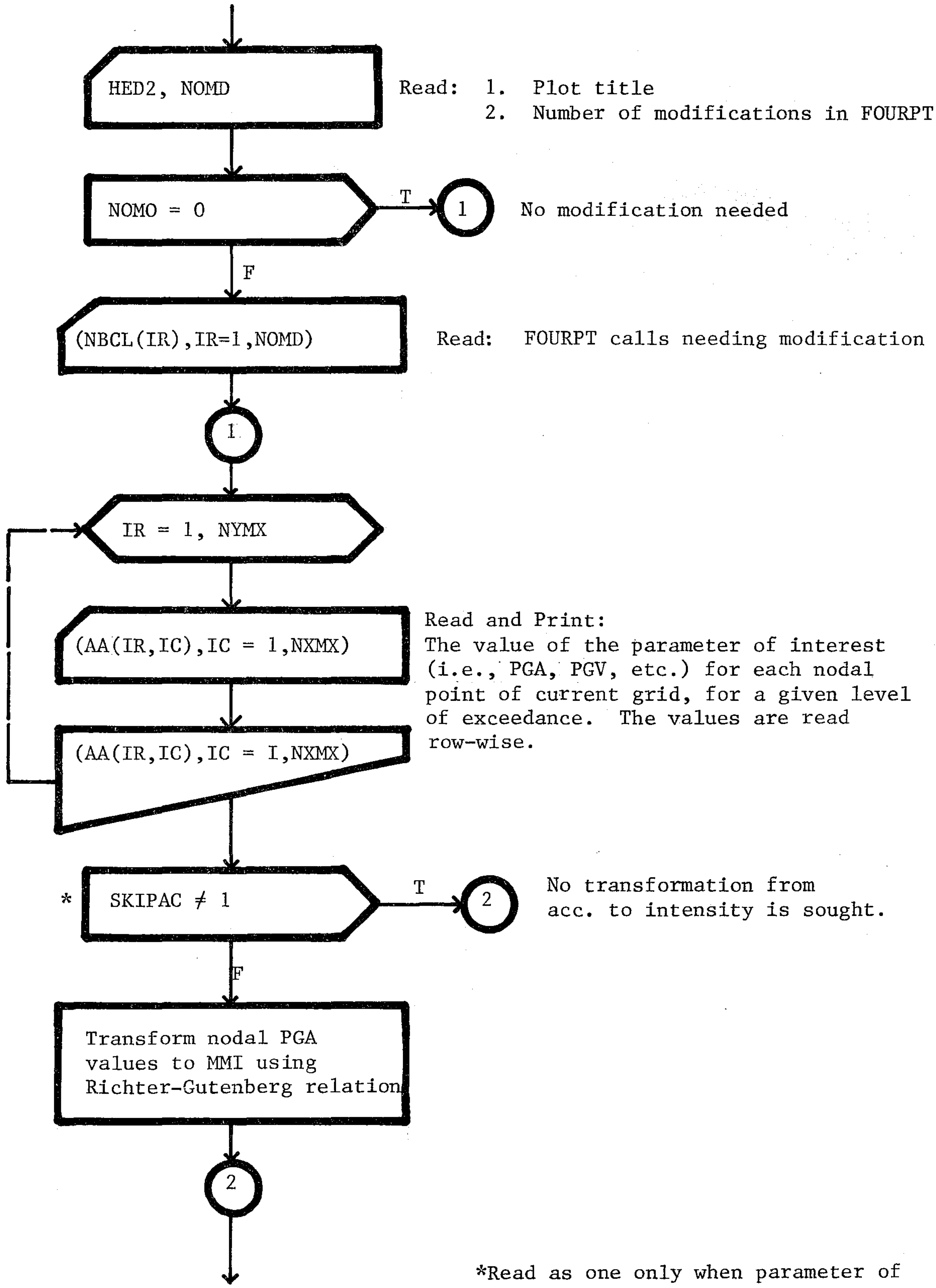
Print: Plot type plus Lambert projection parameters



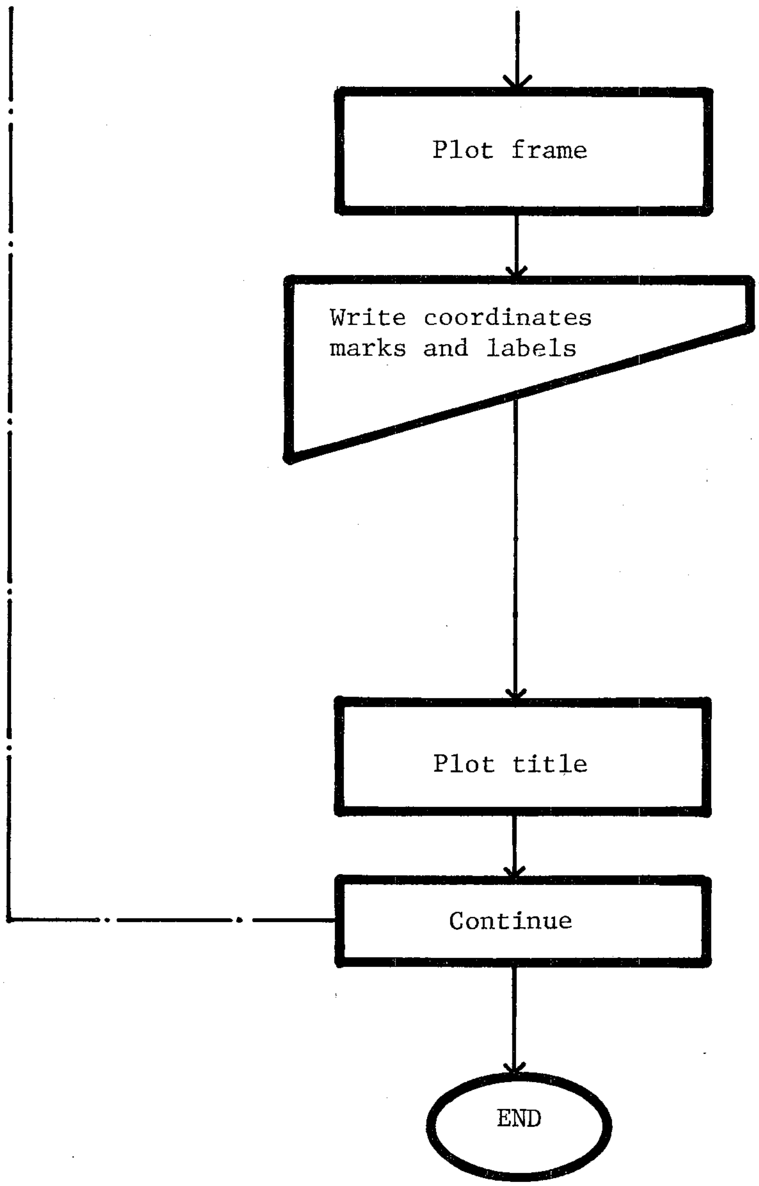
Read and Print:
1. Number of plots with same parameters
2. Number of columns in grid
3. Number of rows in grid
4. Plot frame ? If 0 = NO
5. Acc. to int. ? If 0 = NO

Read:
1. X-coordinate of grid's origin
2. Y-coordinate of grid's origin
3. X-coordinate of right bottom corner
4. Y-coordinate of right bottom corner
5. X-coordinate of left top corner
6. Y-coordinate of left top corner

Read and Print:
1. X-distance between marks
2. Y-distance between marks
3. X-distance between labels
4. Y-distance between labels
5. Increments between contours
6. Label every XMDC contour
7. Degree marks inside grid? If 0 = NO



*Read as one only when parameter of interest is PGA and a transformation to MMI is sought


Plot frame
Write coordinates marks and labels
Plot title
Continue
END

11.5 Sample Problem

A seismic exposure map for the ground parameter "PGA" (Peak Ground Acceleration) for a future time period of 50 years and for a probability of exceedance of 5 percent (95 percent probability of non-exceedance) is required for the region shown in Figure 9-10. The computer output as obtained by program CONST.PROB (Chapter X, Figure 10-4) is used as part of the input for program PLOT.ISO.

Figure 11-1 shows the listing of the input data deck for program PLOT.ISO. Each data set as described in Section 11.3 is indicated in the figure by the corresponding item number.

```
INPUT DATA FOR PROGRAM PLOT.ISO (SAMPLE PROBLEM)

     1     3     0  PROGRAM PLOT.ISO (SAMPLE PROBLEM) ------------ I
  30.000   0.000     31.000  2000000. ------------------------------ II
     1     4     4     0     0 ------------------------------------- III
  30.000  30.000    33.000    30.000    30.000    33.000 ----------- IV
   1.00    1.000     1.000     1.000    30.000     1.000 ----------- V
PROGRAM PLOT.ISO (SAMPLE PROBLEM) ---------------------------------- VI
    29.799   58.539   57.560   55.042 ---------+
    51.670  237.877  211.770   97.206          |  VIII
    66.431  112.671   54.623   57.831          |
    37.881   54.183   19.932   19.041 ---------+
```

Figure 11-1

Figure 11-2

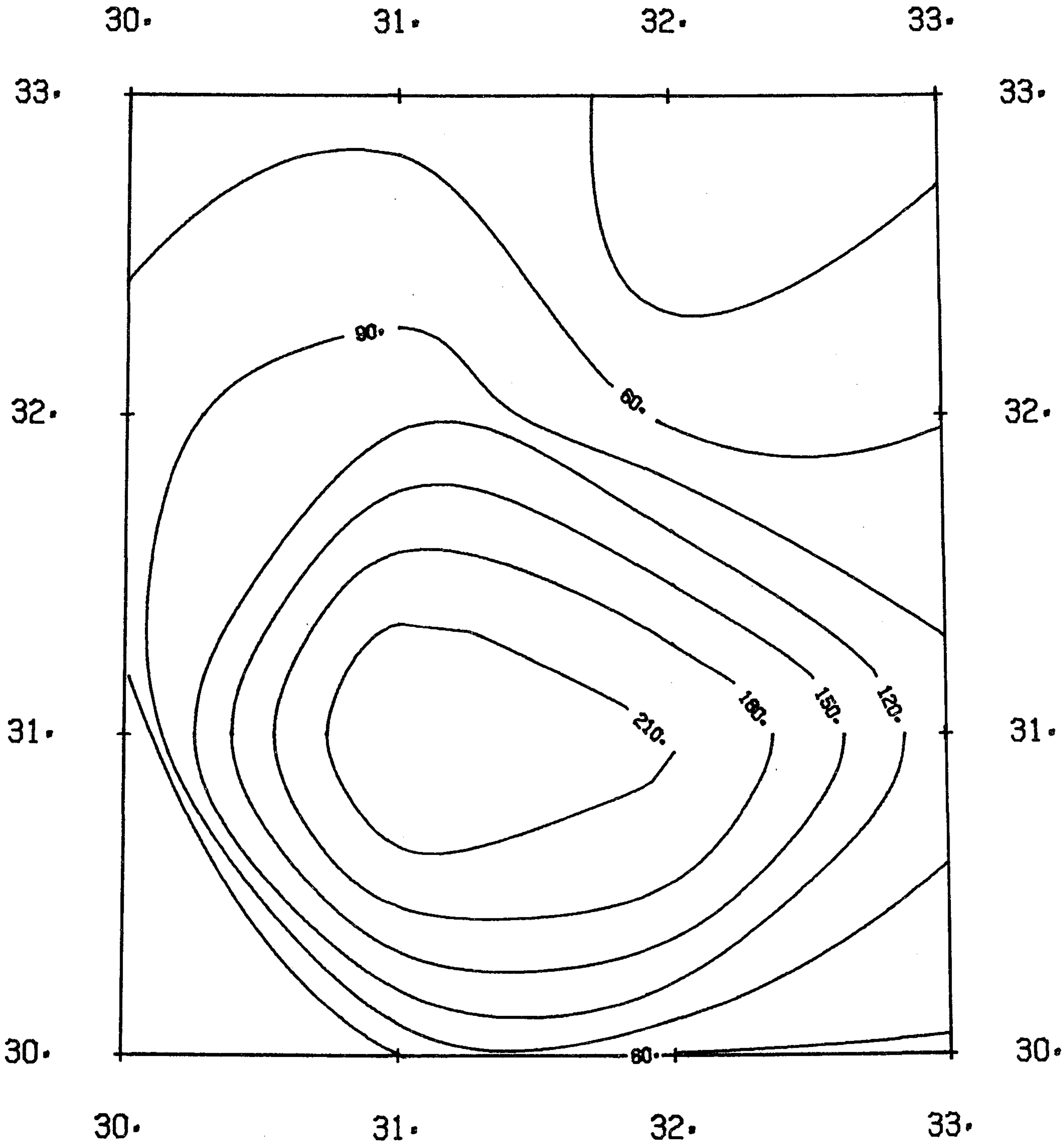
OUTPUT FOR PROGRAM PLOT.ISO (SAMPLE PROBLEM)-AS OBTAINED ON LINE PRINTER-

```
  PROGRAM PLOT.ISO (SAMPLE PROBLEM)                                          1  DIFFERENT FRAMES
PLOT TYPE                          1
STANDARD LATITUDE 1          30.0000
STANDARD LATITUDE 2           0.0
STANDARD LONGITUDE           31.0000
SCALE               1  TO  2000000.0
NUMBER OF PLOTS                    1
NO OF POINTS IN X DIR              4
NO OF POINTS OF Y DIR              4
PLOT FRAME? 0=NO                   0
INT FROM ACC? 0=NO                 0
X MARK  EVERY                 1.0000
Y MARK  EVERY                 1.0000
X LABEL EVERY                 1.0000
Y LABEL EVERY                 1.0000
CONTOUR LINE  EVERY          30.0000
CONTOUR LABEL EVERY              1.0  LINES
CROSSES INSIDE? 0=NO             0.0
GRID COORDINATES  X     30.000    33.000    33.000    30.000
                  Y     30.000    30.000    33.000    33.000
PLOT TYPE      1   NUMBER     1
DATA MATRIX  FIRST LINE CORRESPOND TO SOUTH, LAST TO NORTH

PROGRAM PLOT.ISO (SAMPLE PROBLEM)                                                0  MODIFIED CALLS IN FOURPT
    29.799    58.539    57.560    55.042
    51.670   237.877   211.770    97.206
    66.431   112.671    54.623    57.831
    37.881    54.183    19.932    19.041
LOW VALUE                    19.041
HIGH VALUE                  237.877
NUMBER OF COUNTOURS               7
CONTOUR       1   LEVEL      30.000
CURVE      1  STARTS AT    1  ENDS AT    2
CURVE      2  STARTS AT    3  ENDS AT    5
CONTOUR       2   LEVEL      60.000
CURVE      1  STARTS AT    1  ENDS AT    5
CURVE      2  STARTS AT    6  ENDS AT   10
CONTOUR       3   LEVEL      90.000
CURVE      1  STARTS AT    1  ENDS AT    9
CONTOUR       4   LEVEL     120.000
CURVE      1  STARTS AT    1  ENDS AT    6
CONTOUR       5   LEVEL     150.000
CURVE      1  STARTS AT    1  ENDS AT    6
CONTOUR       6   LEVEL     180.000
CURVE      1  STARTS AT    1  ENDS AT    6
CONTOUR       7   LEVEL     210.000
CURVE      1  STARTS AT    1  ENDS AT    6
```

Figure 11-3

Seismic Exposure Map for PGA, Probability of Exceedance of 5 Percent and Time Period of 50 Years



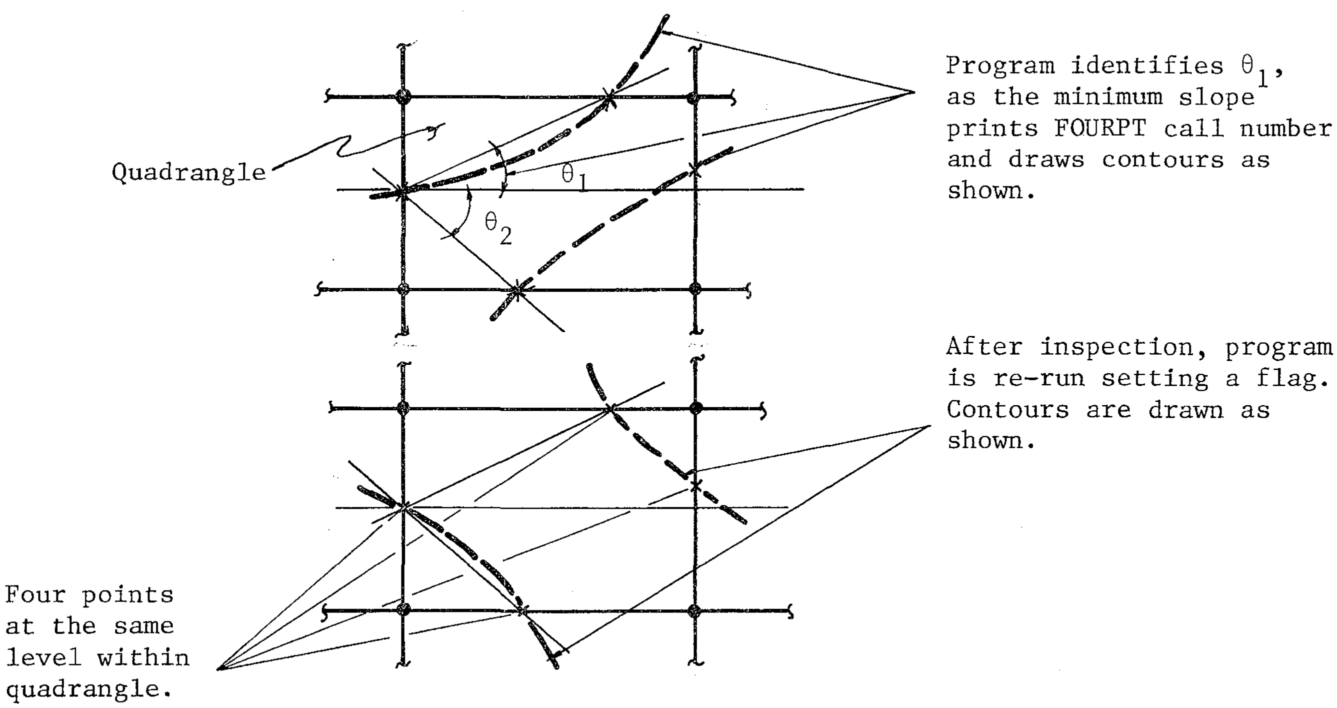
11.6 Output for Program PLOT.ISO

Figure 11-2 shows the output for the sample problem as obtained on the line printer.

Figure 11-3 shows the exposure map*, as obtained on the Calcomp Plotter. The units of the acceleration levels are in cm/sec^2.

---

*Explanatory Note: When the contour is not uniquely defined (i.e., there are four points at the same level within a quadrangle, see figure below), the program draws the contour such that the change in slope is minimum and prints a message (FOURPT call number). If after inspection of the plot, it appears that the other choice should have been made, the program should be re-run setting a flag (NBCL--see Data Sets VI and VII) for that FOURPT call number. The contour corresponding to the largest slope variation will then be drawn.



APPENDIX A

References

References

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9. TERA Corporation, (April 1978), Influence of Seismicity Modeling on Seismic Hazard Analysis, Berkeley, California.

10. Steers, J.A., (1927), Study of Map Projections, University of London Press Limited.

APPENDIX B

Program PLOT.DATA

APPENDIX B

Program PLOT.DATA

Purpose: This program checks and plots the data used in the main program (SEISMIC.HAZARD) in Chapter IX. It uses the same input as program SEISMIC. HAZARD, with the following addition necessary for plotting.

1. The first card defining the number of plots and the plotter to be used.
2. One card at the beginning of each data set (area) describing the spacing for labels and marks.

Input Format

I. Identification Card--(5I5,52A1)--One Card

Col.	1-5	NOTP	(Number of data sets to be plotted)
	6-10	ICAL	(Plotter size: 3 = 11 inches-default. 4 = 33 inches)
	11-15	NN	(Flag for Lambert Projection; 0 = 0/180° 1 = 0/360°)
	16-20	PLOT	(Plot data? 0 = NO)
	21-25	PLFR	(Plot frame? 0 = NO)
	26-77	HED1	(Run Identification)

II. Label Description--(7F10.0)--One card

Col.	1-10	DXCR	(X-distance, degrees, between marks)
	11-20	DYCR	(Y-distance, degrees, between marks)
	21-30	DXLB	(X-distance, degrees, between labels)
	31-40	DYLB	(Y-distance, degrees, between labels)
	41-50	DCLV	(Increment between contours)
	51-60	XMDC	(Label every XMDC contour)
	61-70	CRCR	(Marks inside grid? 0 = 0)

Note: The cards following are the same as for Program SEISMIC.HAZARD.

Do-Loop on "NOTP" starts at Card 2.

Figure 1 shows the input data deck for Program PLOT.DATA (same data as in sample problem in Chapter IX).

Figure 2 shows the output as obtained on the line printer.

Figure 3 shows the output as obtained on the Calcomp plotter.

Figure 1

INPUT DATA FOR PROGRAM PLOT.DATA (SAMPLE PROBLEM

```
   1    3    0    1    0   SAMPLE PROBLEM                                   I
1.          1.          1.          1.          1.          1.             II
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
30.00       0.000       31.000      2000000.
30.000      30.00       33.000      30.000     30.000     33.00
   2    1   13    3    1    1    2    0    1   12    1   10    0    0   18
 50.00      0.25        3.50
   1  30.686     31.854     -10.000
   2  30.343     32.024     -10.000
   3  30.657     32.705     -10.100
   4  31.070     32.500     -10.100
   5  32.800     31.878      -2.000
   6  32.800     30.195      -2.000
   7  32.286     30.390      -5.000
   8  32.286     31.573      -5.000
   9  31.686     30.634     -10.000
  10  31.686     31.207     -10.000
  11  30.629     31.780     -10.000
  12  31.029     31.268     -10.000
  13  31.371     30.439     -10.000
   1    4    3    2
   8   10    9    7
   5    8    7    6
AREA SOURCE 1                                                                  12
   1    0    0    0    0
   1
 0.000      -10.100  94.000     -10.000
 250.00     15.000    2.400      2.600      1.500      2.100      0.800      1.600
   1.500     0.400    1.250      0.210      0.150      0.110      0.370
AREA SOURCE 2                                                                  12
   2    0    0    0    1
   1    1
 0.000      -10.000  75.000      -5.000   140.000     -2.000
   250.00    38.500   4.500      2.500      4.500      5.000      4.500      1.400
   6.800     4.100    4.050       .280      0.150      0.150
LINE SOURCE 1                                                                  13
   2   11    1    1
    100.0    28.000   3.000      2.500      1.500      4.000      5.600      3.000
      2.3     2.800   2.500      0.300      0.190      0.110      0.20
ACCELERATION PGA      20.00       50.000     1500.00
 190.67   0.823308    0.000      1.561272  0.568       0.00
 190.67   0.823308    0.000      1.561272  0.568       0.00
        85  3.000     -15.000     0.8643    0.4626     10.00      10.00      0.100
 0.00       0.00      0.00       0.00       0.00       5.00       6.00       7.600
 9.20      12.00      15.00      18.00      26.00      45.00      80.00      135.00
 230.00    400.00
GRID FOR SAMPLE PROBLEM (PROGRAM SEISMIC HAZARD)
 30.00      30.00     33.00      30.00      30.00      33.00      0.00          4    4
```

(Bracket from "PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)" to the final GRID line:) same data for program SEISMIC.HAZARD (see Chapter IX)

OUTPUT FOR PROGRAM PLOT.DATA (SAMPLE PROBLEMM)-AS OBTAINED ON LINE PRINTER

```
SAMPLE PROBLEM
NUMBER OF AREAS                  1
PLOT? 0=NO                       1
CALCOMP SIZE                     3
NN FOR LAMBERT                   0
PLOT FRAME? 0=NO                 0
AREA      1
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
PROGRAM SEISMIC HAZARD (SAMPLE PROBLEM)
STANDARD LATITUDE 1         30.0000
STANDARD LATITUDE 2          0.0000
STANDARD LONGITUDE          31.0000
SCALE              1  TO  2000000.0
FRAME SIZE
 XXOR =    30.00  YYOR =    30.00  XXRT =    33.00  YYRT =    30.00  XXUP =    30.00  YYUP =    33.00
X MARK  EVERY                1.0000
Y MARK  EVERY                1.0000
X LABEL EVERY                1.0000
Y LABEL EVERY                1.0000
CROSSES INSIDE? 0=NO            1.0
NUMBER OF AREA SOURCES           2
NUMBER OF LINE SOURCES           1
NUMBER OF NODES                 13
NUMBER OF ELEMENTS               3
NUMBER OF GRIDS                  1
NUMBER OF VARIABLES              1
NUMBER OF ATT/VARIABLE           2
LINES PRINTED PER SITE           4
MAX NO. OF MAG.                 18
SAVE RESULTS ON DISK (PLOTTING FORMAT)   40  VALUES PER SITE

SAVE COPY OF OUTPUT ON DISK    4  LINES PER SITE

TIME PERIOD   MAG INC   SMALLEST MAG
    50.00       0.25       3.50
NODAL COORDINATES   (  13  NODES)
INDEX   WCC INDEX        X COORD        Y COORD         Z (KM)         X (KM)         Y (KM)
    1           1         30.686         31.854        -10.000         66.808        205.394
    2           2         30.343         32.024        -10.000         34.405        224.409
    3           3         30.657         32.705        -10.100         64.340        299.938
    4           4         31.070         32.500        -10.100        103.162        277.113
    5           5         32.800         31.878         -2.000        267.133        209.351
    6           6         32.800         30.195         -2.000        270.052         22.574
    7           7         32.286         30.390         -5.000        220.274         43.545
    8           8         32.286         31.573         -5.000        218.808        174.835
    9           9         31.686         30.634        -10.000        162.398         70.125
   10          10         31.686         31.207        -10.000        162.020        133.717
   11          11         30.629         31.780        -10.000         61.378        197.193
   12          12         31.029         31.268        -10.000         99.335        140.295
   13          13         31.371         30.439        -10.000        132.241         48.348
ELEMENTS DESCRIPTION   (   3  ELEMENTS)
INDEX    I    J    K    L    RENUMBERED    I    J    K    L
    1    1    4    3    2                  1    4    3    2
    2    8   10    9    7                  8   10    9    7
    3    5    8    7    6                  5    8    7    6
AREA SOURCE 1
NUMBER OF BANDS      1    BOUNDARY COND      0    0    0    0
```

```
NUMBER OF ELEMENT IN EACH BAND STARTING WITH DEEPEST ONE     1
SOURCE SECTION IN X AND Z TERMS
          X       0.000      94.000
          Z     -10.100     -10.000
TIME DATA BASE              250.000
NO OF OCC                    15.000
NO OF DIFF MAG.              12.000
TOTAL NO OF MAG.             14.620
DISTRIBUTION OF MAG.
      3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500      5.750
      2.400      2.600      1.500      2.100      0.800      1.600      1.500      0.400      1.250      0.210
      6.000      6.250
      0.150      0.110
AREA SOURCE 2
NUMBER OF BANDS     2    BOUNDARY COND       0    0    0    1
NUMBER OF ELEMENT IN EACH BAND STARTING WITH DEEPEST ONE     1    1
SOURCE SECTION IN X AND Z TERMS
          X       0.000      75.000     140.000
          Z     -10.000      -5.000      -2.000
TIME DATA BASE              250.000
NO OF OCC                    38.500
NO OF DIFF MAG.              12.000
TOTAL NO OF MAG.             37.930
DISTRIBUTION OF MAG.
      3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500      5.750
      4.500      2.500      4.500      5.000      4.500      1.400      6.800      4.100      4.050      0.280
      6.000      6.250
      0.150      0.150
LINE SOURCE     1
LINE SOURCE 1
   2  SEGMENTS   BOUNDARY CONDITION     1    1  STARTING AT NODE    11
TIME DATA BASE              100.000
NO OF OCC                    28.000
NO OF DIFF MAG.              13.000
TOTAL NO OF MAG.             28.000
DISTRIBUTION OF MAG.
      3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500      5.750
      3.000      2.500      1.500      4.000      5.600      3.000      2.300      2.800      2.500      0.300
      6.000      6.250      6.500
      0.190      0.110      0.200
ATTENUATION RELATIONSHIPS
ACCELERATION PGA          IC=     20.000       MN=     50.000       MX=  1500.000
        B1         B2         B3         B4      LN SIG      MG MX
    190.670      0.823      0.000      1.561      0.568      0.000
    190.670      0.823      0.000      1.561      0.568      0.000
C1               0.864
C2               0.463
DEPTH          -15.000
LOG-NORMAL DISTRIBUTION ON ATTENUATION
NO OF SIG ON EACH SIDE OF MEAN      3.0
NO OF INCREMENTS IN DIST             85
INTG. STEP VERT. (KM)            10.000
INTG. STEP HOR.  (KM)            10.000
EPSILON          (KM)             0.100
HORIZONTAL RUPTURE LENGTHS (KM)(VERTICAL=HORIZONTAL/2)
      3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500      5.750
      0.000      0.000      0.000      0.000      0.000      5.000      6.000      7.600      9.200     12.000
      6.000      6.250      6.500      6.750      7.000      7.250      7.500      7.750
     15.000     18.000     26.000     45.000     80.000    135.000    230.000    400.000
NO INCREMENTS VERT       0     0     0     0     0     0     0     0     0     0     0     0
```

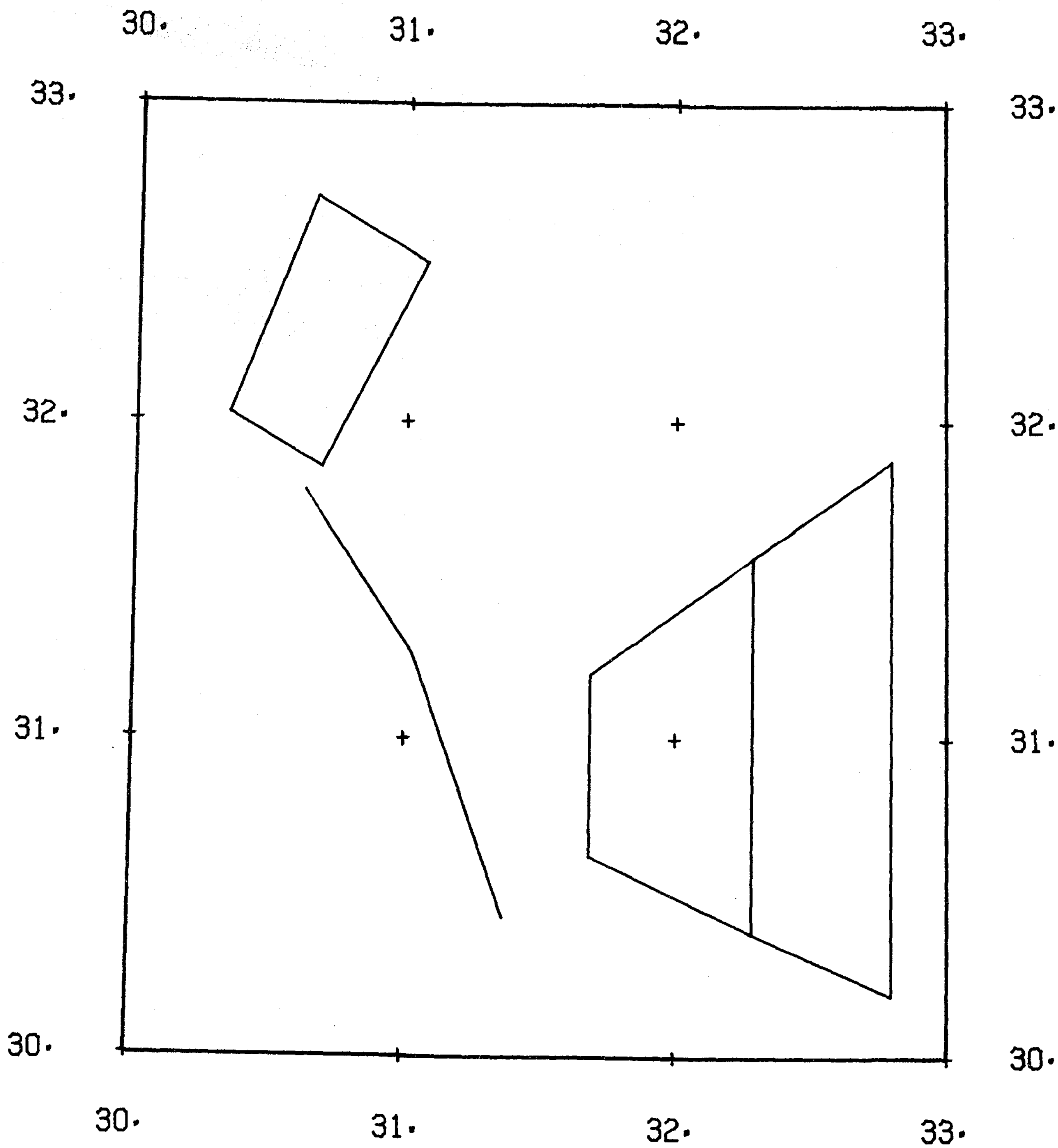
```
NO INCREMENTS VERT        0       2       4       6      10      20
NO INCREMRNTS HOR         0       0       0       0       0       0       0       0       0       0       0
NO INCREMRNTS HOR         2       4       8      12      22      40

SOURCE        1    (AREA)         1    BANDS
BAND          1    FIRST ELEMENT IS      1            1   ELEMENTS
*** (NEXT) X DO NOT INCREASE *** (TOP,BOT) -0.3882161E 02 -0.3240324E 02
ELEMENT       1                AREA           SLOPE              X              X              Z
                            3315.83                                          0.00         -10.10
                                                             80.28          80.25         -10.00
TOTAL SEISMIC AREA CONSTANT           3315.83          LAMBDA               0.45
SOURCE        2    (AREA)         2    BANDS
BAND          1    FIRST ELEMENT IS      2            1   ELEMENTS
ELEMENT       2                AREA           SLOPE              X              X              Z
                            5645.20                                          0.00         -10.00
                                                            -57.72         -57.03          -5.00
BAND          2    FIRST ELEMENT IS      3            1   ELEMENTS
ELEMENT       3                AREA           SLOPE              X              X              Z
                            7893.91                                          0.00          -5.00
                                                            -49.54         -48.71          -2.00
TOTAL SEISMIC AREA CONSTANT          13539.12          LAMBDA               0.28
SOURCE        3    (LINE)         2    SEGMENTS
SEGMENT             1    LENGTH        68.40
SEGMENT             2    LENGTH        97.66
TOTAL SEISMIC AREA CONSTANT            166.05          LAMBDA               1.69

GRID NUMBER       1
GRID FOR SAMPLE PROBLEM (PROGRAM SEISMIC HAZARD)                                  NXMX =      4  NYMX =      4
 XXOR =    30.00  YYOR =    30.00  XXRT =    33.00  YYRT =    30.00  XXUP =    30.00  YYUP =    33.00
```

Exact values for sources' horizontal proportions (in km)--to be used as input for program SEISMIC. HAZARD (see Chapter IX.

Figure 3 Seismic Source Map



APPENDIX C

Program Listings

Available on Request
from
The John A. Blume Earthquake Engineering Center