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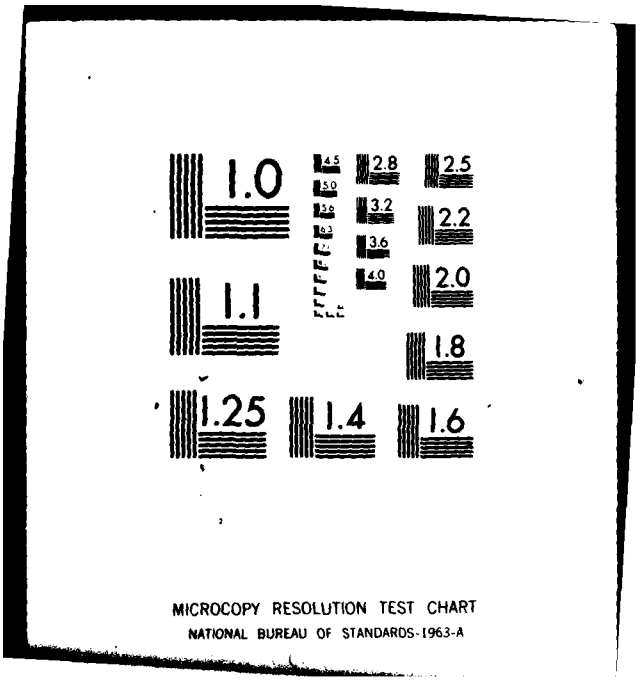
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THE JOINT OCCURRENCE OF EARTHQUAKES AND FLOODS

by

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This paper describes methods of computing the probability that an earthquake occurs during a period of high reservoir pool elevation. The procedure can apply to dams that are normally dry or at lower pool levels, such as flood control dams, as well as dams with significant operational pool levels. Probabilities of the joint occurrence of earthquake and flood events have been computed for a number of cases on the basis of annual risk, as well as 50- and

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100-year project life risk. The use of charts and tables developed from these computations and given in the paper is subject to the restrictive assumptions stated in the text.

PREFACE

The report presents a revised and expanded version of "Notes on the Joint Occurrence of Earthquakes and Floods," which was distributed to participants at the Office, Chief of Engineers (OCE), Consultant's Meeting on 9 March 1978 at the U. S. Army Engineer Waterways Experiment Station (WES). This work was performed for OCE under the Civil Works Research Unit (CWIS) 31246, "Dynamic Stresses and Permanent Deformations in Earth Structures."

This report was prepared by Ms. M. E. Hynes-Griffin of the Earthquake Engineering and Geophysics Division (EE&GD), Geotechnical Laboratory (GL), under the general direction of Dr. A. G. Franklin, Research Civil Engineer, EE&GD; Dr. P. F. Hadala, Chief, EE&GD; and Mr. J. P. Sale, Chief, GL.

COL John L. Cannon, CE, was Commander and Director of the WES during the conduct of this study. COL Nelson P. Conover, CE, was Commander and Director during the publication of the report. Mr. F. R. Brown was Technical Director.

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THE JOINT OCCURRENCE OF EARTHQUAKES AND FLOODS

PART I: INTRODUCTION

Purpose and Scope

1. A decision that faces the engineer who evaluates the seismic safety of dams, planned and existing, is the choice of pool elevation behind the dam. The presence of water not only adversely affects the performance of dams subjected to dynamic loads but also increases the potential for drastic consequences downstream. Since many dams normally have very low pools or are dry for most of their lifetime, such as some flood control dams, the appropriate choice of water level for seismic stability analysis is not necessarily the same pool levels chosen for use in static safety analyses. The risk that an earthquake and a flood will occur simultaneously at a damsite may be negligible compared to other possible conditions that could result in the failure of a dam.

2. This paper presents a procedure for describing, in quantitative, probabilistic terms, the risk of observing a combined earthquake/flood event. The mathematical model developed herein incorporates annual high pool levels, the duration of water storage at or above the high pool level, and the occurrence of an earthquake during the time the water is stored. The assumptions and restrictions of the model are discussed to provide perspective as well as suggest areas for future study to reduce the model's limitations and eventually allow calculation of the probability that a dam will fail due to the occurrence of a flood or an earthquake or both during its lifetime.

Definitions

3. For the convenience of the reader, certain pertinent terms used in this report are defined below.

Cumulative plot. A graph of the proportion of times an

unknown quantity exceeds a specific value versus that specific value.

Independent. Two events are independent if knowledge that one event has occurred in no way changes your estimate of the probability that the other event will occur.

Probability. A numerical measure between zero and unity which gives the likelihood that an event will occur. Zero probability means that it is impossible for the event to happen; unity means the event is known to happen with certainty.

Probability distribution. A mathematical description of the behavior of an unknown quantity with respect to the possible values it could have. The sum or integral of the probability distribution over all possible values of the unknown quantity equals unity.

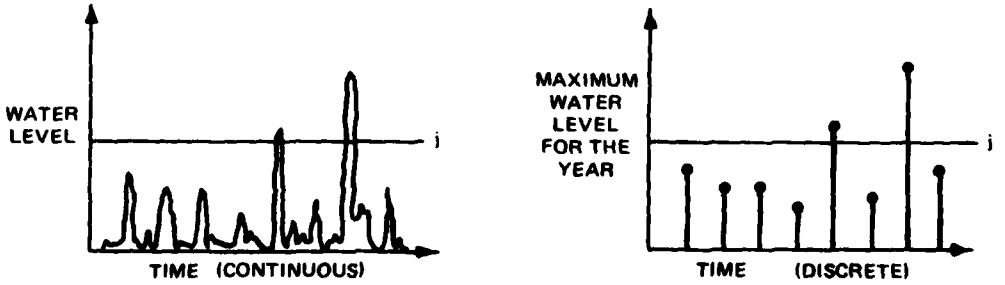
Reliability. The reliability of a structure is the probability that it will perform satisfactorily during its intended lifespan.

Return periods. For yearly events, return periods are called average annual return periods and are the inverse of the probability that an unknown quantity will exceed a specific value in a specific period of time.

PART II: FLOOD LEVELS AND RETURN PERIODS

4. Average annual return periods are often used to describe the occurrence of floods in time. These return periods are defined as the reciprocal of the probability that a particular flood level is exceeded in any year (Benjamin and Cornell, 1970*). This is not the probability that the water reaches, but does not exceed, a specific level. Failure to distinguish between these two probabilities has led to much misunderstanding in the use of the phrase "return period."

5. The exceedance probabilities, which are inverted to obtain return periods, are estimated from time records of water levels or estimated water levels based on rainfall data and drainage area. Figure 1a shows a continuous record of water level versus time. In Figure 1b, the time scale is divided into discrete units of one year each. The maximum water level for each year is then recorded and plotted on a cumulative graph of water level versus proportion greater than a given water level, as shown in Figure 2.



a. CONTINUOUS WATER LEVEL RECORD

b. MAXIMUM ANNUAL WATER LEVEL RECORD

Figure 1. Water level record

6. The cumulative plot may be used to estimate a probability distribution to describe the occurrence of water levels. Special

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* Benjamin, J. R. and Cornell, C. A., Probability, Statistics, and Decision for Civil Engineers, McGraw-Hill, New York, 1970.

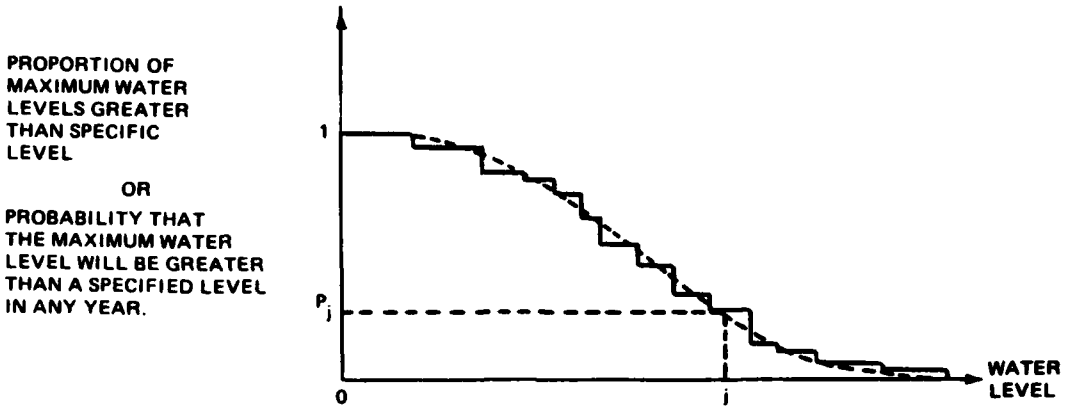


Figure 2. Cumulative plot of maximum annual water levels

modeling techniques are applied if sufficient data are not available for associating probabilities with very large floods. This procedure is outlined in hydrology handbooks, such as V. T. Chow's.* The return period T_j for a water level greater than j is $1/P_j$ where P_j, as given above, is the probability that the maximum water level in any year exceeds the value j.

7. With an annual model, only one flood event per year is allowed. This may be acceptable if flood levels are quite high with respect to normal pool levels and the probability of having two floods producing water levels exceeding the level of interest is negligible compared to the probability of one flood of this magnitude.

8. If the water levels of interest are yearly operational levels, then the water level is no longer random but known with certainty. In this case, uncertain flood events are not considered.

9. After a high water level is reached, the question to be answered is: "How long will the water be stored at or above that elevation?" For large, rare floods, duration of storage may not be well known. Even for seasonal, well-known water levels, duration may vary considerably. The likelihood of seeing various durations can be

* Chow, Ven Te, Handbook of Applied Hydrology: A Compendium of Water Resources Technology, McGraw-Hill, New York, 1964.

estimated from available data on flood pools. Duration N could be expressed in integer units of weeks, and a probability distribution $P(n)_{N|F_j}$ conditional on the occurrence of a pool F_j exceeding level j could be estimated for any specific duration value n given a water level j.

10. The notation conventions are: capital letters represent the unknown quantity and lower case letters represent possible values the unknown quantity could have. A vertical line is read "given that" and indicates that the probability values are conditional on knowing with certainty that the event following the line has occurred. In this problem, N is the unknown duration of the liquid storage period, and n is a specific number of weeks N could equal. The expression $P(n)_{N|F_j}$ is read as the probability that the storage period (N) takes on the value (n) given that a flood event (F) has occurred which produces a pool level greater than j.

11. For rare flood events, these N weeks must be consecutive and only one flood event is allowed per year. If the water levels are known to occur each year and several times each year, a more sophisticated model is necessary since the duration of storage for each high water level event must be handled separately when combined with earthquake occurrences. Also, water may not be carried over from year to year if rare floods are being modeled.

PART III: EARTHQUAKE LEVELS

12. The probability model is greatly simplified if it can be assumed that floods do not affect the occurrence of earthquakes and vice versa. This rules out isolated events such as induced seismicity or flooding due to failure of upstream dams during an earthquake. Assuming independence of floods and earthquakes is much less restrictive than some of the other assumptions involved in this analysis. The above instances can be modeled separately at a later stage, if desired.

13. The occurrence of earthquakes can also be described by return periods. For a few areas of the United States, curves of earthquake magnitude versus return period have been developed from the data base. These curves give the probability that an earthquake greater than some magnitude i will occur in any single time interval. If annual return periods are used, only one earthquake per year is allowed, and the analyst cannot specify when it will occur during that year. So, unless the storage time is known to equal one full year, annual return periods of earthquakes are inappropriate.

14. Clearly, to treat the problem, earthquake events must be expressed in the same time units as the flood water storage duration. If storage is expressed in weeks, it is assumed (for a simple model) that one earthquake event can occur in any week and that knowledge that an earthquake has occurred in a particular week does not change the estimate of the probability that an earthquake could occur in any other week. In other words, it is assumed that weeks are independent for the occurrence of earthquakes and that there is no seasonal behavior associated with earthquakes over the year. It may be unreasonable to try to make the time interval any smaller than a week since the earthquake event is defined to include the main shock and all its aftershocks, which could easily require a week to occur.

15. A weekly return period for exceeding an earthquake level i* can be calculated from the annual return period T_i based on the above assumptions. In order to maintain the same expected number of earthquakes per year, the following must be true:

$$\begin{pmatrix}\text{number of trials} \\ \text{in years}\end{pmatrix}\begin{pmatrix}\text{probability of} \\ \text{success in} \\ \text{years}\end{pmatrix} = \begin{pmatrix}\text{number of} \\ \text{trials in} \\ \text{weeks}\end{pmatrix}\begin{pmatrix}\text{probability of} \\ \text{success in} \\ \text{weeks}\end{pmatrix}$$

or

$$(1 \text{ year})\left(\frac{1}{T_i}\right) = (52 \text{ weeks})(\text{probability of success in weeks})$$

$$\text{The probability of exceeding earthquake level } i \text{ in any week} = \frac{1}{52\ T_i}$$

Here, success means that an earthquake does occur.

---

* The word "level" has been used intentionally instead of some more meaningful and specific parameters such as Magnitude and Intensity at the project location or maximum bedrock acceleration at the site. Any of these parameters (or others), which have engineering significance and for which sufficient data exist to develop a cumulative plot similar to Figure 2, could be used.

PART IV: PROBABILITY MODEL FOR COMBINED EARTHQUAKE/FLOOD OCCURRENCE

Description of Model

16. Now all the pieces are available to build a simplified model for calculating the probability of observing the combined load earthquake/flood at least once during a dam's lifetime. The probability that an earthquake that exceeds level i will occur in any week can be expressed; the duration of storage at flood pool levels is known, $N = n$, or the uncertainty about the duration can be expressed by $P(n)_{N|F_j}$; and the annual probability that a flood will occur that exceeds some specified level j, given by $\frac{1}{T_j}$, is known, or operational pool levels are to be analyzed and are assumed to be known with certainty.

17. The probability that one or more earthquakes will occur during the storage time N in any one year is

$$
\begin{aligned}
P_{E|N,F_j} &= P[\text{one or more earthquakes exceeding level } i \text{ during } N \text{ weeks in one year}] \\
&= 1 - P[\text{no earthquakes exceeding level } i \text{ during } N \text{ weeks in one year}] \\
&= 1 - P[\text{no earthquake exceeding level } i \text{ during the first week and the second week...and the } n^{th} \text{ week}] \\
&= 1 - P[\text{no earthquake exceeding level } i \text{ during any single week}]^n \\
&= 1 - \left[1 - \frac{1}{52\ T_i}\right]^n
\end{aligned}
\tag{1}
$$

The above expression is conditional on having had a flood F that exceeds level j to produce the pool and knowing that duration N takes on the value n. To include uncertainty on the value N, multiply Equation 1 by $P(n)_{N|F_j}$.

Thus,

$$P_{E,N|F_j} = {}^{P(n)}_{N|F_j} \left\{1 - \left[1 - \frac{1}{52\ T_i}\right]^n\right\} \tag{2}$$

If it is known that $N = n$ exactly, then ${}^{P(n)}_{N|F_j}$ equals unity. If N varies, to include all possible n values for the given flood level, sum Equation 2 over all possible n values to obtain an average probability value unconditional on N :

$$P_{E|F_j} = \sum_{n=1}^{52} {}^{P(n)}_{N|F_j} \left\{1 - \left[1 - \frac{1}{52\ T_i}\right]^n\right\} \tag{3}$$

18. To include the uncertainty that the flood event exceeding some level j occurs, multiply Equation 3 by $\frac{1}{T_j}$:

$$P_{E,F_j} = \frac{1}{T_j} \sum_{n=1}^{52} {}^{P(n)}_{N|F_j} \left\{1 - \left[1 - \frac{1}{52\ T_i}\right]^n\right\} \tag{4}$$

$$= \frac{1}{T_j} P_{E|F_j} = P_{F_j}\ P_{E|F_j}$$

If operational levels are of concern, then the probability of having the water level is unity and $P_{E,F} = P_{E|F}$. Equation 4 gives the probability of exceeding some flood level j , storing the water in the reservoir for N weeks, and having one or more earthquakes occur during those N weeks for any single year. This is the probability of observing the earthquake/flood load case in any single year.

19. If the design lifetime of the structure is K years, the probability of observing the load case at least once during the dam lifetime can be calculated as follows:

$$P[\text{observe E/F load at least once in K year lifetime}] = 1 - P[\text{do not see load in K years}]$$

$$= 1 - [1 - P(\text{do see load in any single year})]^K \quad (5)$$

$$= 1 - \left\{1 - \frac{1}{T_j} \sum_{n=1}^{52} {}^{P(n)}_{N|F_j} \left[1 - \left(1 - \frac{1}{52\ T_i}\right)\right]^n\right\}^K$$

20. The above expression assumes that one flood event per year exceeds level j and results in storage of water for a period of n consecutive weeks.

21. Plates 1 through 3 and Table 1 have been prepared for selected project lifetimes K and selected pool durations n based on Equation 5. By means of the assumption that the flood pool duration N is known and equals n, Equation 5 reduces to that shown on Table 1 since ${}^{P(n)}_{N|F_j} = 1$ when $N = n$ and is zero for $N \neq n$.

22. If the durations are known with certainty and water levels in any one year are known, then Equation 5 is also suitable for several high water level events in a year where n is the total duration of high water level.

Limitations of Model

23. A considerably more sophisticated model is required if the probability of several random floods in any year is desired, earthquake main shock and aftershock events have variable time lengths, and duration is to be expressed on a continuous time scale as well as allow stored water to be carried over from year to year. Flood events which exceed spillway capacity should be eliminated since this would result in an entirely different mode of failure of the dam.

24. This model only tells if a particular pool level or earthquake magnitude or acceleration has been exceeded. It does not tell by how much. Refinement of the model to include all flood levels and all

earthquakes of interest is possible and will circumvent the need for choosing an arbitrary risk level for the load case.

PART V: SUGGESTIONS FOR RESEARCH

25. A systematic evaluation of the dam's reliability would have to include all possible modes of failure (earthquakes and floods, sliding, overtopping, piping, etc.) compared to resistance to each loading case. If several dams are involved, an overall system reliability could be estimated for the region. The earthquake/flood load case is a first step in the overall system reliability evaluation, and further research on this step might extend along the lines suggested in the following paragraphs.

26. In order to evaluate the risk of dam failure at a site due to the joint occurrence of earthquakes and floods, it is necessary to take into account all possible flood levels and all possible earthquake events. The likelihood of observing the various flood or earthquake levels can be described by their respective probability density functions. A probability density function (pdf) for annual maximum flood levels can be determined from the return periods as follows:

T_j = return period for an annual maximum flood level exceeding j

$P_j = \frac{1}{T_j}$ = the probability that the maximum flood level in any year exceeds j (see Figure 2)

$F_F(j) = 1 - P_j$ = the probability that the maximum flood level in any year is less than or equal to j ; i.e., $F_F(j)$ is the cumulative probability distribution function describing annual maximum flood levels

$\frac{dF_F(j)}{dj} = f_F(j)$ = the probability density function describing annual maximum flood levels

27. A similar procedure is used to develop a probability density function for earthquake levels. If the time interval of interest is weeks and the occurrence of an earthquake in any one week has no effect on the probability of having an earthquake in any other week, the

probability P_i of having an earthquake that exceeds level i in any week is equal to $1/52\ T_i$ where T_i is the annual return period for earthquakes exceeding level i . A probability density function describing the occurrence of earthquake levels is determined as follows:

$P_i = \frac{1}{52\ T_i}$ = the probability that an earthquake exceeding level i occurs in any week

$1 - P_i$ = the probability of having an earthquake less than or equal to level i in any week

$= F_E(i)$

= the cumulative probability distribution function describing the occurrence of various levels of earthquakes in any week

$\frac{dF_E(i)}{di} = f_E(j)$ = the probability density function describing the occurrence of various levels of earthquakes in any week

28. If it is acceptable to assume that earthquakes and floods are independent, that no more than one flood can occur in any year, that the duration of storage of the flood pool is equal to one week, and that only one earthquake can occur in any week, then a simple joint probability density function $f_{E,F}(i,j)$ describing the occurrence of both floods and earthquakes can be developed:

$f_{E,F}(i,j)$ = the joint probability density function for earthquakes and floods (conditional on the aforementioned assumptions)

$= f_E(i) \cdot f_F(j)$

29. Figure 3 shows earthquake levels versus water levels. On each axis is plotted the associated pdf . Contours of the joint pdf , $f_{E,F}(i,j)$, are also shown.

30. The next step is more difficult. If it is possible to estimate the combinations of earthquakes and floods that would lead to

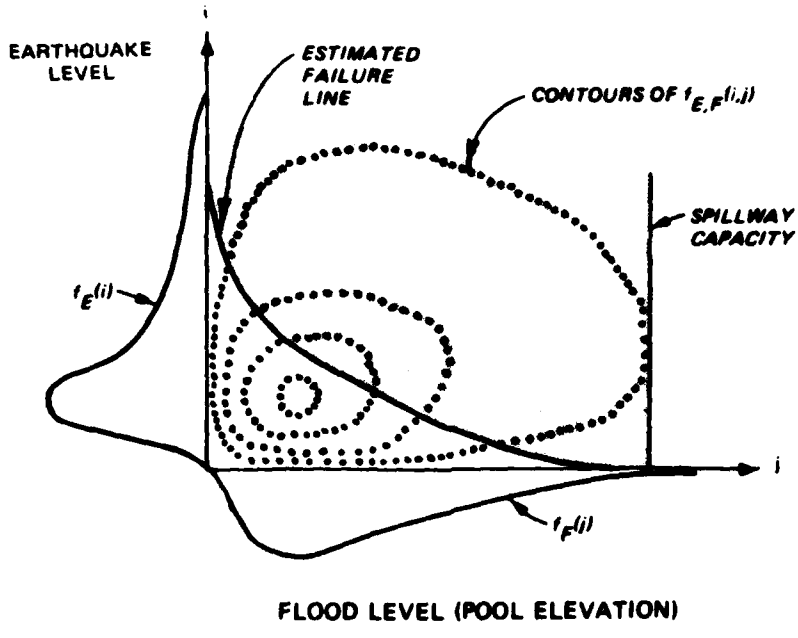


Figure 3. Region of floods and earthquakes leading to failure

failure of a dam, then the probability of failure due to this joint load condition can be estimated. A line must be drawn which gives the bounds on combinations of earthquake and flood levels which would lead to failure of a specific dam.

31. Within today's state of the art, it is probably not possible to draw such a sharp line. However, it might be possible to get the experts to agree on a band, the upper bound of which would surely result in failure and the lower bound of which would surely be safe. Unless done carefully, this process could be deceptive. A significant percentage of the engineered dams that have failed never saw loads larger than those for which they were thought to be safe by their designers until the first signs of distress actually appeared. Several levels of in-house and independent review of the design and the construction practice provide a very strong hedge against such an occurrence. The development of the lower bound to the failure band should be treated in this way. For the purpose of demonstration, it will be assumed a line (or band edge) can be drawn.

32. The shaded area of Figure 3, which is bounded by this line, gives the limits over which $f_{E,F}(i,j)$ must be integrated to give the probability that the joint occurrence of an earthquake and flood leads to failure of the dam under study in any single year.

$$P_{fail} = \iint_{\text{shaded region}} f_{E,F}(i,j)\, di\, dj$$

33. All combinations of i and j which fall above the estimated failure line lead to failure of the dam. The failure probability value P_{fail}, from integration of $f_{E,F}(i,j)$ over the proper limits, can be used in a model for failure of the dam by this cause in the lifetime k of the dam as follows:

$$P[\text{dam fails due to an E/F event in its lifetime } k] = 1 - \left[1 - P_{fail}\right]^K$$

34. If the process described above is followed using the low edge of a band describing failure condition as the limit of integration, the P_{fail} becomes the upper bound to the probability of failure in a given year and $1 - \left[1 - P_{fail}\right]^K$ is the upper bound to the probability of failure due to an earthquake/flood event in the project lifetime. This upper bound is still subjective and is strongly dependent on the quality of the review process.

35. If specific pool levels are of interest, for example, due to the increase in potential damage as the pool level increases, the consequences can be weighted with the probability of failure at a specific pool level and then weighted again with the probability of observing that specific pool level.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

36. It is recommended that a closer examination of the assumptions used in the model given in Part V be performed and that attempts be made to reformulate it in such a way as to make it less restrictive before actual numbers are put in the foregoing formulation (that shown in Figure 3). Underlying implications of the model are not always self-evident, and many simplifying assumptions have been made to achieve the above model--all of which take the model one step further away from describing reality. The presentation in Part V is meant primarily to show the kind of model that would be most useful (one that combines the probabilities of seeing the loads and the failure combinations of loads and includes the lifetime of the constructed facility). Probabilistic tools are now available to handle this situation. Further study of this problem could lead to an acceptable probabilistic formulation within a short period of time if the designers and reviewers can provide the failure curve or band. While the state of the art of design and construction may not yet permit drawing of accurate failure bands and the general level of public understanding of acceptable risk is not such that probabilistic designs in this area will be practical in the next few years, the concepts can provide "thinking aids" for the designer and reviewer and should be pursued with this limited goal in mind.

Table 1

Risk Values For Specific Design Lifetimes, K , and Durations of Water Storage, n

P[observe earthquake/flood load at least once during lifetime of dam] = Risk

K = 10 , n = 1

	$T_i = 10$	$T_i = 100$	$T_i = 1000$
$T_j = 10$	1.9×10^{-3}	1.9×10^{-4}	1.9×10^{-5}
$T_j = 100$	1.9×10^{-4}	1.9×10^{-5}	1.9×10^{-6}
$T_j = 1000$	1.9×10^{-5}	1.9×10^{-6}	1.9×10^{-7}

K = 10 , n = 10

	$T_i = 10$	$T_i = 100$	$T_i = 1000$
$T_j = 10$	1.9×10^{-2}	1.9×10^{-3}	1.9×10^{-4}
$T_j = 100$	1.9×10^{-3}	1.9×10^{-4}	1.9×10^{-5}
$T_j = 1000$	1.9×10^{-4}	1.9×10^{-5}	1.9×10^{-6}

K = 10 , n = 52

	$T_i = 10$	$T_i = 100$	$T_i = 1000$
$T_j = 10$	9.1×10^{-2}	9.9×10^{-3}	1.0×10^{-3}
$T_j = 100$	9.5×10^{-3}	1.0×10^{-3}	1.0×10^{-4}
$T_j = 1000$	9.5×10^{-4}	1.0×10^{-4}	1.0×10^{-5}

K = 50 , n = 1

	$T_i = 10$	$T_i = 100$	$T_i = 1000$
$T_j = 10$	9.6×10^{-3}	9.6×10^{-4}	9.6×10^{-5}
$T_j = 100$	9.6×10^{-4}	9.6×10^{-5}	9.6×10^{-6}
$T_j = 1000$	9.6×10^{-5}	9.6×10^{-6}	9.6×10^{-7}

K = 50 , n = 10

	$T_i = 10$	$T_i = 100$	$T_i = 1000$
$T_j = 10$	9.1×10^{-2}	9.6×10^{-3}	9.6×10^{-4}
$T_j = 100$	9.5×10^{-3}	9.6×10^{-4}	9.6×10^{-5}
$T_j = 1000$	9.5×10^{-4}	9.6×10^{-5}	9.6×10^{-6}

K = 50 , n = 52

	$T_i = 10$	$T_i = 100$	$T_i = 1000$
$T_j = 10$	3.8×10^{-1}	4.9×10^{-2}	5.0×10^{-3}
$T_j = 100$	4.7×10^{-3}	5.0×10^{-3}	5.0×10^{-4}
$T_j = 1000$	4.8×10^{-3}	5.0×10^{-4}	5.0×10^{-5}

K = 100 , n = 1

	$T_i = 10$	$T_i = 100$	$T_i = 1000$
$T_j = 10$	1.9×10^{-2}	1.9×10^{-3}	1.9×10^{-4}
$T_j = 100$	1.9×10^{-3}	1.9×10^{-4}	1.9×10^{-5}
$T_j = 1000$	1.9×10^{-4}	1.9×10^{-5}	1.9×10^{-6}

K = 100 , n = 10

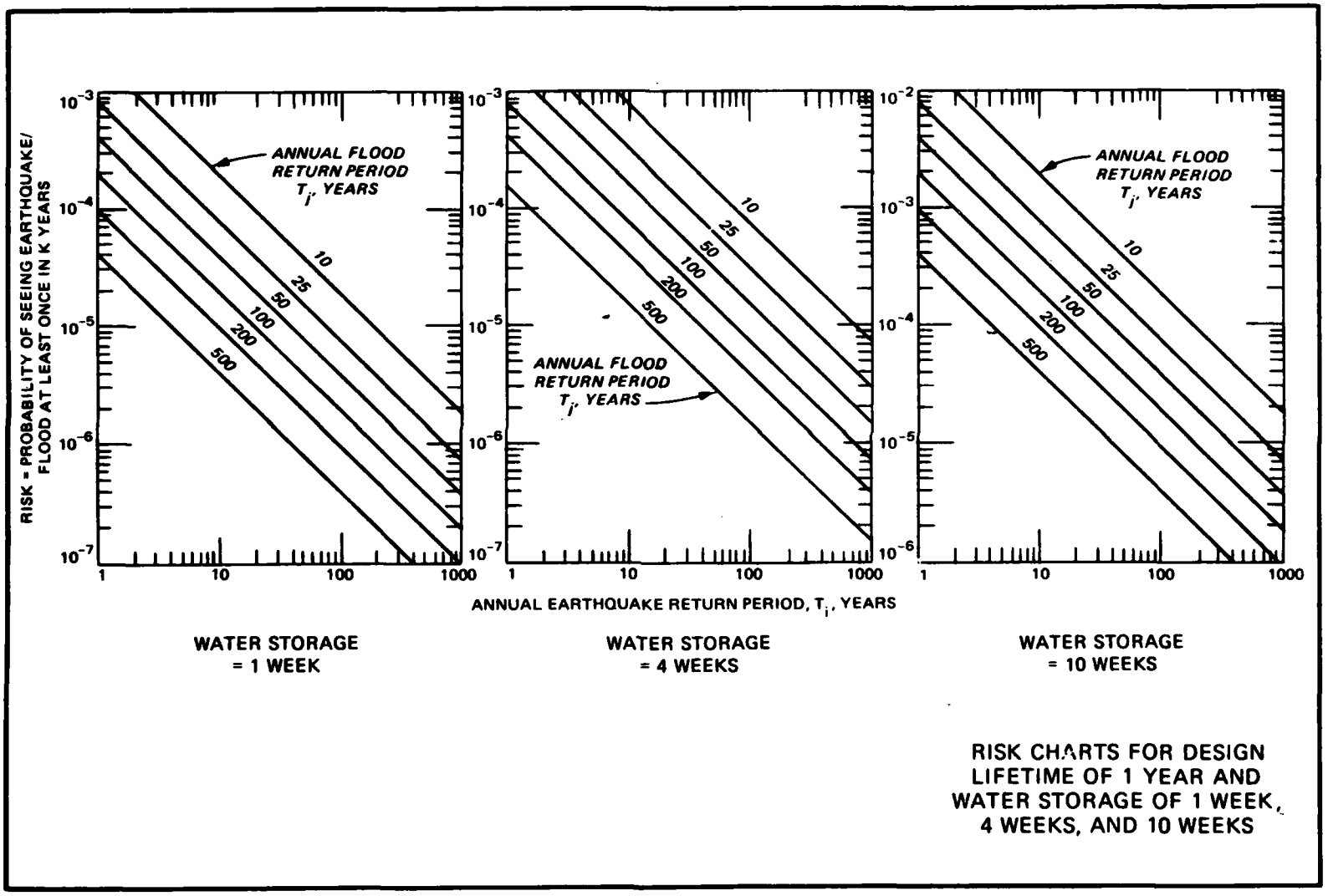
	$T_i = 10$	$T_i = 100$	$T_i = 1000$
$T_j = 10$	1.7×10^{-1}	1.9×10^{-2}	1.9×10^{-3}
$T_j = 100$	1.9×10^{-2}	1.9×10^{-3}	1.9×10^{-4}
$T_j = 1000$	1.9×10^{-3}	1.9×10^{-4}	1.9×10^{-5}

K = 100 , n = 52

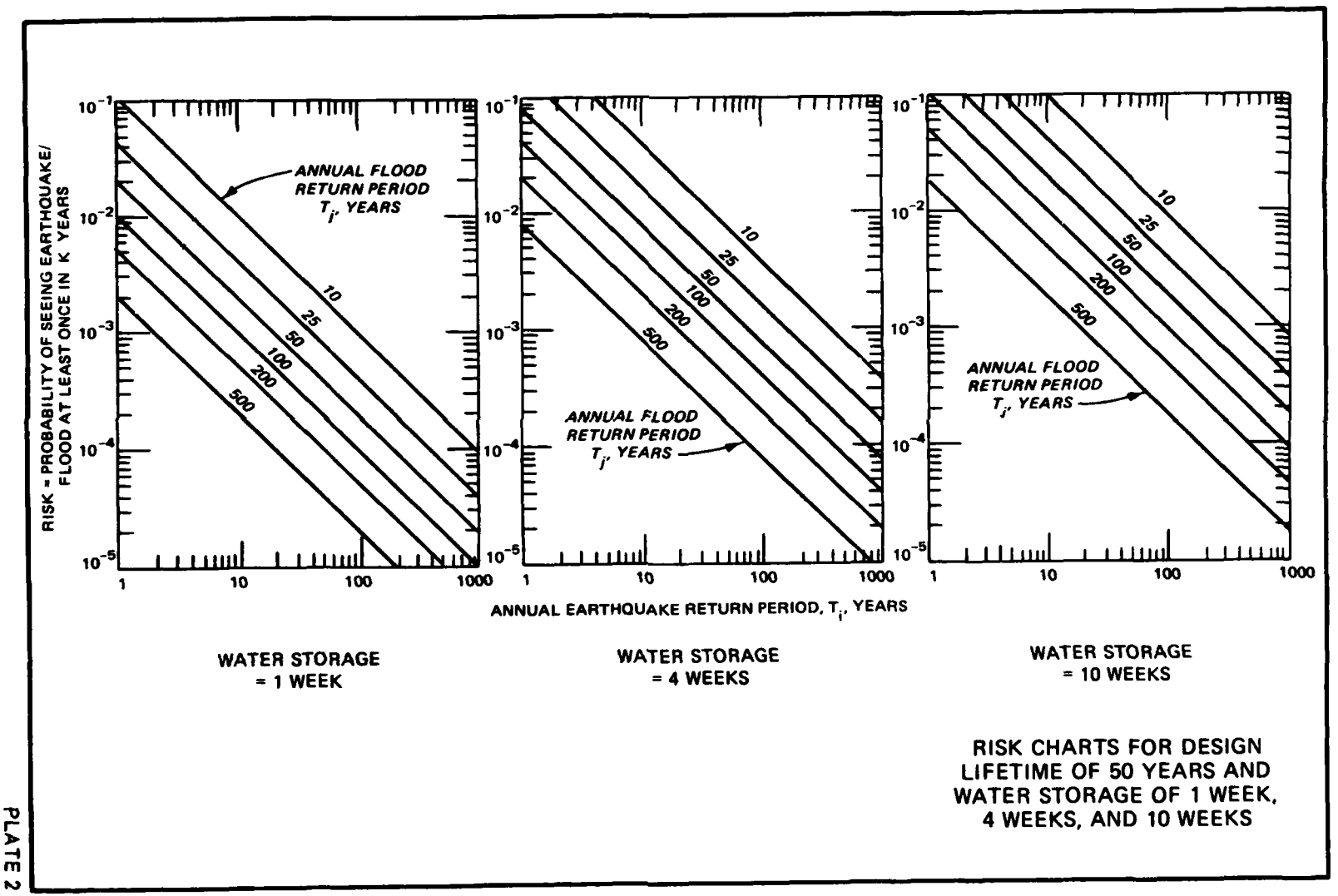
	$T_i = 10$	$T_i = 100$	$T_i = 1000$
$T_j = 10$	6.2×10^{-1}	9.5×10^{-2}	1.0×10^{-2}
$T_j = 100$	9.1×10^{-2}	9.9×10^{-3}	1.0×10^{-3}
$T_j = 1000$	9.5×10^{-3}	1.0×10^{-3}	1.0×10^{-4}

$$\text{Risk} = 1 - \left\{1 - \frac{1}{T_j}\left[1 - \left(1 - \frac{1}{52\,T_i}\right)^n\right]\right\}^K$$

PLATE 1



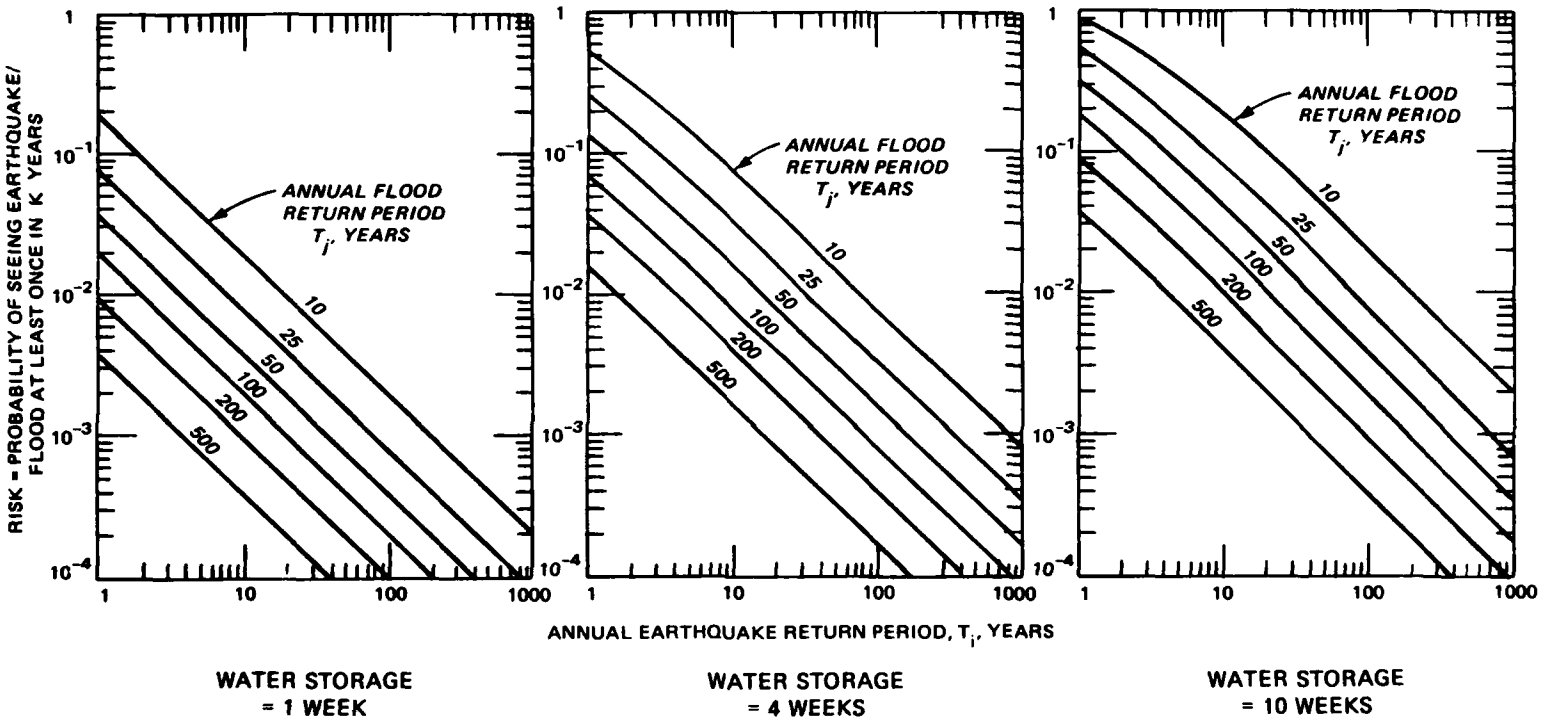
RISK CHARTS FOR DESIGN LIFETIME OF 1 YEAR AND WATER STORAGE OF 1 WEEK, 4 WEEKS, AND 10 WEEKS



RISK CHARTS FOR DESIGN LIFETIME OF 50 YEARS AND WATER STORAGE OF 1 WEEK, 4 WEEKS, AND 10 WEEKS

PLATE 2

PLATE 3



RISK CHARTS FOR DESIGN LIFETIME OF 100 YEARS AND WATER STORAGE OF 1 WEEK, 4 WEEKS, AND 10 WEEKS

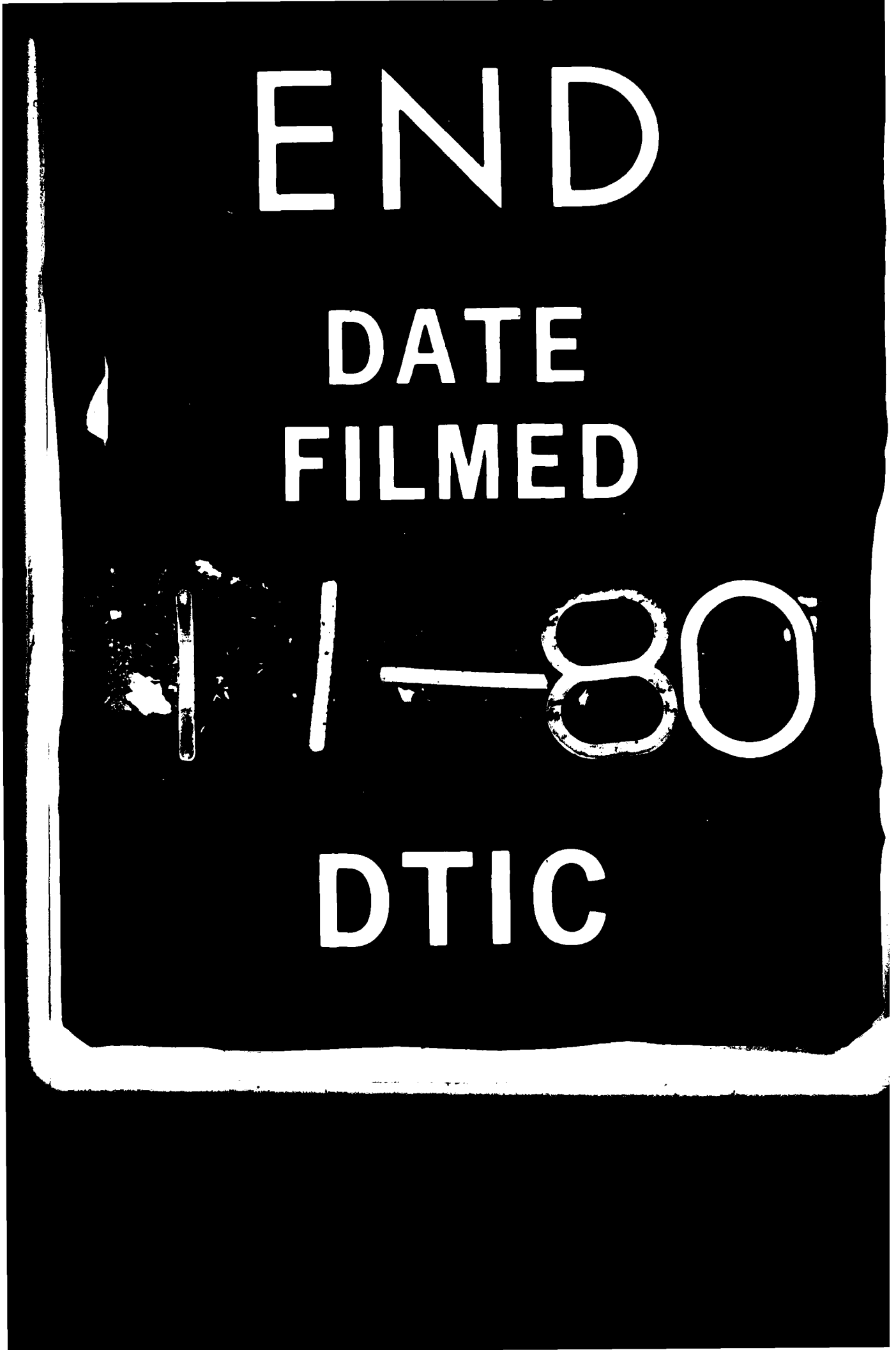
APPENDIX A: NOTATION

E	The occurrence of an earthquake
E_i	The occurrence of an earthquake exceeding level i
F	The occurrence of a flood
F_j	The occurrence of a flood exceeding level j
N	Unknown duration of storing flood water
n	Possible values for N in weeks
P_j	The probability that the maximum water level exceeds j in any year
$P(n)$ $N\|F_j$	The probability distribution describing duration of flood water storage given that a flood has occurred resulting in a reservoir pool exceeding level j
T_i	Annual return period for an earthquake exceeding level i
T_j	Annual return period for a flood exceeding level j
K	Design lifetime of the dam

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Hynes-Griffin, Mary Ellen
The joint occurrence of earthquakes and floods / by Mary Ellen Hynes-Griffin. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
18, [1], 1 p., [2] leaves of plates : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; GL-80-10)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under CWIS 31246.

1. Earthquake hazards. 2. Earthquake prediction. 3. Flood forecasting. 4. Reservoirs. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; GL-80-10.
TA7.W34m no.GL-80-10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