OPTIMUM SEISMIC PROTECTION FOR NEW BUILDING CONSTRUCTION IN EASTERN METROPOLITAN AREAS

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Internal Study Report No. 10

EVALUATION OF EXPECTED LOSSES AND TOTAL PRESENT COST: PRELIMINARY SENSITIVITY ANALYSIS

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A computer program to evaluate expected future losses due to earthquakes and to determine the best strategy for earthquake protection of buildings based on a minimum expected cost criterion is presented. The program can be used for analyzing the seismic performance of a particular building or of a mix of buildings of different types. The input information required is identified, and the principal computations carried out by the program are summarized. Details of the input data format are presented and a typical program printout is shown. The results of a preliminary sensitivity analysis, in which the effects of the following input parameters were investigated, are examined: the earthquake occurrence probabilities; the damage state cost ratios; the initial cost penalties; and the discount rate. The sensitivity with respect to the choice of damage probabilities, can be assessed indirectly by comparing the expected future losses associated with the various design strategies. The damage probabilities for modern tall buildings for the five design strategies considered are given. The damage state categories are listed in terms of the direct cost of repairs and in terms of associated non-physical costs.

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PREFACE

This report is one of a series of internal study reports issued under NSF Grant GK-27955X on Optimum Seismic Protection for New Building Construction in Eastern Metropolitan Areas. The general methodology has been presented in earlier study reports and in a report based upon an oral presentation to the National Conference on Earthquake Engineering held in Los Angeles in February 1972 (Reference 1).

List of Internal Study Reports

1. R.V. Whitman, "Preliminary Work Plans and Schedules," August, 1971.

2. E.H. Vanmarcke and R.V. Whitman, "Background for Preliminary Expected Future Loss Computations," October, 1971.

3. P.J. Trudeau, "Identification of Typical Soil Profiles in the Boston Basin Area," November, 1971.

4. J.M. Biggs, "Comparison of Wind and Seismic Forces on Tall Buildings," December, 1971.

5. R.V. Whitman, "Contribution to State-of-the-Art Report of the Earthquake Committee of the IABSE-ASCE Tall Buildings Committee--Economic and Social Aspects," March, 1972.

6. J.E. Brennan and R.J. McNamara, "Optimum Seismic Protection for New Building Construction in Eastern Metropolitan Areas," April, 1972.

7. C.A. Cornell and H.A. Merz, "Analysis of the Seismic Risk on Firm Ground for Sites in the Central Boston Metropolitan Area," January, 1972.

8. R.V. Whitman, J.W. Reed, P. Marshall, "1967 Caracas Venezuela Earthquake Tall Building Damage Review," May, 1972.

9. R.V. Whitman and E.H. Vanmarcke, "Damage Statistics from Japanese Earthquakes," May, 1972.

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EXPECTED FUTURE LOSS AND TOTAL PRESENT COST COMPUTATIONS

A computer program has been written to evaluate expected future losses due to earthquakes, and to determine the best strategy for earthquake protection of buildings based on a minimum expected cost criterion. The reader is referred to the report by R. V. Whitman et al. [1] for overall methodology, terminology, etc. The program can be used for analyzing the seismic performance of a particular building or of a mix of buildings of many different types. The input information required is identified in Section 1, and the principal computations carried out by the program are summarized in Section 2. Finally, Section 3 refers to Appendices A, B, and C in which detailed information is given about the program.

1. INPUT DATA

Constants

K1 = Number of building types

K2 = Number of design strategies

K3 = Number of damage states

K4 = Number of intensity categories

DELTA = Discount rate

Vectors

NUMB(I) = [Number of buildings of type i] (K1 elements)

CRPL(I) = [Construction cost of type i building] (K1 elements)

IZONE(J) = [Number characterizing design strategy j] (K2 elements)

IDAM(K) = [Number characterizing damage state k] (K3 elements)

CDR(K) = [Ratio of repair cost to construction cost for damage state k] (K3 elements)

XINT(L) = [MM Intensity characterizing intensity category l] (K4 elements)

RISK(L) = [Annual probability of occurrence of quake with intensity in category l] (K4 elements)

Matrices

CIR(I,J) = Initial cost penalty for building type I designed under strategy J, expressed as a fraction of "zone 0" construction cost for building type i. (dimension: K1 X K2)

P(I,J,K,L) = Fraction of buildings of type I designed under strategy J expected to be in damage state K following an earthquake with intensity in category L. (dimension: K1 X K2 X K3 X K4)

2. PRINCIPAL COMPUTATIONS

The annual expected losses expressed as a fraction of the "zone 0" construction cost, for type I buildings designed under strategy J is

$$C(I,J) = \sum_{L=1}^{K4} CC(I,J,L) = \sum_{K=1}^{K3} CCC(I,J,K)$$

where CC(I,J,L) = the contribution to the expected losses due to intensity category L, and CCC(I,J,K) = the contribution to the expected losses due to damage state K. These contributions are related to the damage probabilities, the earthquake occurrence probabilities and the repair cost fractions in the following way:

$$CC(I,J,L) = \sum_{K=1}^{K3} P(I,J,K,L) \times CDR(K) \times (1 + CIR(I,J)) \times RISK(L)$$

$$CCC(I,J,K) = \sum_{K=1}^{K4} P(I,J,K,L) \times CDR(K)(1 + CIR(I,J)) \times RISK(L)$$

The total expected cost of earthquake protection for a building of type I designed under strategy J, again expressed in terms of the "zone 0" (or strategy 0) construction cost, is given by

$$TECR(I,J) = CIR(I,J) + \frac{1}{DELTA} C(I,J).$$

The first term is the initial cost penalty (which vanishes when J = 0), and the second term represents the average discounted future losses due to earthquakes. The reciprocal of the discount rate, $(DELTA)^{-1}$, can be interpreted as the effective design life of the building.

The best design strategy, J(I), for building type I is that which minimizes the total expected cost.

$$TECR(I,J(I)) = \min_{J} TECR(I,J)$$

If a common strategy must be used to design many different types of buildings, then the quantity to be minimized with respect to J is

$$TEC(J) = \sum_{I=1}^{K1} TECR(I,J) \times CRPL(I) \times NUMB(I)$$

and the best overall strategy is J* for which

$$TEC(J^*) = \min_{J} TEC(J)$$

Unless each "suboptimal" strategy J(I) (the best if only buildings of type I are considered) coincides with the overall optimal strategy J*, there will be a non-zero "opportunity loss" whose expected value is given below.

$$TEC(J^*) = \sum_{I=1}^{K1} TECR(I,J(I)) \times CRPL(I) \times NUMB(I)$$

In the analysis which follows, only one building type is involved, i.e., K1 = 1 and NUMB(1) = 1. The opportunity loss is of course equal to zero in this case.

3. PROGRAM LISTING AND INPUT-OUTPUT FORMAT

A listing of the computer program is given in Appendix A, and details of the input data format are presented in Appendix B. A typical program printout is shown in Appendix C.

SENSITIVITY ANALYSIS

This section examines the results of a preliminary sensitivity analysis in which we investigate the effects of the following input parameters:

-- the earthquake occurrence probabilities: RISK(L)

-- the damage state cost ratios: CDR(K)

-- the initial cost penalties: CIR(I,J)

-- the discount rate: DELTA

The sensitivity with respect to the choice of damage probabilities, P(I,J,K,L), can be assessed indirectly by comparing the expected future losses associated with the various design strategies.

Table 1 gives the damage probabilities for modern tall buildings for the five design strategies considered (i.e., these correspond to Zones 0,1,2,3, and 4; the last has a zone factor of two). These were estimated from preliminary results obtained from the San Fernando earthquake damage data.

Table 2 lists the damage state categories, described (i) by words, (ii) in terms of the direct cost of repairs, c_k, and (iii) in terms of associated non-physical costs, c'_k. Both c_k and c'_k are expressed as fractions of the construction cost. We will see that physical and non-physical costs do not need to be combined until the final stage in the computations, and that different discount factors can be applied to them.

The earthquake intensity categories correspond to various levels of Modified Mercalli Intensity (note that the fractional values V1.5 and V11.5 are used). The earthquake occurrence probabilities are chosen on

STRATEGY 0

	IV	V	VI	VI.5	VII	VII.5
0	0.97000	0.90000	0.40000	0.20000	0.04000	0.0
1	0.03000	0.08000	0.30000	0.30000	0.21000	0.01000
2	0.0	0.02000	0.20000	0.35000	0.37000	0.10000
3	0.0	0.0	0.10000	0.10000	0.21000	0.25000
4	0.0	0.0	0.0	0.05000	0.10000	0.30000
5	0.0	0.0	0.0	0.0	0.07000	0.25000
6	0.0	0.0	0.0	0.0	0.0	0.06000
7	0.0	0.0	0.0	0.0	0.0	0.02000
8	0.0	0.0	0.0	0.0	0.0	0.01000

STRATEGY 1

0.98000	0.92000	0.42000	0.23000	0.09000	0.04000
0.02000	0.07000	0.35000	0.35000	0.27000	0.08000
0.0	0.01000	0.19000	0.31000	0.33000	0.15000
0.0	0.0	0.04000	0.08000	0.17000	0.30000
0.0	0.0	0.0	0.03000	0.09000	0.20000
0.0	0.0	0.0	0.0	0.05000	0.18000
0.0	0.0	0.0	0.0	0.0	0.04000
0.0	0.0	0.0	0.0	0.0	0.01000
0.0	0.0	0.0	0.0	0.0	0.0

STRATEGY 2

0.99000	0.95000	0.44000	0.27000	0.14000	0.10000
0.01000	0.04000	0.36000	0.40000	0.33000	0.15000
0.0	0.01000	0.18000	0.25000	0.29000	0.20000
0.0	0.0	0.02000	0.06000	0.13000	0.20000
0.0	0.0	0.0	0.02000	0.08000	0.16000
0.0	0.0	0.0	0.0	0.03000	0.15000
0.0	0.0	0.0	0.0	0.0	0.03000
0.0	0.0	0.0	0.0	0.0	0.01000
0.0	0.0	0.0	0.0	0.0	0.0

STRATEGY 3

1.00000	0.97000	0.45000	0.30000	0.20000	0.15000
0.0	0.03000	0.40000	0.45000	0.40000	0.20000
0.0	0.0	0.15000	0.20000	0.25000	0.25000
0.0	0.0	0.0	0.05000	0.10000	0.15000
0.0	0.0	0.0	0.0	0.05000	0.15000
0.0	0.0	0.0	0.0	0.0	0.08000
0.0	0.0	0.0	0.0	0.0	0.02000
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

STRATEGY 4

1.00000	1.00000	0.95000	0.50000	0.40000	0.35000
0.0	0.0	0.05000	0.40000	0.40000	0.30000
0.0	0.0	0.0	0.10000	0.15000	0.25000
0.0	0.0	0.0	0.0	0.05000	0.08000
0.0	0.0	0.0	0.0	0.0	0.02000
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

Damage Probabilities

TABLE 1

TABLE 2

Damage States

	Description of Level of Damage	c_k Repair Costs (Ratio to Construction Cost)	c'_k Non-Physical Costs (Ratio to Construction Cost)
0	No Damage	0	0.0
1	Minor non-structural damage--a few walls and partitions cracked, incidental mechanical and electrical damage	.001	0.0
2	Localized non-structural damage--more extensive cracking (but still not widespread); possibly damage to elevators and/or other mechanical/ electrical components	.005	0.005
3	Widespread non-structural damage--possibly a few beams and columns cracked, although not noticeable	.02	0.1
4	Minor structural damage--obvious cracking or yielding in a few structural members; substantial non-structural damage with widespread cracking	.05	0.2
5	Substantial structural damage requiring repair or replacement of some structural members; associated extensive non-structural damage	.10	0.5
6	Major structural damage requiring repair or replacement of many structural members; associated non-structural damage requiring repairs to major portion of interior; building vacated during repairs	.30	1.3
7	Building condemned	1.0	2.5
8	Collapse	1.0	5

the basis of information contained in Internal Study Report No. 7 [2] on Boston seismic risk. The array of values labelled "low risk" in Table 3 represents a best estimate, as given in Internal Study Report No. 7, of the relationship between annual risk and intensity. See also in Fig.1. The arrays labelled "moderate risk" and "high risk" constitute progressively more conservative representations of the risk of earthquake occurrence in Boston.

The most useful results are the <u>annual expected cost ratios</u>, C(I,J), given in Table 4a (repair costs) and Table 4b (non-physical costs). These quantities will be denoted here by C_j and C'_j, respectively. They are based on computations in which the damage state cost ratios, CDR(K), are taken equal to the repair costs c_k and the non-physical costs c'_k, respectively. The total expected future loss under strategy j, L_j, is the sum of contributions due to physical and non-physical costs. Assuming that different discount factors (δ and δ') may have to be applied to the different loss components, L_j takes the following form:

$$L_j = \frac{1}{\delta} C_j + \frac{1}{\delta'} C'_j$$

Three sets of values of L_j, corresponding to different cost components and discount factors, are given in Tables 5a (only repair costs; $\delta = 0.05$), 5b ($\delta = 0.05$; $\delta' = 0.05$) and 5c ($\delta = 0.05$; $\delta' = 0.020$).

Finally, Table 6 gives several estimates of the initial cost increases expressed as fractions of the "zone 0" construction cost. (In the program these are denoted by CIR(J); here the symbol A_j is used for notational convenience.) The estimates in the first column correspond to the values given by Leslie and Biggs [3]. To determine the best strategy based

FIGURE 1

Annual Earthquake Risk vs. Intensity Curve for Boston (Ref. 2)

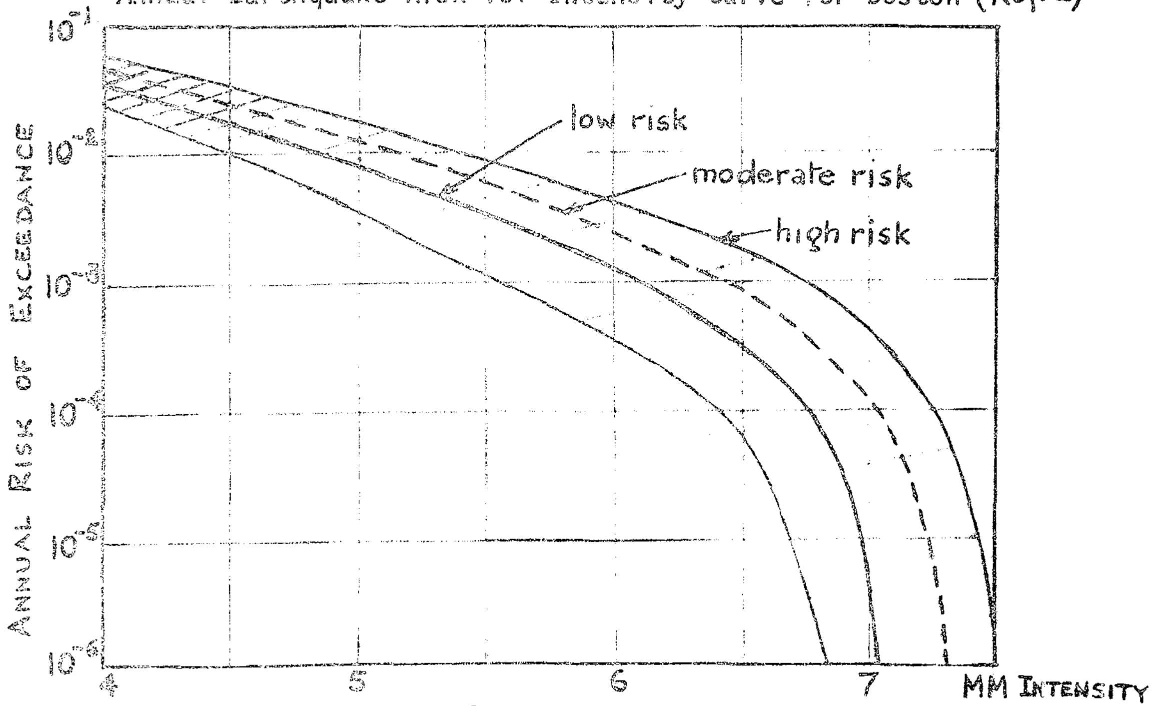

TABLE 3

Earthquake Occurrence Probabilities

Intensity	Low Risk	Moderate Risk	High Risk
IV	0.0310	0.035	0.046
V	0.0075	0.010	0.014
VI	0.0011	0.002	0.003
VI.5	0.0004	0.0085	0.0016
VII	2×10^{-6}	0.00015	0.0004
VII.5	10^{-10}	10^{-7}	2×10^{-6}

TABLE 4a

Strategy j	Low Risk	Moderate Risk	High Risk
0	$.171 \times 10^{-4}$	$.355 \times 10^{-4}$	$.635 \times 10^{-4}$
1	$.117 \times 10^{-4}$	$.252 \times 10^{-4}$	$.459 \times 10^{-4}$
2	$.883 \times 10^{-5}$	$.193 \times 10^{-4}$	$.354 \times 10^{-4}$
3	$.509 \times 10^{-5}$	$.115 \times 10^{-4}$	$.211 \times 10^{-4}$
4	$.874 \times 10^{-6}$	$.248 \times 10^{-5}$	$.513 \times 10^{-5}$

C_j = Ratio of Annual Expected Repair Costs to Construction Cost

TABLE 4b

Strategy j	Low Risk	Moderate Risk	High Risk
0	$.434 \times 10^{-4}$	$.106 \times 10^{-3}$	$.203 \times 10^{-3}$
1	$.244 \times 10^{-4}$	$.659 \times 10^{-4}$	$.132 \times 10^{-3}$
2	$.165 \times 10^{-4}$	$.459 \times 10^{-4}$	$.926 \times 10^{-4}$
3	$.671 \times 10^{-5}$	$.201 \times 10^{-4}$	$.422 \times 10^{-4}$
4	$.446 \times 10^{-5}$	$.268 \times 10^{-5}$	$.547 \times 10^{-5}$

C'_j = Ratio of Annual Expected Non-Physical Costs to Construction Cost

TABLE 5a

Strategy j	Low Risk	Moderate Risk	High Risk
0	$.342\times10^{-3}$	$.710\times10^{-3}$	$.127\times10^{-2}$
1	$.234\times10^{-3}$	$.504\times10^{-3}$	$.918\times10^{-3}$
2	$.177\times10^{-3}$	$.386\times10^{-3}$	$.708\times10^{-3}$
3	$.102\times10^{-3}$	$.230\times10^{-3}$	$.422\times10^{-3}$
4	$.175\times10^{-4}$	$.496\times10^{-4}$	$.103\times10^{-3}$

Total Expected Future Loss $L_j^{(1)} = \frac{1}{0.05} C_j$

TABLE 5b

Strategy j	Low Risk	Moderate Risk	High Risk
0	$.121\times10^{-2}$	$.283\times10^{-2}$	$.535\times10^{-2}$
1	$.722\times10^{-3}$	$.182\times10^{-2}$	$.356\times10^{-2}$
2	$.507\times10^{-3}$	$.130\times10^{-2}$	$.256\times10^{-2}$
3	$.236\times10^{-3}$	$.632\times10^{-3}$	$.127\times10^{-2}$
4	$.263\times10^{-4}$	$.103\times10^{-3}$	$.212\times10^{-3}$

Total Expected Future Loss $L_j^{(2)} = \frac{1}{0.05} C_j + \frac{1}{0.05} C'_j$

TABLE 5c

Strategy j	Low Risk	Moderate Risk	High Risk
0	$.251\times10^{-2}$	$.601\times10^{-2}$	$.114\times10^{-1}$
1	$.145\times10^{-2}$	$.359\times10^{-2}$	$.752\times10^{-2}$
2	$.100\times10^{-2}$	$.268\times10^{-2}$	$.534\times10^{-2}$
3	$.452\times10^{-3}$	$.123\times10^{-2}$	$.253\times10^{-2}$
4	$.392\times10^{-4}$	$.184\times10^{-3}$	$.376\times10^{-3}$

Total Expected Future Loss $L_j^{(3)} = \frac{1}{0.05} C_j + \frac{1}{0.02} C'_j$

TABLE 6

Strategy j	$A_j^{(1)}$	$A_j^{(2)}$	$A_j^{(3)}$
0	0.0	0.0	0.0
1	0.003	0.001	0.002
2	0.020	0.005	0.004
3	0.050	0.010	0.010
4	0.085	0.020	0.020

Fractional Initial Cost Increases

TABLE 7

Optimal Design Strategies

Different Assumptions on Initial Costs	Different Discount Rates	Low Risk	Moderate Risk	High Risk
$A_j^{(1)}$	$L_j^{(1)}$	0	0	0
	$L_j^{(2)}$	0	0	0
	$L_j^{(3)}$	0	0	1
$A_j^{(2)}$	$L_j^{(1)}$	0	0	0
	$L_j^{(2)}$	0	1	1
	$L_j^{(3)}$	1	1	1
$A_j^{(3)}$	$L_j^{(1)}$	0	0	0
	$L_j^{(2)}$	0	0	0
	$L_j^{(3)}$	0	1	2

on minimum expected cost it suffices to add the fractional initial cost increases, A_j, to the expected future losses, L_j, given in Table 5. A list of resulting optimal strategies is given in Table 7. Either Zone 0 or Zone 1 is optimal in all but one of the cases studied.

CONCLUSION

The tentative conclusion is that there is little benefit to be expected from earthquake design in the Boston area unless one or several of the critical parameters, i.e., the risk of higher intensity, the risk of total damage and the non-physical costs, take on values beyond the bounds considered herein. It must be emphasized that these bounds are indeed preliminary, and may be very sensitive to assumptions made about quantities that are still being studied.

REFERENCES

1. Whitman, R.V., C.A. Cornell, E.H. Vanmarcke and J.W. Reed, "Methodology and Initial Damage Statistics," Department of Civil Engineering Research Report R72-17, M.I.T., March 1972.

2. Merz, H. and C.A. Cornell, "Analysis of the Seismic Risk on Firm Ground for Sites in the Central Boston Metropolitan Area," Study Report No. 7, January 1972.

3. Leslie, S.K. and J.M. Biggs, "Earthquake Code Evolution and the Effect of Seismic Design on the Cost of Buildings," Department of Civil Engineering Research Report R72-20, M.I.T., May 1972.

APPENDIX A

Listing of the Computer Program

```
C-----------------------------------------------------------------------
C  PROGRAM FOR EXPECTED FUTURE LOSS AND TOTAL PRESENT COST COMPUTATIONS
C
C                                                BY D.W. FOR E.H.V.
C-----------------------------------------------------------------------
C----- K1 DIMENSIONS
      DIMENSION NUMB(80),CRPL(80),JSTAR(80),CPLOSS(80)
C----- K2 DIMENSIONS
      DIMENSION IZONE(5),TEC(5),TICOST(5),XFCOST(5)
C----- K3 DIMENSIONS
      DIMENSION IDAM(9),CDR(9)
C---- K4 DIMENSIONS
      DIMENSION RISK(6),XINT(6)
C----- K1 BY K2 DIMENSICNS
      DIMENSION CIR(80,5),TECR(80,5),C(80,5)
C---- K2 BY K3 DIMENSICNS
      DIMENSION CNTDAM(5,9)
C---- K2 BY K4 DIMENSIONS
      DIMENSION CNTINT(5,6)
C---- K1 BY K2 BY K3; K1 BY K2 BY K4; K1 BY K2 BY K3 BY K4
      DIMENSION CCC(80,5,9),CC(80,5,6),P(5,5,9,6)
C
      DIMENSION TITLE(20)
C-----------------------------------------------------------------------
C     READ INPUT
C-----------------------------------------------------------------------
C
      READ(5,1008) TITLE
      READ(5,1001) K1,K2,K3,K4,I1,DELTA,XNU
      DO 120 I=1,K1
      READ(5,1003) NUMB(I),CRPL(I),(CIR(I,J),J=1,K2)
120   CONTINUE
      READ(5,1009) (IZONE(J),J=1,K2)
      READ(5,1009) (IDAM(K),K=1,K3)
      READ(5,1007) (CDR(K),K=1,K3)
      READ(5,1008)(XINT(L),L=1,K4)
      READ(5,1006) (RISK(L),L=1,K4)
      DO 130 I=1,K1
      DO 130 J=1,K2
      DO 130 K=1,K3
      READ(5,1006) (P(I,J,K,L),L=1,K4)
  130 CONTINUE
C
C-----------------------------------------------------------------------
C      INITIALIZE COMPUTED ARRAYS
C-----------------------------------------------------------------------
C
  140 CONTINUE
   10 DO 30 J=1,5
      TICOST(J)=0.
      XFCOST(J)=0.
      TEC(J)=0.
      DO 30 I=1,80
```

```
      C(I,J)=0.
      DO 20 K=1,9
   20 CCC(I,J,K)=0.
      DO 30 L=1,6
   30 CC(I,J,L)=0.
      DO 40 I=1,60
   40 DPLOSS(I)=0.
      DO 60 J=1,5
      DO 50 K=1,9
   50 CNTDAM(J,K)=0.
      DO 60 L=1,6
   60 CNTINT(J,L)=0.
      SUPL=0.
C
C-----------------------------------------------------------------------
C     PRINT INPUT
C-----------------------------------------------------------------------
C
      WRITE(6,2001) TITLE,K1,K2,K3,K4,I1,DELTA,XNU
      WRITE(6,2002) K1,K2
      DO 121 I=1,K1
  121 WRITE(6,2003) I,NUMB(I),CRPL(I),(CIR(I,J),J=1,K2)
      WRITE(6,2004) (IZONE(J),J=1,K2)
      WRITE(6,2005) (IDAM(K),K=1,K3)
      WRITE(6,2006) (CDR(K),K=1,K3)
      WRITE(6,2007)(XINT(L),L=1,K4)
      WRITE(6,2008) (RISK(L),L=1,K4)
C
C-----------------------------------------------------------------------
C     BEGIN CALCULATIONS OF INTERMEDIATE MATRICES
C-----------------------------------------------------------------------
C
      DO 210 I=1,K1
      JMIN=1
      DO 210 J=1,K2
      WRITE(6,2011) I,IZONE(J)
      WRITE(6,2009)
      DO 190 K=1,K3
      DO 180 L=1,K4
  180 CCC(I,J,K)=CCC(I,J,K)+P(I,J,K,L)*CDR(K)*RISK(L)*(1.+CIR(I,J))
      C(I,J)=C(I,J)+CCC(I,J,K)
  190 WRITE(6,2010) (P(I,J,K,L),L=1,K4)
      TECR(I,J)=CIR(I,J)+C(I,J)*(XNU/DELTA)
      IF(TECR(I,JMIN).GT.TECR(I,J)) JMIN=J
      DO 200 L=1,K4
      DO 200 K=1,K3
  200 CC(I,J,L)=CC(I,J,L)+P(I,J,K,L)*CDR(K)*RISK(L)*(1.+CIR(I,J))
      JSTAR(I)=JMIN
      WRITE(6,2007) (XINT(L),L=1,K4)
      WRITE(6,2012) (CC(I,J,L),L=1,K4)
      WRITE(6,2005) (IDAM(K),K=1,K3)
      WRITE(6,2013) (CCC(I,J,K),K=1,K3)
      WRITE(6,2014) C(I,J),TECR(I,J)
```

```
  210 CONTINUE
C-----WRITE OUT SUBOPTIMAL STRATEGIES HERE IF DESIRED
      ISTRT=1
      DO 280 J=1,K2
      DO 220 I=1,K1
      TEC(J)=TEC(J)+TECR(I,J)*CRPL(I)*NUMB(I)
      TICOST(J)=TICOST(J)+CIR(I,J)*CRPL(I)*NUMB(I)
  220 XFCOST(J)=XFCOST(J)+C(I,J)*CRPL(I)*NUMB(I)
      XFCOST(J)=XFCOST(J)*XNU/DELTA
      IF(TEC(ISTRT).GT.TEC(J)) ISTRT=J
      WRITE(6,2033) IZONE(J),TEC(J),TICOST(J),XFCOST(J)
C
C-----------------------------------------------------------------------
C     CONTRIBUTIONS DUE TO VARIOUS DAMAGE STATES (FOR EACH STRATEGY)
C-----------------------------------------------------------------------
C
      DO 240 K=1,K3
      DO 230 I=1,K1
  230 CNTDAM(J,K)=CNTDAM(J,K)+CCC(I,J,K)*CRPL(I)*NUMB(I)
      CNTDAM(J,K)=CNTDAM(J,K)*XNU/DELTA
  240 WRITE(6,2034) IDAM(K),CNTDAM(J,K)
      WRITE(6,2035)
C
C-----------------------------------------------------------------------
C     CONTRIBUTIONS DUE TO VARIOUS INTENSITY RANGES
C-----------------------------------------------------------------------
C
      DO 260 L=1,K4
      DO 250 I=1,K1
  250 CNTINT(J,L)=CNTINT(J,L)+CC(I,J,L)*CRPL(I)*NUMB(I)
      CNTINT(J,L)=CNTINT(J,L)*XNU/DELTA
  260 WRITE(6,2036) XINT(L),CNTINT(J,L)
  280 CONTINUE
      WRITE(6,2037) IZONE(ISTRT)
      DO 300 I=1,K1
      J=JSTAR(I)
      OPLOSS(I)=(TECR(I,ISTRT)-TECR(I,J))*CRPL(I)*NUMB(I)
      SOPL=SOPL+OPLOSS(I)
  300 JSTAR(I)=IZONE(J)
C ***  WARNING ** JSTAR IS NOW IZONE VALUE (FOR FINAL PRINTOUT)
      WRITE(6,2038) (I,JSTAR(I),OPLOSS(I),I=1,K1)
      WRITE(6,2039) SOPL
      READ(5,1007) (CDR(K),K=1,K3)
      IF (CDR(1)) 400,140,140
  400 CONTINUE
      CALL EXIT
C
C-----------------------------------------------------------------------
C     FORMAT STATEMENTS
C-----------------------------------------------------------------------
C
 1001 FORMAT(5I5,/,2F10.3)
 1003 FORMAT(I10,F10.2,6F10.5)
```

```
1006 FORMAT(8F10.5)
1007 FORMAT(10F3.4)
1008 FORMAT(20A4)
1009 FORMAT(9I5)
1010 FORMAT(10F8.5)
2001 FORMAT('1EXPECTED FUTURE LOSS AND TOTAL PRESENT COST COMPUTATIONS
    1',/,' -------- ------ ---- --- ----- ------- ---- ------------',/,
    1'0',20A4,/,
    2'0NUMBER OF BUILDING TYPES........',I3,/,
    3' NUMBER OF DESIGN STRATEGIES.....',I3,/,
    4' NUMBER OF DAMAGE STATES.........',I3,/,
    5' NUMBER OF INTENSITIES...........',I3,/,
    6' SPECIFIED TIME HORIZON CODE.....',I3,/,
    7' DISCOUNT RATE...................',F4.2,/
    8' ANNUAL QUAKE OCCURRENCE RATE...',F4.2,/)
2002 FORMAT('0TYPE',5X,'NO.OF',4X,'  INITIAL  ',10X,'INITIAL COST PENAL
    1TIES MATRIX (',I3,'X',I2,')',/,10X,'BLDGS',7X,'COST',/,' ----',5X,
    2'-----',4X,'-----------',10X,'-----------------------------------
    3--')
2003 FORMAT(I5,I10,F15.2,6F15.5)
2004 FORMAT('0DESIGN STRATEGIES :',10I5)
2005 FORMAT('0FOR DAMAGE STATE : ', 2X,10I10)
2006 FORMAT(' REPAIR/INITIAL COST RATIO =',10F10.5)
2007 FORMAT('0FOR MERCALLY INTENSITY  ',10(3X,A4,3X))
2008 FORMAT(' PROBABILITY OF QUAKE IS ',10E10.4)
2009 FORMAT('0DAMAGE PROBABILITY MATRIX FROM INPUT :',/,' ------ ------
    1----- ------ ---- -----',/)
2010 FORMAT(10F13.5)
2011 FORMAT('1BUILDING TYPE',I3,30X,'STRATEGY',I3,/,' -------- ----',
    1' --',30X,'-------- --',/)
2012 FORMAT(10X,'CC =',12X,10E10.4)
2013 FORMAT(10X,'CCC =',14X,10E10.4)
2014 FORMAT('0',   'C = ',E13.4,/,'0',   'TECR = ',E10.4)
2033 FORMAT('1TOTAL EXPECTED COST CALCULATIONS',/,
    1' ----- -------- ---- ------------',/,
    2'0FOR STRATEGY',I3,/,' --- -------- --',//,
    1'0TOTAL EXPECTED COST.....',F12.2,/,
    2'0INITIAL COST............',F12.2,/,
    3'0EXPECTED FUTURE COST....',F12.2,/,
    6'6CONTRIBUTIONS DUE TO THE VARIOUS DAMAGE STATES :',/,
    7' ------------- --- -- --- ------- ------ ------',/,
    7'0DAMAGE STATE',12X,'CONTRIBUTION',/,
    8' ------ -----',12X,'------------',/)
2034 FORMAT(I13,10X,F14.4)
2035 FORMAT('6CONTRIBUTIONS DUE TO THE VARIOUS INTENSITY RANGES :',/,
    1' ------------- --- -- --- ------- --------- ------',/,
    1'0INTENSITY RANGE',12X,'CONTRIBUTION',/,
    2' --------- -----',12X,'------------',/)
2036 FORMAT(10X,A4,12X,F14.4)
2037 FORMAT('1',5X,'****************************************',/,6X,
    1'*  OVERALL OPTIMAL STRATEGY IS ',I2,'  *' ,/,6X,
    3'**************************************')
2038 FORMAT('6OPPORTUNITY LOSS COMPUTATION :',/,
```

```
     1' ----------- ---- -----------',/,
     1'OBLDG',4X,'SUBOPTIMAL',4X,'COMPUTATION',/
     2' TYPE',5X,'STRATEGY',/,' ----',4X,'----------',4X,'-----------',
     3/,(I5,10X,I5,5X,F14.4))
2039 FORMAT('0SUMMATION OF OPPORTUNITY LOSS COMPUTATIONS =',F12.4)
      END
```

APPENDIX B

Input Data Format

INPUT DATA FORMAT

A. Title Card - Format (20A4)

Columns 1-80 of this card will be printed as a title at the beginning of the output.

B. Control Card - Format (5I5)

Column 1-5 K1 -- The integer number of building types for this run (max 80)

6-10 K2 -- The integer number of design strategies for this run (max 5)

11-15 K3 -- The integer number of damage states for this run (max 9)

16-20 K4 -- The integer number of intensities for this run (max 6)

21-25 I1 -- The Time Horizon code (not used at present)

C. Control Card - Format (2F10.3)

Column 1-10 -- Discount Rate

11-20 -- Average annual rate of earthquake occurrence

D. Buildings Information Cards - Format (I10,F10.2,6F10.5)

One card for each building type must be input.

Column 1-10 Number of buildings of type i

11-20 Replacement cost of building

21-30 Initial cost penalties [one for each design

31-40 strategy (K2)]

etc.

E. <u>Strategy Card</u> - <u>Format (5I5)</u>

Each five columns represents a Strategy Number (usually input will be 0, 1, 2, 3, 4). There should be K2 numbers on this card.

F. <u>Damage State Card</u> - <u>Format (9I5)</u>

Each five column field represents a Damage State Number (usually 0, 1, 2, 3, 4, 5, 6, 7, 8). There should be K3 numbers on this card.

G. <u>Repair/Initial Cost Ratio Card</u> - <u>Format (9F8.4)</u>

Each 8-column field represents the Repair/Initial Cost for one Damage State. There would be K3 numbers on this card also (each field corresponds with a field on Card F, above).

H. <u>Modified Mercalli Intensity Card</u> - <u>Format (6A4)</u>

Each 4-column field on this card represents a Mercalli Intensity. There should be K4 Fields filled in, usually with a Roman Numeral.

I. <u>Earthquake Risk Card</u> - <u>Format (6F10.5)</u>

Each 10-column field on this card represents the probability of occurrence of earthquake in the corresponding Mercalli Intensity Range. There should be K4 fields, each corresponding with a field on Card H, above.

J. <u>Damage Probability Matrix Cards</u> - <u>Format (6F10.5)</u>

The Damage Probability matrix should be input as follows:

a. On each card there should be K4 probabilities, one for each Mercalli Intensity.

b. There should be K3 of these cards, one for each Damage State.

c. There should be K2 sets of K3 cards each, one for each Design Strategy.

d. This should be repeated for each building, i.e., K1 times (K1 sets of K2 sets of K3 cards each).

Total number of damage probability cards input should be K1 x K2 x K3.

K. <u>Additional Repair/Initial Cost Ratio Card</u> - <u>Format (9F8.4)</u>

Same as G. Each time this card is repeated (there is no limit on the number) a complete run is performed using all of the previously read data with these new repair/initial cost ratios. If a -1 is placed in card columns 1 and 2, the program terminates.

** To end program the last card must have a -1 punched in columns 1 and 2.

APPENDIX C

Typical Program Printout

The output shown herein is for the case in which the "High Risk" occurrence probabilities (Table 3) and the Initial Cost Increases $A_j^{(1)}$ (Table 6) are used. The damage state cost ratios, CDR(K) are equal to $c_k + 2c'_k$ (Table 2), and the discount rate is 0.05. This is equivalent to evaluating the expected future losses using the formula

$$L_j = \frac{1}{0.05} C_j + \frac{1}{0.025} C'_j \; .$$

EXPECTED FUTURE LOSS AND TOTAL PRESENT COST COMPUTATIONS

SENSITIVITY STUDY

NUMBER OF BUILDING TYPES.......... 1
NUMBER OF DESIGN STRATEGIES...... 5
NUMBER OF DAMAGE STATES.......... 9
NUMBER OF INTENSITIES............ 6
SPECIFIED TIME HORIZON CODE...... 1
DISCOUNT RATE....................0.05
ANNUAL QUAKE OCCURRENCE RATE....1.00

TYPE	NO. OF BLDGS	INITIAL COST	INITIAL COST PENALTIES MATRIX (1X 5)				
1	1	8000000.00	0.00000	0.00300	0.02000	0.05000	0.08500

DESIGN STRATEGIES : 0 1 2 3 4

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	9
REPAIR/INITIAL COST RATIO =	0.0	0.00100	0.01500	0.22000	0.45000	1.10000	2.90000	6.00000	11.000

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
PROBABILITY OF QUAKE IS	0.4600E-01	0.1400E-01	0.3000E-02	0.1600E-02	0.4000E-03	0.2300E-05

BUILDING TYPE 1 STRATEGY 0

DAMAGE PROBABILITY MATRIX FROM INPUT :

0.97000	0.90000	0.40000	0.20000	0.04000	0.0
0.03000	0.08000	0.30000	0.30000	0.21000	0.01000
0.0	0.02000	0.20000	0.35000	0.37000	0.10000
0.0	0.0	0.10000	0.10000	0.21000	0.25000
0.0	0.0	0.0	0.05000	0.10000	0.30000
0.0	0.0	0.0	0.0	0.07000	0.25000
0.0	0.0	0.0	0.0	0.0	0.06000
0.0	0.0	0.0	0.0	0.0	0.02000
0.0	0.0	0.0	0.0	0.0	0.01000

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.2760E-05	0.1064E-04	0.1518E-03	0.1602E-03	0.1392E-03	0.3482E-05

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.7928E-05	0.4765E-04	0.2356E-03	0.1085E-03	0.6270E-04	0.6960E-06	0.4800E-06	0.44…

C = 0.4680E-03

TECR = 0.1009E 01 - 1. = 0.009

BUILDING TYPE 1 STRATEGY 1

DAMAGE PROBABILITY MATRIX FROM INPUT :

0.98000	0.92000	0.42000	0.23000	0.09000	0.04000
0.02000	0.07000	0.35000	0.35000	0.27000	0.08000
0.0	0.01000	0.19000	0.31000	0.33000	0.15000
0.0	0.0	0.04000	0.08000	0.17000	0.30000
0.0	0.0	0.0	0.03000	0.09000	0.20000
0.0	0.0	0.0	0.0	0.05000	0.18000
0.0	0.0	0.0	0.0	0.0	0.04000
0.0	0.0	0.0	0.0	0.0	0.01000
0.0	0.0	0.0	0.0	0.0	0.0

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.1843E-05	0.6169E-05	0.7211E-04	0.1157E-03	0.1107E-03	0.2133E-05

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.7247E-05	0.4021E-04	0.1395E-03	0.7637E-04	0.4486E-04	0.6647E-06	0.2404E-06	0.0

C = 0.3086E-03

TECR = 0.1009E 01 - 1. = 0.009

EXPECTED FUTURE LOSS AND TOTAL PRESENT COST COMPUTATIONS

SENSITIVITY STUDY

NUMBER OF BUILDING TYPES........ 1
NUMBER OF DESIGN STRATEGIES..... 5
NUMBER OF DAMAGE STATES......... 9
NUMBER OF INTENSITIES........... 6
SPECIFIED TIME HORIZON CODE..... 1
DISCOUNT RATE...................0.05
ANNUAL QUAKE OCCURRENCE RATE....1.00

TYPE	NO. OF BLDGS	INITIAL COST	INITIAL COST PENALTIES MATRIX (1X 5)				
1	1	8000000.00	0.00000	0.00300	0.02000	0.05000	0.08500

DESIGN STRATEGIES : 0 1 2 3 4

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
REPAIR/INITIAL COST RATIO =	0.0	0.00100	0.01500	0.22000	0.45000	1.10000	2.90000	6.00000	11.000

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
PROBABILITY OF QUAKE IS	0.4600E-01	0.1400E-01	0.3000E-02	0.1600E-02	0.4000E-03	0.2000E-05

BUILDING TYPE 1 STRATEGY 0

DAMAGE PROBABILITY MATRIX FROM INPUT :

0.97000	0.90000	0.40000	0.20000	0.04000	0.0
0.03000	0.08000	0.30000	0.30000	0.21000	0.01000
0.0	0.02000	0.20000	0.35000	0.37000	0.10000
0.0	0.0	0.10000	0.10000	0.21000	0.25000
0.0	0.0	0.0	0.05000	0.10000	0.30000
0.0	0.0	0.0	0.0	0.07000	0.25000
0.0	0.0	0.0	0.0	0.0	0.06000
0.0	0.0	0.0	0.0	0.0	0.02000
0.0	0.0	0.0	0.0	0.0	0.01000

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.2760E-05	0.1064E-04	0.1518E-03	0.1602E-03	0.1392E-03	0.3482E-05

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.7928E-05	0.4765E-04	0.2396E-03	0.1085E-03	0.6270E-04	0.6960E-06	0.4800E-06	0.4400E-0

C = 0.4680E-03

TECR = 0.1009E 01 - 1. = 0.009

BUILDING TYPE 1 STRATEGY 1

DAMAGE PROBABILITY MATRIX FROM INPUT :

0.98000	0.92000	0.42000	0.23000	0.09000	0.04000
0.02000	0.07000	0.35000	0.35000	0.27000	0.08000
0.0	0.01000	0.19000	0.31000	0.33000	0.15000
0.0	0.0	0.04000	0.08000	0.17000	0.30000
0.0	0.0	0.0	0.03000	0.09000	0.20000
0.0	0.0	0.0	0.0	0.05000	0.18000
0.0	0.0	0.0	0.0	0.0	0.04000
0.0	0.0	0.0	0.0	0.0	0.01000
0.0	0.0	0.0	0.0	0.0	0.0

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.1843E-05	0.6169E-05	0.7211E-04	0.1157E-03	0.1107E-03	0.2133E-05

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.7247E-05	0.4021E-04	0.1395E-03	0.7607E-04	0.4486E-04	0.4647E-06	0.2404E-06	0.0

C = 0.3086E-03

TECR = 0.1009E 01 - 1. = 0.009

BUILDING TYPE 1 STRATEGY 2

DAMAGE PROBABILITY MATRIX FROM INPUT :

0.99000	0.95000	0.44000	0.27000	0.14000	0.10000
0.01000	0.04000	0.36000	0.40000	0.33000	0.15000
0.0	0.01000	0.18000	0.25000	0.29000	0.20000
0.0	0.0	0.02000	0.06000	0.13000	0.20000
0.0	0.0	0.0	0.02000	0.08000	0.16000
0.0	0.0	0.0	0.0	0.03000	0.15000
0.0	0.0	0.0	0.0	0.0	0.03000
0.0	0.0	0.0	0.0	0.0	0.01000
0.0	0.0	0.0	0.0	0.0	0.0

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.9292E-06	0.5373E-05	0.4521E-04	0.8516E-04	0.8264E-04	0.1742E-05

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.5802E-05	0.3625E-04	0.5261E-04	0.5847E-04	0.2733E-04	0.3515E-06	0.2424E-06	0.0

C = 0.2211E-03

TECR = 0.1024E 01 - 1 = 0.024

BUILDING TYPE 1 STRATEGY 3

DAMAGE PROBABILITY MATRIX FROM INPUT :

1.00000	0.97000	0.45000	0.30000	0.20000	0.15000
0.0	0.03000	0.40000	0.45000	0.40000	0.20000
0.0	0.0	0.15000	0.20000	0.25000	0.25000
0.0	0.0	0.0	0.05000	0.10000	0.15000
0.0	0.0	0.0	0.0	0.05000	0.15000
0.0	0.0	0.0	0.0	0.0	0.08000
0.0	0.0	0.0	0.0	0.0	0.02000
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.0	0.8610E-06	0.1630E-04	0.4740E-04	0.3989E-04	0.1027E-05

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.5120E-05	0.2677E-04	0.5426E-04	0.1873E-04	0.3608E-06	0.2378E-06	0.0	0.0

C = 0.1055E-03

TECR = 0.1052E 01 - 1. = 0.052

BUILDING TYPE 1 STRATEGY 4

DAMAGE PROBABILITY MATRIX FROM INPUT :

1.00000	1.00000	0.95000	0.50000	0.40000	0.35000
0.0	0.0	0.05000	0.40000	0.40000	0.30000
0.0	0.0	0.0	0.10000	0.15000	0.25000
0.0	0.0	0.0	0.0	0.05000	0.08000
0.0	0.0	0.0	0.0	0.0	0.02000
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.0	0.0	0.3127E-06	0.6338E-05	0.1138E-04	0.1278E-06

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.1582E-05	0.6896E-05	0.9247E-05	0.3753E-07	0.0	0.0	0.0	0.0

C = 0.1816E-04

TECR = 0.1085E 01 - 1. = 0.085

BUILDING TYPE 1 STRATEGY 2

DAMAGE PROBABILITY MATRIX FROM INPUT :

0.99000	0.95000	0.44000	0.27000	0.14000	0.10000
0.01000	0.04000	0.36000	0.40000	0.33000	0.15000
0.0	0.01000	0.18000	0.25000	0.29000	0.20000
0.0	0.0	0.02000	0.06000	0.13000	0.20000
0.0	0.0	0.0	0.02000	0.08000	0.16000
0.0	0.0	0.0	0.0	0.03000	0.15000
0.0	0.0	0.0	0.0	0.0	0.03000
0.0	0.0	0.0	0.0	0.0	0.01000
0.0	0.0	0.0	0.0	0.0	0.0

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.9292E-06	0.5373E-05	0.4521E-04	0.8516E-04	0.8264E-04	0.1742E-05

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.5802E-05	0.3625E-04	0.5261E-04	0.5847E-04	0.2733E-04	0.3515E-06	0.2424E-06	0.0

C = 0.2211E-03

TECR = 0.1024E 01 - 1 = 0.024

BUILDING TYPE 1 STRATEGY 3

DAMAGE PROBABILITY MATRIX FROM INPUT :

1.00000	0.97000	0.45000	0.30000	0.20000	0.15000
0.0	0.03000	0.40000	0.45000	0.40000	0.20000
0.0	0.0	0.15000	0.20000	0.25000	0.25000
0.0	0.0	0.0	0.05000	0.10000	0.15000
0.0	0.0	0.0	0.0	0.05000	0.15000
0.0	0.0	0.0	0.0	0.0	0.08000
0.0	0.0	0.0	0.0	0.0	0.02000
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.0	0.8610E-06	0.1630E-04	0.4740E-04	0.3989E-04	0.1027E-05

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.5120E-05	0.2677E-04	0.5426E-04	0.1873E-04	0.3608E-06	0.2378E-06	0.0	0.0

C = 0.1055E-03

TECR = 0.1052E 01 - 1. = 0.052

BUILDING TYPE 1 STRATEGY 4

DAMAGE PROBABILITY MATRIX FROM INPUT :

1.00000	1.00000	0.95000	0.50000	0.40000	0.35000
0.0	0.0	0.05000	0.40000	0.40000	0.30000
0.0	0.0	0.0	0.10000	0.15000	0.25000
0.0	0.0	0.0	0.0	0.05000	0.08000
0.0	0.0	0.0	0.0	0.0	0.02000
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

FOR MERCALLY INTENSITY	IV	V	VI	VI.5	VII	VII5
CC =	0.0	0.0	0.3127E-06	0.6338E-05	0.1138E-04	0.1279E-06

FOR DAMAGE STATE :	0	1	2	3	4	5	6	7	8
CCC =	0.0	0.1582E-05	0.6056E-05	0.9247E-05	0.3753E-07	0.0	0.0	0.0	0.0

C = 0.1816E-04

TECR = 0.1085E 01 - 1. = 0.085

TOTAL EXPECTED COST CALCULATIONS

FOR STRATEGY 0

TOTAL EXPECTED COST..... 8074874.00

INITIAL COST............. 8000000.00

EXPECTED FUTURE COST.... 74881.38

CONTRIBUTIONS DUE TO THE VARIOUS DAMAGE STATES :

DAMAGE STATE	CONTRIBUTION
0	0.0
1	1268.4844
2	7623.3477
3	38332.7656
4	17366.3826
5	10031.9766
6	111.3599
7	76.7999
8	70.3999

CONTRIBUTIONS DUE TO THE VARIOUS INTENSITY RANGES :

INTENSITY RANGE	CONTRIBUTION
IV	441.5991
V	1702.3979
VI	24287.9766
VI.5	25625.5820
VII	22266.8398
VII5	557.1255

TOTAL EXPECTED COST CALCULATIONS

FOR STRATEGY 1

TOTAL EXPECTED COST..... 8073364.00

INITIAL COST............ 8023994.00

EXPECTED FUTURE COST.... 49377.05

CONTRIBUTIONS DUE TO THE VARIOUS DAMAGE STATES :

DAMAGE STATE	CONTRIBUTION
0	0.0
1	1159.5459
2	6433.4609
3	22322.0469
4	12171.8047
5	7177.4492
6	74.3513
7	38.4575
8	0.0

CONTRIBUTIONS DUE TO THE VARIOUS INTENSITY RANGES :

INTENSITY RANGE	CONTRIBUTION
IV	294.8411
V	987.0769
VI	11537.2656
VI.5	18510.8984
VII	17705.8398
VII5	341.2014

TOTAL EXPECTED COST CALCULATIONS

FOR STRATEGY 2

TOTAL EXPECTED COST..... 8195358.00

INITIAL COST............ 8159996.00

EXPECTED FUTURE COST.... 35369.10

CONTRIBUTIONS DUE TO THE VARIOUS DAMAGE STATES :

DAMAGE STATE	CONTRIBUTION
0	0.0
1	928.3257
2	5800.1289
3	14818.0469
4	9354.6875
5	4372.8867
6	56.2367
7	38.7840
8	0.0

CONTRIBUTIONS DUE TO THE VARIOUS INTENSITY RANGES :

INTENSITY RANGE	CONTRIBUTION
IV	148.6719
V	859.7109
VI	7233.2031
VI.5	13626.0938
VII	13222.7344
VII5	278.6946

TOTAL EXPECTED COST CALCULATIONS

FOR STRATEGY 3

TOTAL EXPECTED COST..... 8416862.00

INITIAL COST............ 8399993.00

EXPECTED FUTURE COST.... 16875.86

CONTRIBUTIONS DUE TO THE VARIOUS DAMAGE STATES :

DAMAGE STATE	CONTRIBUTION
0	0.0
1	820.1299
2	4282.8516
3	8680.8281
4	2996.2766
5	57.7279
6	38.0480
7	0.0
8	0.0

CONTRIBUTIONS DUE TO THE VARIOUS INTENSITY RANGES :

INTENSITY RANGE	CONTRIBUTION
IV	0.0
V	137.7598
VI	2607.5959
VI.5	7285.3477
VII	6382.8633
VII5	164.2949

TOTAL EXPECTED COST CALCULATIONS

FOR STRATEGY 4

TOTAL EXPECTED COST..... 8682891.00

INITIAL COST............ 8679992.00

EXPECTED FUTURE COST.... 2906.08

CONTRIBUTIONS DUE TO THE VARIOUS DAMAGE STATES :

DAMAGE STATE	CONTRIBUTION
0	0.0
1	317.1194
2	1103.3801
3	1479.5803
4	6.0048
5	0.0
6	0.0
7	0.0
8	0.0

CONTRIBUTIONS DUE TO THE VARIOUS INTENSITY RANGES :

INTENSITY RANGE	CONTRIBUTION
IV	0.0
V	0.0
VI	50.0399
VI.5	1014.1423
VII	1821.4529
VII5	20.4496

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*************************************
*  OVERALL OPTIMAL STRATEGY IS   1  *
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OPPORTUNITY LOSS COMPUTATION :

BLDG TYPE	SUBOPTIMAL STRATEGY	COMPUTATION
1	1	0.0

SUMMATION OF OPPORTUNITY LOSS COMPUTATIONS = 0.0