UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Estimation of Earthquake Losses to Buildings (Except Single Family Dwellings)

by

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SUMMARY

This study is the eleventh in a series of investigations, beginning in 1967, dealing with the estimation of earthquake damage to various types of buildings. A methodology is developed in this report for determining inventory and estimating losses resulting from various postulated earthquakes occurring individually and for various ensembles of earthquakes. Five broad classes of buildings are considered. The building classes studied cover most of the building types in the San Francisco Bay area with the exception of one to four family dwellings, lifeline facilities, and special types of structures such as oil refineries and storage facilities, military installations, and bridges. One to four family dwellings were considered in an earlier report (Rinehart and others, 1976). This methodology, based on the seismic record, ground shaking, construction practice, and building inventory in the San Francisco Bay area can be adapted with appropriate adjustments for use in obtaining rough estimates of probable earthquake losses in other areas of the country.

Adaptation of the methodology developed for the San Francisco Bay area to other areas of the country will require careful attention to differences in design and construction practice, loss-ground shaking relationships, and inventory methods. The most difficult problem in transferring this methodology to other areas of the country will be in obtaining suitable building inventories. The building inventory method developed here depends on land-use classification in the San Francisco

Bay area. Extension of the methodology to other areas of the country will depend upon the extent to which local land-use classification schemes can be incorporated into the methodology.

Losses are expressed in terms of the average percentage of the total actual cash value required to fully repair, in kind, any building of a particular building class. Dollar losses may be obtained by estimating the total cash value of buildings in each building class. If building replacement costs are estimated and dollar losses obtained, the results may be combined with dollar losses estimated for one to four family dwellings in a previous report to obtain dollar loss estimates covering nearly all building types in the San Francisco Bay area (excluding lifeline structures, bridges, oil refineries, and other special purpose structures).

We hope that this report will prove of interest to those involved in disaster policy formulation, earthquake insurance, engineering design, building codes, disaster preparedness planning, and disaster assistance.

The following are specific results and conclusions that are considered particularly significant:

1. The study has developed a better understanding of the structure of the annual loss pattern (as reflected in 10-yr moving averages).
2. Annual losses computed using different segments of the historical earthquake record gave rates that varied greatly. In general, average annual loss estimates based on the seismicity during the period 1800-1899 (100 yrs) were the highest; whereas, the average

annual losses based on the period 1907-1974 (68 yrs) were the lowest. This reflects the lower seismicity of the San Francisco Bay area since 1906.

3. Average annual losses based on a simulated 1,000-yr seismicity in the study area appear to present the most useful values for average losses in the area.
4. There were significant variations in average losses among building classes as well as among subclasses. For example, average losses obtained using a 1,000-yr simulated seismicity record for building subclasses within Class III-Steel frame buildings, ranged from 0.22 to 0.78 percent per yr. Annual losses for all building classes considered ranged from 0.12 to 0.15 percent per yr (Class II-All-metal buildings) to 1.44 percent per yr (Class V-E-Unreinforced solid unit masonry of unreinforced brick, unreinforced concrete brick, unreinforced stone, or unreinforced concrete, where the loads are carried in whole or in part by the walls and partitions). The large differences in average annual losses among different building classes (the largest ratio was 12:1) have important implications for earthquake preparedness and hazard mitigation programs.
5. Annual losses based on a moving 10-yr average show wide variation and have little predictive value because of the erratic time and spatial occurrence of earthquakes.
6. Percent losses to building classes considered are generally substantially higher than for single family dwellings investigated in earlier reports.

7. The study has developed a building classification and inventory technique that: (a) provides a reasonable method of determining the distribution and type of buildings in an area, and (b) can be applied throughout the country.

8. Methods for the determination of the distribution of ground shaking associated with earthquakes have been considerably refined over the methods used in earlier studies. Corrections for site geology have also been included.

9. The techniques developed and the results obtained in this study could be extended and applied in a number of ways to public policy decisions and program planning. For example, examination of the percent loss-M.M. intensity curves in this report clearly shows the classes of structures most likely to sustain heavy damage in earthquakes. Users with local knowledge of the spatial distribution of construction types can easily make preliminary judgments of the probable damage pattern in a destructive earthquake. In addition, users who are familiar with differences among design and construction practices in the San Francisco Bay area and some other area and who have some familiarity with the characteristics of earthquake damage, can perhaps, modify the loss-ground shaking curves to better approximate conditions in their area of interest. Thus, estimates of probable losses can be made by careful adaption and extension of the methods developed in this report.

10. As already stated, the building inventory technique presented in this report has general applicability but it is dependent on a thorough understanding of land-use classification methods used in each area studied. The inventory technique used in this report is relatively straightforward to apply but, even so, the assembly of a building inventory for any metropolitan area is a difficult task. The method has the significant advantage of providing sufficient detail for damage estimation while being generally applicable throughout the country. Inventorying such community elements as utilities, public facilities, transportation systems, and so forth, depends on special knowledge of each area under study but it is possible to develop a general technique. Inventory techniques used in disaster preparedness studies of the San Francisco, Los Angeles, Seattle, and Salt Lake City areas for the Federal Disaster Assistance Administration of HUD could be applied to extend economic loss estimates to lifeline systems.

11. Three recommendations for future investigation are that:
    a. Inventory methodologies and loss-intensity relationships be further developed in order to provide reliable dollar loss estimates to all building classes as well as procedures practical for general usage regardless of geographic location.
    b. The distribution of ground shaking and losses related to various levels of ground shaking be treated probabilistically.
    c. Studies of losses associated with geologic effects of earthquakes (landslides, liquefaction, and so forth) be undertaken.

ACKNOWLEDGMENTS

Advice and guidance was provided by W. A. Rinehart of the National Oceanographic and Atmospheric Administration (NOAA), who was principally responsible for a study of earthquake losses to single family dwellings similar in concept to this study. The computer programing was done by Michael McGrath and Stanley Hanson of the U.S. Geological Survey. They made very important contributions both in the programing and in the development of the computational philosophy.

INTRODUCTION

This is the eleventh report prepared for the Department of Housing and Urban Development (HUD) since 1967 that relates to the problem of earthquake damage. Four of these reports were prepared for HUD, Federal Disaster Assistance Administration (FDAA), and its predecessor, the President's Office of Emergency Preparedness (OEP). They discuss the types of losses that might occur to facilities critical to disaster preparedness and recovery, given certain postulated earthquakes in specific areas. The areas discussed are the nine-county San Francisco Bay region, Los Angeles and Orange Counties, California, the Puget Sound, Washington, and Salt Lake City-Ogden-Provo, Utah, areas (Algermissen, Rinehart, and Dewey, 1972; Algermissen and others, 1973; Hopper and others, 1975; Rogers and others, 1976). The other seven reports have the more general goal of the analysis of earthquake damage and the development of the methodology for the estimation of earthquake losses resulting from damage to a wide range of structures. The first of these seven reports (U.S. Department of Commerce, 1967) presents the results of an attempt to gather basic seismological and engineering data related to earthquake losses. The studies completed in 1969 (Steinbrugge and others, 1969; Algermissen and others, 1969; U.S. Coast and Geodetic Survey, 1969) present estimates of losses to single family dwellings in California for: (1) a number of postulated individual earthquakes; and (2) aggregate losses for several time intervals. The results of a conference on seismic risk assessment specifically dealing with HUD's interests in this area were reported on in 1972 (Algermissen, 1972).

The performance of single family dwellings in the San Fernando, California, earthquake of February 9, 1971, was investigated (McClure, 1973) in an attempt to obtain additional recent single family dwelling damage data. The estimation of losses to single family dwellings was updated and revised in a report completed last year (Rinehart, 1976). This report in a sense completes a cycle of study in earthquake loss estimation. It provides a methodology for the computation of earthquake losses to a wide range of buildings other than single family dwellings. It makes available a technique for the estimation of virtually the total losses to all kinds of buildings likely to occur as a result of earthquakes of different magnitudes. The HUD-Department of the Interior, U.S. Geological Survey (USGS) Interagency Agreement has also resulted in a number of other articles in technical journals (Algermissen, Rinehart, and Stepp, 1972; Steinbrugge and others, 1976).

OBJECTIVE

The broad objective of this study is stated in the Detailed Work Program (1973) of Task I of the Department of Housing and Urban Development-Department of the Interior Interagency Agreement: "Extend the basic method of loss estimation already developed to the estimations of losses to other residential, commercial, industrial, and high-rise structures in California." Methods for the estimation of earthquake losses to single family dwellings in California were developed in earlier studies. The purpose of this study is to present a methodology for the estimation of losses to buildings other than dwellings, to complement earlier studies of single family dwellings, and to provide a general technique for the estimation of: (1) total losses from single large earthquakes, and (2) average losses resulting from earthquakes over a period of time.

The economic loss to buildings resulting from earthquakes depends on three principal factors:

1. The spatial distribution and kinds of buildings exposed to ground shaking and geological hazards (landslides, liquefaction, surface faulting, and so forth). In general, the buildings must be separated into appropriate classes and their spatial distribution determined in some manner.
2. The spatial distribution of earthquake shaking associated with a single earthquake or an ensemble of earthquakes in time.
3. The relationships between (1) and (2) that result in economic loss.

GEOGRAPHIC AREA COVERED BY THE STUDY

The decision was made to use the San Francisco Bay nine-county[1] area (fig. 1) for the development of the methodology and as the test area for the calculation of losses resulting from selected single earthquakes and aggregate losses due to a number of earthquakes over a period of time. There were a number of reasons for this decision, among which the principal are: (1) the investigators are familiar with the area and consequently maximum use of their professional judgment was possible, (2) the area has a reasonably high seismicity, and more importantly, (3) the earthquakes that have affected the San Francisco Bay area have been relatively well studied.

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[1] The San Francisco Bay area is considered to be made up of: San Francisco, San Mateo, Santa Clara, Alameda, Contra Costa, Solano, Napa, Sonoma, and Marin Counties.

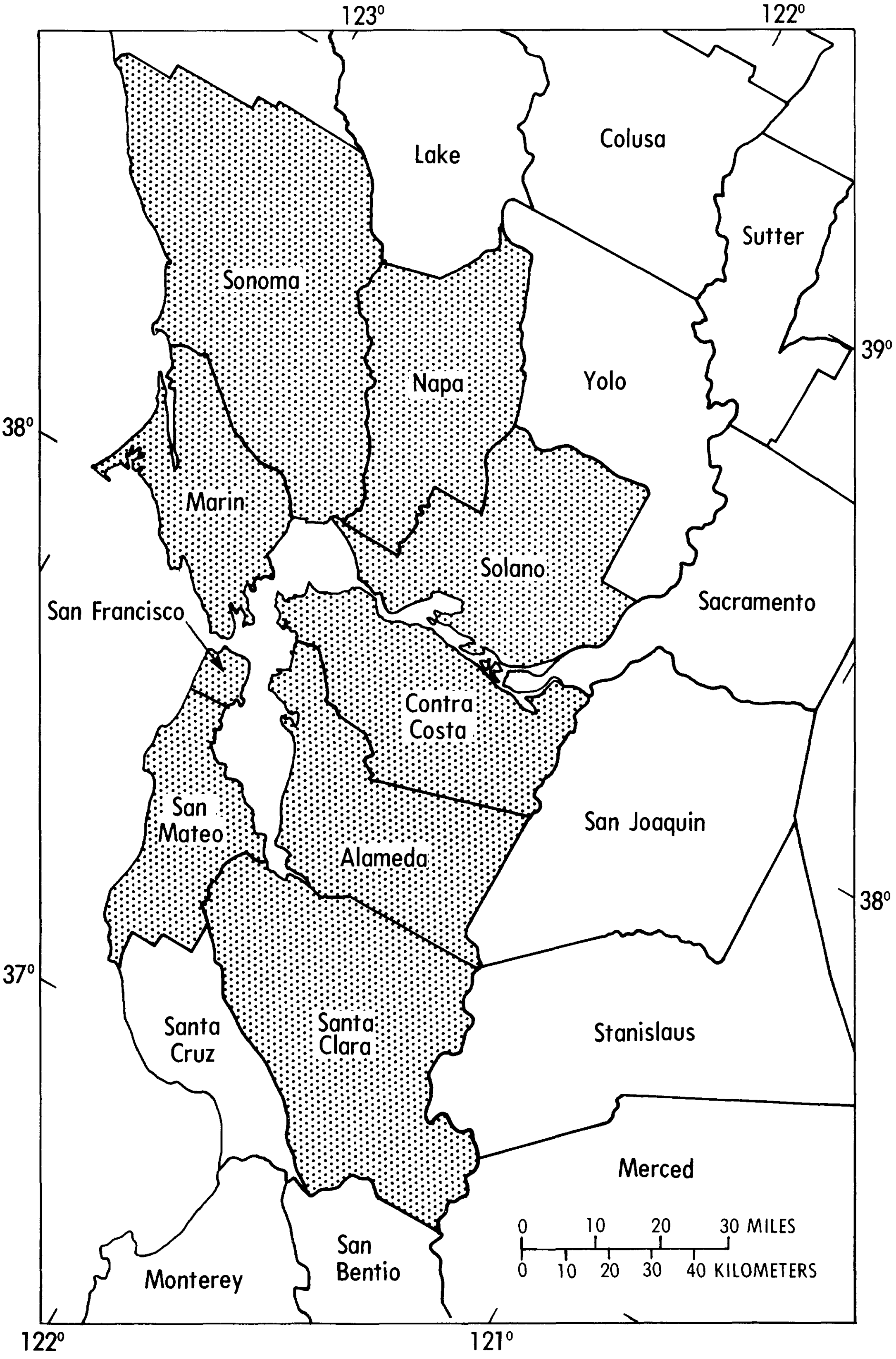

Figure 1.--Location map of northern California showing the nine-county area studied in this report.

BUILDING CLASSIFICATION

Historical background of building classifications developed for insurance purposes

Two distinctly different building classification systems used by many insurance companies, one for the Eastern United States and another originally for California, have developed over the past 50 years. The classifications developed for California were subsequently used in all of the other Western States including Alaska and Hawaii. The building classification system used for the Western States is of most interest to this study since: (1) the largest volume of earthquake insurance is written in the Western United States; and (2) the utility of the classification system as it applies to earthquake damage has been much more widely tested in the Western United States than in the East.

The general form of the present insurance building classes used in the Western United States by major segments of the insurance industry was developed after the Santa Barbara, California, earthquake of June 29, 1925, although earthquake insurance rules and rates existed in California in 1920 and probably for some years before then. The building classes developed in 1925 have been used successfully since that time and have been updated and changed as practices have changed. Recently the Insurance Services Office (ISO) has developed a new building classification system which replaces the existing eastern and western classifications with a single system. The new classification is largely based on the western classification system.

Building classifications used in this study

The new building classification system developed by the ISO has been selected with only minor changes for use in this study. The differences between the classification used here and the ISO building classification are so minor they need not be considered. The ISO classification was selected because it is based on classifications which have been used successfully in insurance work for over 50 years in the Western United States and because nearly all of the earthquake damage in the past 50 years has occurred in the Western United States (including Alaska and Hawaii). The classification has been tested with practically the complete history of damaging earthquakes in the United States in the past 50 years. In addition, the classification is widely used today in the insurance industry and is well suited to the estimation of losses as a function of building value. The most important reason for the use of the ISO building classification system in this study of the simulation of earthquake losses is that the system makes available to us, in a convenient and straightforward manner, over 50 years of industry experience in earthquake loss evaluation in the United States.

The building classifications used in this study are given in table 1. Figures 2 through 8 illustrate some of the building types in the building classification system. The illustrations are simplified descriptions of the large majority of buildings that are included in each classification. It is important to understand that these illustrations, by themselves, do not necessarily allow the exact placement of a building within a particular subclass. The illustrations have been included with the intention of allowing those who may be unfamiliar with the classification scheme to quickly identify and place most structures into a general class.

Table 1.--Building classification used in this study

Class I-Wood frame

Class I-A

1. Wood frame and frame stucco dwellings regardless of area and height.
2. Wood frame and frame stucco buildings, other than dwellings, which do not exceed 3 stories in height and do not exceed 3,000 sq ft in ground floor area.
3. Wood frame and frame stucco habitational structures which do not exceed 3 stories in height regardless of area.

Class I-B

Wood frame and frame stucco buildings not qualifying under Class I-A.

Class II-All-metal buildings

Class II-A

One story all-metal buildings which have a floor area not exceeding 20,000 sq ft.

Class II-B

All-metal buildings not qualifying under Class II-A.

Class III-Steel frame buildings

Class III-A

Buildings having a complete steel frame with all loads carried by the steel frame. Floors and roofs shall be of poured-in-place reinforced concrete, or of concrete fill on metal decking welded to the steel frame (open web steel joists excluded). Exterior walls shall be of poured-in-place reinforced concrete or of reinforced unit masonry placed within the frame. Buildings shall have a least width to height above ground (or above any setback) ratio of not exceeding one to four. Not qualifying are buildings having column-free areas greater than 2,500 sq ft (such as auditoriums, theaters, public halls, etc.).

Table 1.--Building classification used in this study--Continued

Class III-Steel frame buildings

Class III-B

Buildings having a complete steel frame with all loads carried by the steel frame. Floors and roofs shall be of poured-in-place reinforced concrete or metal, or any combination thereof, except that roofs on buildings over three stories may be of any material. Exterior and interior walls may be of any non-load carrying material.

Class III-C

Buildings having some of the favorable characteristics of Class III-A but otherwise falling into Class III-B.

Class III-D

Buildings having a complete steel frame with floors and roofs of any material and with walls of any non-load bearing materials.

Class IV-Reinforced concrete, combined reinforced concrete and structural steel frame

Note: Class IV-A, B, and C buildings shall have all vertical loads carried by a structural system consisting of one or a combination of the following: (a) poured-in-place reinforced concrete frame, (b) poured-in-place reinforced concrete bearing walls, (c) partial structural steel frame with (a) and/or (b). Floors and roof shall be of poured-in-place reinforced concrete, except that materials other than reinforced concrete may be used for the roofs on buildings over 3 stories.

Class IV-A

Buildings having a structural system as defined by the note (above) with poured-in-place reinforced concrete exterior walls or reinforced unit masonry exterior walls placed within the frame. Buildings shall have at least width to height above ground (or above any setback) ratio of not exceeding one to three. Not qualifying are buildings having column-free areas greater than 2,500 sq ft (such as auditoriums, theaters, public halls, and so forth).

Class IV-B

Buildings having a structural system as defined by the note (above) with exterior and interior nonbearing walls of any material.

Table 1.--Building classification used in this study--Continued

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Class IV-Reinforced concrete, combined reinforced
concrete and structural steel frame

Class IV-C

Buildings having some of the favorable characteristics of Class IV-A but otherwise falling into Class IV-B.

Class IV-D

Buildings having (a) a partial or complete load carrying system of precast concrete, and/or (b) reinforced concrete lift slab floors and/or roofs, and (c) otherwise qualifying for Classes IV-A, B, or C.

Class IV-E

Buildings having a complete reinforced concrete frame, or a complete frame of combined reinforced concrete and structural steel. Floors and roofs may be of any material while walls may be of any non-load bearing material.

Class V-Mixed construction

Class V-A

1. Dwellings, not over two stories in height, constructed of poured-in-place reinforced concrete, with roofs and second floors of wood frame.
2. Dwellings, not over two stories in height, constructed of adequately reinforced brick or hollow concrete block masonry, with roofs and floors of wood.

Class V-B

One story buildings having superior earthquake damage control features including exterior walls of (a) poured-in-place reinforced concrete, and/or (b) precast reinforced concrete, and/or (c) reinforced brick masonry or reinforced concrete brick masonry, and/or (d) reinforced hollow concrete block masonry. Roofs and supported floors shall be of wood or metal diaphragm assemblies. Interior bearing walls shall be of wood frame or any one or a combination of the aforementioned wall materials.

Class V-C

One story buildings having construction materials listed for Class V-B, but with ordinary earthquake damage control features.

Table 1.--Building classification used in this study--Continued

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Class V-Mixed construction

Class V-D

1. Buildings having reinforced concrete load bearing walls with floors and roofs of wood and not qualifying for Class IV-E.
2. Buildings of any height having Class V-B materials of construction, including wall reinforcement; also included are buildings with roofs and supported floors of reinforced concrete (precast or otherwise) not qualifying for Class IV.

Class V-E

Buildings having unreinforced solid unit masonry of unreinforced brick, unreinforced concrete brick, unreinforced stone, or unreinforced concrete, where the loads are carried in whole or in part by the walls and partitions. Interior partitions may be wood frame or any of the aforementioned materials. Roofs and floors may be of any material. Not qualifying are buildings with nonreinforced load carrying walls of hollow tile or other hollow unit masonry, adobe, or cavity construction.

Class V-F

1. Buildings having load carrying walls of hollow tile or other hollow unit masonry construction, adobe, and cavity wall construction.
2. Any building not covered by any other class.

Classes VI-A, B, C, D, and E-Earthquake resistive construction

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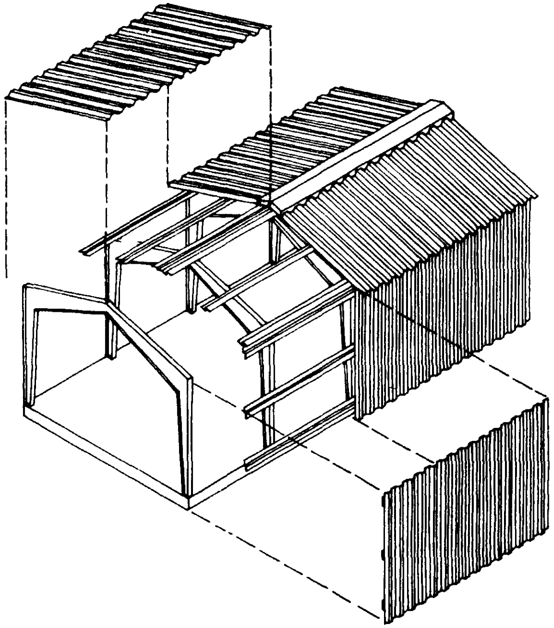
Any building or structure with any combination of materials and with earthquake damage control features equivalent to those found in Classes I through V buildings. Alternatively, a qualifying building or structure may be classed as any class from I through V (instead of VI-A, B, C, D, or E) if the construction resembles that described for one of these classes and if the qualifying building or structure has an equivalent damageability.



Simplified Description of
CLASS II: ALL METAL CONSTRUCTION

Class II-A: 1 story, floor not exceeding 20,000 sq. ft.
Class II-B: All metal of any size.

Note: Cement-asbestos acceptable alternate to metal roofing and/or siding.

Figure 2.--Generalized illustration of Class II structures. (Diagram courtesy Insurance Services Office.)

Simplified Description of
CLASS III: STEEL FRAME
(No shear walls, i.e. no bracing walls)

Class III-A: Superior damage control features.
Class III-B: Ordinary damage control features.
Class III-C: Intermediate damage control features (between III-A and III-B).
Class III-D: As shown, except floors and roof not concrete or metal deck.

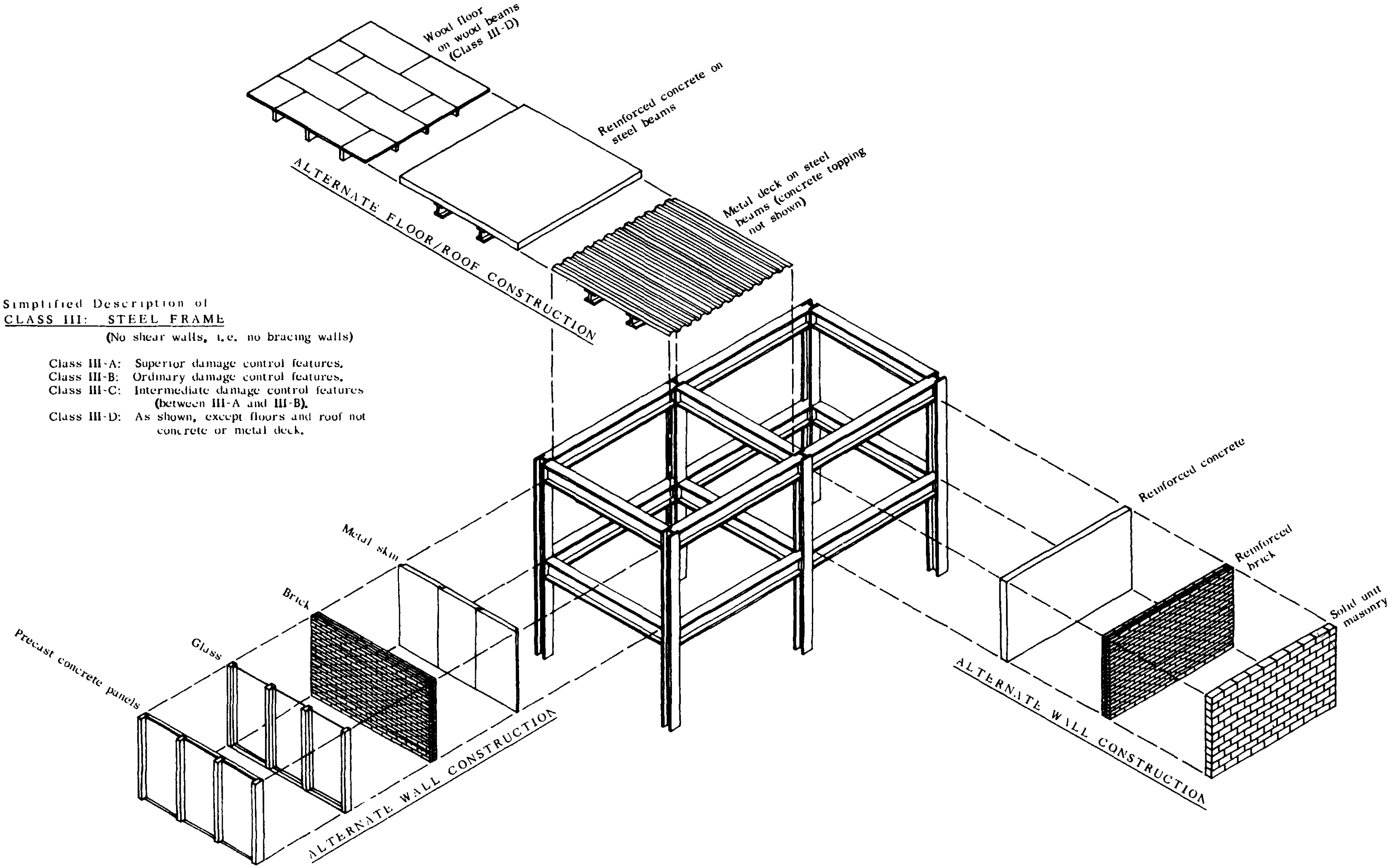
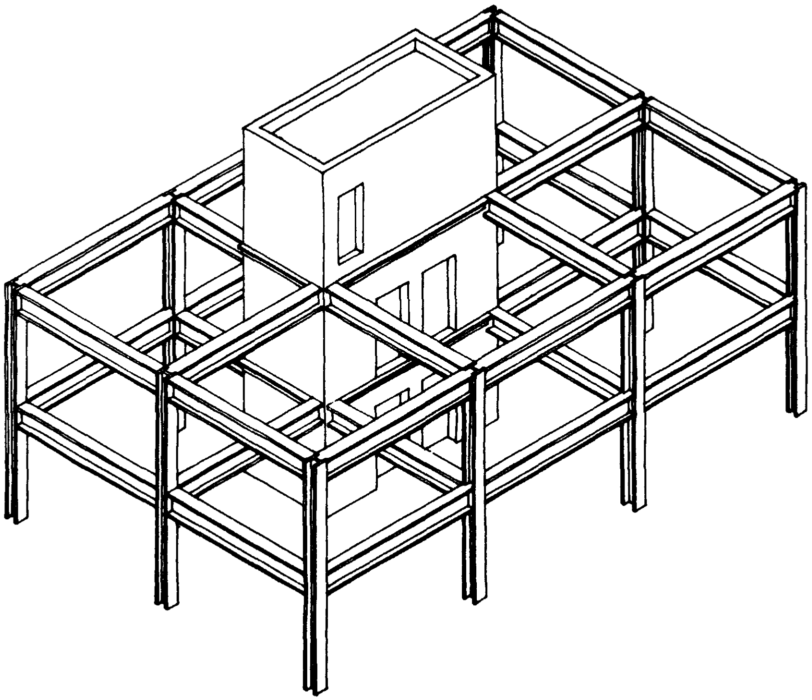


Figure 3.--Generalized illustration of Class III structures.
(Diagram courtesy Insurance Services Office.)



Simplified Description of

CLASS III: STEEL FRAME

(Reinforced concrete shear walls around central core, i.e. central elevators and stairs.)

See previous diagram for kinds of exterior wall construction.

This type of construction often qualifies for Class III A or III-C, but may be found in III-B and III-D.

Figure 4.--Generalized illustration of Class III structures. (Diagram courtesy Insurance Services Office.)

Simplified Description of

CLASS IV: REINFORCED CONCRETE FRAME
(No shear walls -- i.e. no bracing walls)

Class IV-A: Superior damage control features.
Class IV-B: Ordinary damage control features.
Class IV-C: Intermediate damage control features (between IV-A and IV-B).
Class IV-D: Precast reinforced concrete, lift slab (shown elsewhere).
Class IV-E: As shown, except floors and roof not concrete.

NOTE: ONLY CLASSES IV-A, IV-B, and IV-C SHOWN IN THE DIAGRAMS.

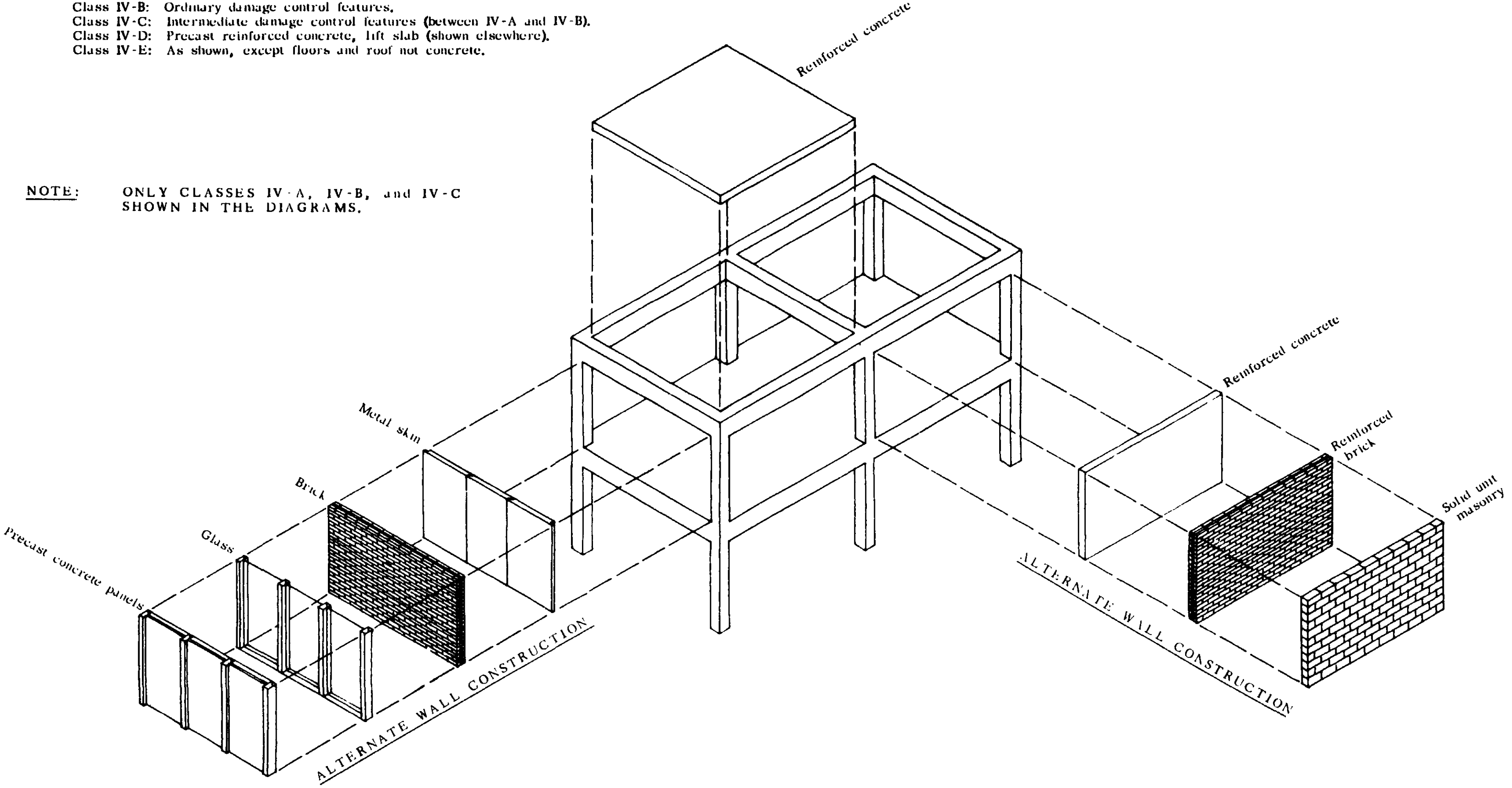


Figure 5.--Generalized illustration of a portion of Class IV structures. (Diagram courtesy Insurance Services Office.)

Simplified Description of

CLASS IV: REINFORCED CONCRETE FRAME

(Reinforced concrete shear walls around central core, i.e. central elevators and stairs.

See previous diagram for kinds of exterior wall construction.

This type of construction often qualifies for Class IV-A or IV-C, but may be found in IV-B, IV-D, and IV-E.

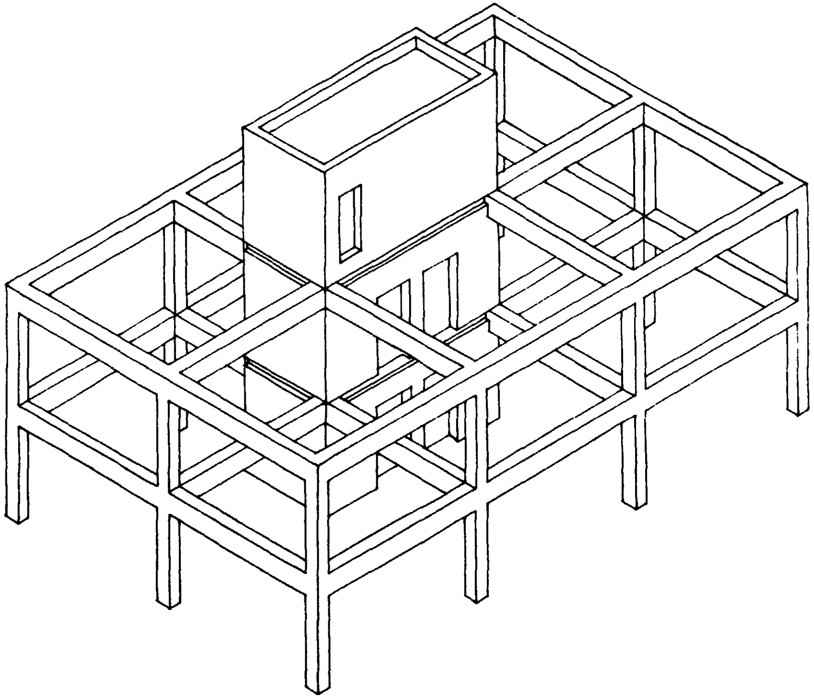
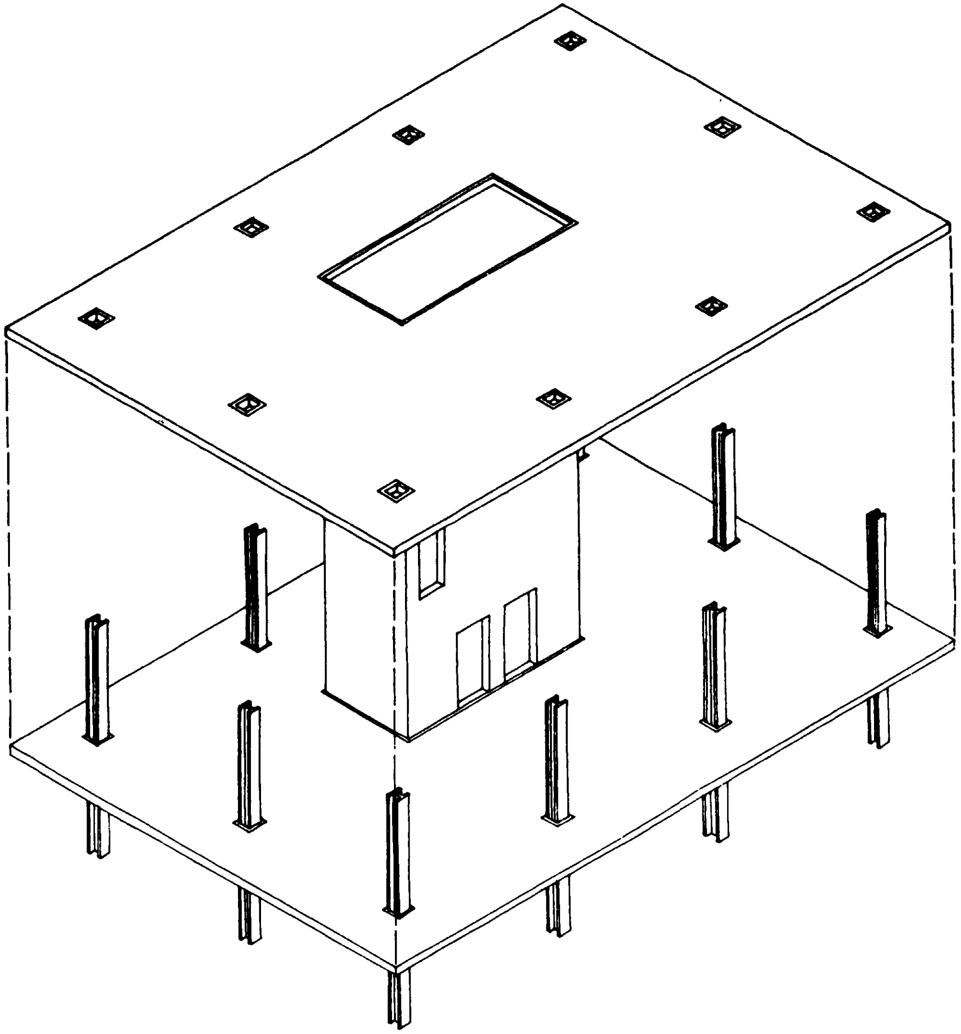


Figure 6.--Generalized illustration of a portion of Class IV structures. (Diagram courtesy Insurance Services Office.)



Simplified Description of

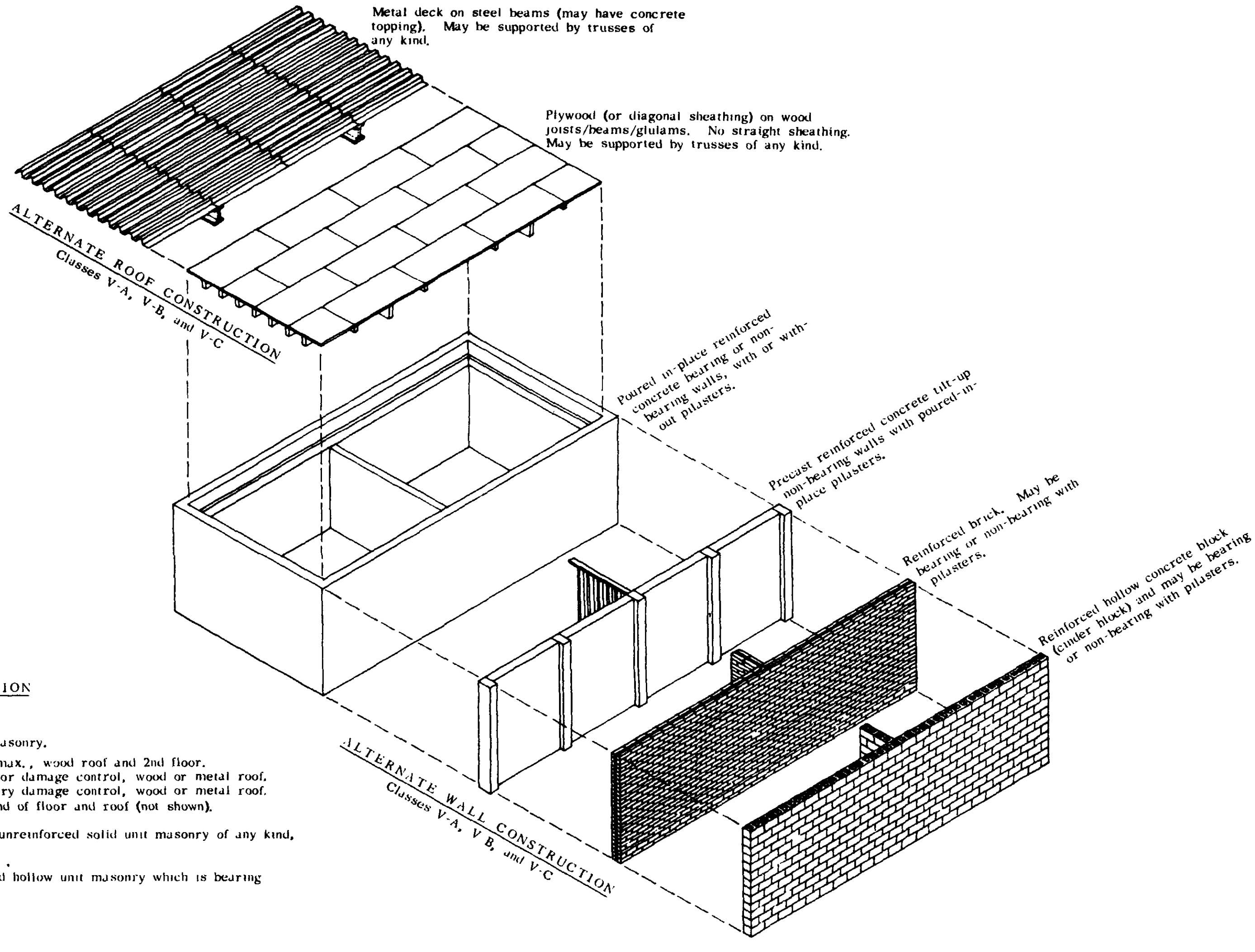
CLASS IV-D: LIFT SLAB CONSTRUCTION

Floors and roof are of poured reinforced concrete and are usually prestressed. Floors and roof are cast one-upon-another at ground level, then jacked up the columns (usually steel) to their respective final levels, and often braced by a central core of reinforced concrete. The central core normally contains the stairs and the elevators.

Class IV-D precast concrete construction not shown.

Exterior walls may be of any material.

Figure 7.--Generalized illustration of Class IV structures. (Diagram courtesy Insurance Services Office.)



Simplified Description of

CLASS V: MIXED CONSTRUCTION

Classes V-A, V-B, V-C, and V-D, reinforced concrete or reinforced unit masonry.

Class V-A: Dwelling, 2 story max., wood roof and 2nd floor.
Class V-B: 1 story with superior damage control, wood or metal roof.
Class V-C: 1 story with ordinary damage control, wood or metal roof.
Class V-D: Any height, any kind of floor and roof (not shown).

Class V-E: Unreinforced concrete, or unreinforced solid unit masonry of any kind, and which is bearing (not shown).

Class V-F: Adobe bearing, unreinforced hollow unit masonry which is bearing (not shown).

Figure 8.--Generalized illustration of a portion of Class V structures. (Diagram courtesy Insurance Services Office.)

The key to a successful building classification system is identifying the degree of damage control exercised by the structural system and the ease in recognizing this damage control. Damage control may exist by design on the part of the architect/engineer, or by accident of design, or by being inherent in the construction material. For example, an all-steel gasoline service station falls into the last category. It follows, then, that an appropriately written set of building classification rules will endeavor to pick out the damage control features and reflect them in the classes. The building classification system given in table 1 follows this approach.

Costs to gather adequate building data in the field or through the review of construction drawings for a study such as this are hard to determine. The insurance industry spends millions on field examinations for fire insurance surveys. The cost per earthquake survey is not broken out, but may be roughly approximated on the basis of two buildings per day per engineer (without the usual corollary duties, plus support staff). It is estimated that an inventory determined by a sampling field inspection methodology, including valuations, would cost well in excess of half a million dollars for such a study.

Obviously, the inspection of individual buildings by qualified engineers would provide the optimum building inventory information. This is clearly feasible for small groups of buildings (or other structures or facilities of interest) but is economically unreasonable for the estimation of losses to buildings in areas as large as the nine-county San Francisco Bay area, and it would be unreasonably expensive even at the single-county level in metropolitan areas. Communities might code tax assessment forms and building permit applications with a uniform land-use and building classification, but no mechanism exists to implement such a scheme.

BUILDING INVENTORY

Examination of existing inventory sources

The development of a suitable building inventory, with buildings classified as discussed previously, is an obvious necessity for loss estimation. Steinbrugge and Lagorio (1975) extensively reviewed possible local building inventory data sources in the nine-county San Francisco Bay test area. Their review was conducted in the context of estimating the geographical distribution of property values by specific building construction class and by census tract boundary. Twenty possible sources of building inventory data in the San Francisco Bay area were surveyed.

No single existing data source filled the objective, namely: the determination of the geographic distribution of property values by specified building construction class and by census tract boundaries. Table 2 shows qualitatively the degree to which the various data sources met the aforementioned objective. Costs to utilize the existing data without substantial interpretation, however, were invariably excessive. Almost all data from different sources were incompatible with each other, since they were usually compiled on different bases. In a few cases, some degree of compatibility could be achieved at varying cost.

Other methodologies were examined in addition to those accompanying the aforementioned data sources. None of these additional methodologies were suited for this study.

Table 2.--Summary of data source

[Leaders (---) denote "no", or "unusable data"]

Data source	Building inventory		Property values compiled		Location mapped		Comment
	by occupancy	by construction	by occupancy	by construction	by occupancy	by construction	
I. Seismic safety element	Partial	---	---	---	Partial	---	Each "element" has different basis, resulting in incompatibility.
II. State Board of Equalization	Yes	---	Yes	---	---	---	Building inventory is by varying kinds of use codings.
III. County Assessor's office	Yes	---	Yes	---	---	---	Data bases among counties are inconsistent and results incomplete.
IV. California Office of Emergency Services	---	Negligible	---	---	---	---	Negligible number compiled for only one county.
V. U.S. Army Corps of Engineers	---	Negligible	---	---	---	---	Negligible number compiled.
VI. County Engineering and Road departments	---	---	---	---	---	---	Mapping is not related to occupancy or construction type.
VII. U.S. Geological Survey	---	---	---	---	Partial	---	---
VIII. County Planning departments	---	---	---	---	Partial	---	---
IX. National Bureau of Standards	---	---	---	---	---	---	Generalized program developed. Data have limited applification.
X. Western Economic Research Co.	---	---	---	---	Partial	Partial	Individual structures mapped in some areas. No compilation.
XI. Metropolitan Transportation Commission	---	---	---	---	Partial	---	Very few occupancies listed.
XII. Greater San Francisco Chamber of Commerce	---	---	---	---	---	---	---
XIII. Bay Area Council	---	---	---	---	---	---	---
XIV. Security Pacific Bank	---	---	---	---	Partial	---	---
XV. County and Municipal Building Departments	---	---	---	---	---	---	Blueprints available.
XVI. Sanborn Map	---	---	---	---	Partial	Partial	Only older established areas mapped. No longer in business.
XVII. National Research Bureau, Inc.	Shopping ctrs.	---	Shopping ctrs.	---	Shopping ctrs.	---	---
XVIII. U.S. Bureau of the Census	Dwellings	---	Dwellings	---	Dwellings	---	---
XIX. Association of Bay Area Governments	---	---	---	---	Partial	---	---
XX. Insurance industry	Yes	Yes	---	---	---	---	Data compilation too costly.

Development of a building inventory for this study

The following assumptions and techniques were used to develop the building inventory:

1. It is assumed that a direct correlation exists between specific building classes and land-use designations. For example, it is reasonable to assume that subclass I-A wood frame buildings used as habitational structures and private dwellings, regardless of area, are primarily located in land-use areas designated as residential, single-family, or multi-family units. To cite another example, large area buildings which constitute subclass II-B all-metal structures are normally aircraft hangars, steel plants, major manufacturing facilities, or large warehouses, and accordingly are situated in land-use areas primarily zoned for industrial purposes. This assumption makes possible the determination of the geographic distribution of building classes throughout the study area. Modification of this assumption for any one building class or subclass was made on the basis of professional judgment.
2. All building classes are assumed to be uniformly distributed within their designated mapped zones. Restated, it is assumed that the building values for each building class are, on the average, the same per unit area throughout the study area. This equal distribution of building value is reasonably consistent with policy assumed in zoning ordinances formulated by the respective county planning commissions and regional agencies. This assumption was modified when, based on professional judgment of the authors, it gave obviously incorrect results. In these cases, an appropriate judgment factor was applied to the data.

3. Non-conforming uses are not included in the geographic distribution of building classes. In addition, small isolated pockets of semi-commercial developments in suburban areas of the Bay area, such as for example, Kensington, Alamo, Moraga Crossroads, Almaden Meadows, Orinda Village, among others, are not considered. In comparison to the major commercial areas tabulated, their values are relatively insignificant. However, insofar as possible, their values are included in the nearest major commercial area accounted for by a factor related to population distribution on the basis of the 1970 census. In any event, visual surveys indicate that, except for the all-metal gasoline service stations located in these random pockets, the majority of these structures usually are wood frame buildings.
4. Land use data obtained from the "Atlas of Urban and Regional Change" (U.S. Geol. Survey, 1973) were plotted on the "Census Tract Outline Map," Western Economic Research Co. (1973), converting the land-use designations to the appropriate building class. Data compatibility with the respective land-use maps provided by the various county planning commissions was confirmed by cross-checking data sources. Mapped results were partially verified through data collected from the detailed city and street maps available for urban centers located in the San Francisco Bay area.
5. While detailed field inspection of individual buildings was not a part of this methodology, final mapping results were substantiated through general visual field surveys of critical areas.

6. Special services areas found in the San Francisco Bay area, such as for examples, San Francisco Presidio, Port of San Francisco, Hamilton Air Force Base, Moffett Naval Air Field, U.S. Naval Magazines at Port Chicago and Concord, Oakland Army Base, Oakland Naval Supply Center, Nimitz Field Naval Air Station in Alameda, San Quentin Penitentiary, and Mare Island, among others, were not included in the mapping of building classes.
7. It should be noted that the data on the Western Economic Research map is based on the 1970 United States Census data.
8. The area within each census tract with a particular land-use code (equated to building class) was measured using a planimeter with an accuracy of 0.01 percent. The area of each building class in each census tract was then summed to determine the total area of a particular building class in the nine counties considered in the study. The percentage of any building class in any census tract is then:

$$\frac{\text{Area of the particular building class in the census tract}}{\text{Total area of that building class in the nine-county area}} \text{x100}$$

Notes on inventory development applicable to specific construction classes

The following discussion explains in some detail the authors' general approach to inventory development for each building class.

Class I-Wood frame construction.--Inventory methodologies for subclass I-A structures were developed in an earlier study (Steinbrugge and others, 1969; Algermissen and others, 1969), and the reader is referred to these references. Subsequent computational simplifications do not involve the size or geographical distribution of the inventory. Wood-frame dwellings up to and including four family occupancy were not considered in this study.

Subclass I-B structures consisting of large area non-habitational wood frame units are normally of low comparative value. Exceptions include sawmills (not in the study area), docks (excluded from the study), a few manufacturing plants of substantial value, and others; but their total value is comparatively small. Subclass I-B structures are usually related to mercantile or storage of manufactured goods and similar activities, and they are normally found in areas designated by commercial use codes. Because of low total values and wide uneven distribution of this subclass in comparison to other building classifications, the cost-benefit precluded mapping.

Class II-All-metal construction; subclass II-A.--Buildings in subclass II-A are customarily of light mass and include prefabricated structures. Another type of structure typical of subclass II-A is the gasoline service station. Both types of the above-mentioned structures are normally located in mercantile and industrial zones, and their distribution can be determined in proportion to the areas defined by such use code designations. Distribution for subclass II-A structures was on a 100 percent basis for mercantile areas and a reduced 10 percent basis for industrial zones since they are mainly located in the former land-use areas.

In addition to the service stations and other small area all-metal buildings found in mercantile and industrial areas, a few are also located in a pattern of wide scatter at the intersections of streets and elsewhere in residential zones for the convenience of the residents in non-conforming use code designations. Their geographic location could be conveniently accommodated by distributing an additional 10 percent of their value throughout the study area in accordance with population distribution indicated by the census. The cost-benefit of this refinement is questionable, and therefore this refinement was not included in the computational process.

The following is an example of the procedure outlined above. Table 3 is a typical work sheet for computation of the percentage distribution of Class II-A structures in the nine-county area. The columns in table 3 have the following information:

Col. 1: County name.

Col. 2: Tract number: 1970 census tract number.

Col. 3: 100 percent mercantile (acres): The net mercantile area in acres.

Col. 4: Percent: A percentage determined by dividing the acreage in the census tract (column 3) by the sum of the total mercantile acreage in the study area (55,206.8 acres).

Col. 5: 10 percent industrial (acres): After the acreage of industrial area in the specified tract is determined, list 10 percent of this acreage in this column for every industrial tract (based on data indicating that the geographic distribution of this building class is limited to approximately 10 percent of the industrial area).

Col. 6: Percent: Similar to column 4, except for industrial.

Col. 7: Total: Sum of columns 3 and 5.

Col. 8: Percent of total: Similar to column 4, except applied to column 7. <u>This is the percentage of the total value of the building class located in this census tract</u>.

Table 3.--Sample work sheet for calculation of the percentage distribution of Class II-A structures (see text for explanation)

[Leaders (--) indicate a very low percentage]

Area class: Class II-A
Type: All metal construction-small buildings
Use code areas: Industrial/mercantile

1 County	2 Tract no.	3 100 percent mercantile (acres)	4 Percent	5 10 percent industrial (acres)	6 Percent	7 Total	8 Percent of total
San Francisco	0101	128.0	0.23	--	--	128.0	0.210
	0102	51.2	.09	--	--	51.2	.080
	0126	102.4	.19	--	--	102.4	.170
	0154	51.2	.09	--	--	51.2	.080
	0156	25.6	.05	--	--	25.6	.040
	0157	25.6	.05	--	--	25.6	.040
	0168	76.8	.14	--	--	76.8	.120
	0226	--	--	12.8	.20	12.8	.020
	0227	--	--	12.8	.20	12.8	.020
	0230	--	--	2.56	.04	2.56	.004
	0232	76.8	.14	--	--	76.8	.120
	0233	128.0	.23	--	--	128.0	.210
	0234	128.0	.23	--	--	128.0	.210
	0251	76.8	.14	--	--	76.8	.120
	0257	102.4	.19	--	--	102.4	.170
	0258	51.2	.09	--	--	51.2	.080
	0259	25.6	.05	--	--	25.6	.040
	0264	76.8	.14	--	--	76.8	.120
	0309	51.2	.09	--	--	51.2	.080
	0313	51.2	.09	--	--	51.2	.080
	0332	51.2	.09	--	--	51.2	.080
	0401	25.6	.05	--	--	25.6	.040

Class II-All-metal construction; subclass II-B.--Large-area all-metal buildings include units such as aircraft hangars, steel plants, large warehouses, and manufacturing facilities, which are usually found in industrial areas in accordance with zoning practices. Their geographic distribution was assumed to be uniform throughout the heavy industrialized sections in the study area. Specifically, the mapped areas were limited to the industrial sections designated as such by use codes in accordance with land-use policy established by the respective planning commissions. Reduction allowances were made for the large industrial areas which are known to contain salt ponds, and for historic bay margins not fully developed for industrial use. A 90 percent reduction factor was applied to areas known to relate to petrochemical plants. None were distributed to mercantile zones. The computational process is similar to that discussed for subclass II-A buildings.

Classes III and IV-Steel frame and reinforced concrete.--The geographic distributions of buildings in classes III and IV are sufficiently similar that they may be considered jointly from a mapping standpoint. These jointly mapped classes may be subdivided by story height, as follows: (1) Four stories and over; and (2) up to four stories.

(1) Four stories and over.--Values are usually substantial for each building, and there are an increasing numbers of buildings approaching 50 stories. *Thus, the basic mapping assumption that values are a direct function of land area does not apply for high-rise buildings, and an alternate approach is required*.

The approach used for taller buildings is based on the fact that perhaps 95 percent or more of these multistory buildings are concentrated in a relatively few well-defined locations. For example, considering the congested sections of the metropolitan San Francisco Bay area, the number of buildings over eight stories was recently tabulated as follows[2]:

San Francisco	267
Oakland	38
San Jose	12
Berkeley	17
Palo Alto	5

As a corollary to the previous assumption, it is assumed that all buildings in a given city are subjected to the same ground motions--a reasonable first approximation approach when considering averages as well as the fact that most lie within a short distance of each other. On the basis of the applicable assumptions, table 4 was updated to 1975 from table 46 found in "A Study of Earthquake Losses in the San Francisco Bay Area" (NOAA, 1972). In summary, the inventory of the four-story-and-over buildings may be considered to be concentrated at the center of the high-rise district of each of the five cities listed in table 4 with the dollar values directly proportional to the total floor areas given in table 4.

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[2] Source: "A Study of Earthquake Losses in the San Francisco Bay Area," NOAA (1972), table 46, Multistory Building Inventory for Selected Congested Areas.

Table 4.--Multistory building inventory for selected congested areas
[See text for basis and for limitations.
Areas in thousands of square feet]

Construction material by story height	San Francisco		Oakland		San Jose		Berkeley		Palo Alto	
	Number of buildings	Floor area (x1000)	Number of buildings	Floor area (x1000)	Number of buildings	Floor area (x1000)	Number of buildings	Floor area (x1000)	Number of buildings	Floor area (x1000)
Concrete:										
4-8 stories-----	690	31,405	81	6,840	39	2,726	45	3,467	15	1,062
9-13 stories----	81	6,544	17	2,035	8	861	15	651	4	495
14-up stories---	44	10,297	4	1,421	0	0	1	151	1	134
Total---		48,246		10,296		3,587		4,269		1,691
Steel frame:										
4-8 stories-----	439	21,925	52	3,418	7	234	14	674	1	58
9-13 stories----	98	11,880	13	1,455	6	438	1	199	0	0
14-up stories---	68	20,525	8	1,764	0	0	1	19	0	0
Total---		54,330		6,637		672		892		58

For the purposes of this study, the center of the multistory district of each of the five cities listed has been identified in relation to a census tract number as follows:

City	Census tract number
San Francisco	117
Oakland	4029
Berkeley	4229
San Jose	5008
Palo Alto	5113

(2) One to four stories.--The geographic distribution of these structures is quite scattered. They may be located in new industrial parks, in shopping centers, in long-established core mercantile areas, and many others. Mapping becomes quite difficult without field inspections. The distributions used for this class were the same as those used for Class V, subclasses B, C, and D. The methods used to obtain the distribution are similar to that discussed under subclass II-A.

Class V-Mixed construction; subclass V-A.--Dwellings of mixed construction having unit masonry or concrete walls are too few in number in the study area to be specially mapped. On the other hand, it is reasonable to expect that their geographic distribution will be similar to that for wood frame single family dwellings, and the methods used for subclass I-A buildings in the 1969 NOAA/HUD study could be adapted to this purpose. However, the adaptation was not made since the negative cost-benefit would be the same as it was for the 1969 NOAA/HUD study, and it was not done in that study for the same reasons.

Class V-Mixed construction; subclasses V-B, C, and D.--It is normal to find buildings associated with these subclasses located in somewhat restrictive fire zones and in land-use areas related to commercial and industrial activity. This distribution results from the nature of the materials used and the higher than wood frame costs associated with these subclasses.

With an exception discussed in the next paragraph, subclasses V-B, C, and D buildings were considered to be comingled to such a degree that mapping would be reasonably identical among them. These subclasses were also distributed uniformly over the mapped areas which were identified by land-use for commercial and industrial activity. The methods used to obtain the distributions are similar to that discussed in detail under subclass II-A.

Class V-Mixed construction; subclass V-E.--Subclass V-E includes buildings having unreinforced masonry of brick, concrete block, stone, or unreinforced concrete where loads are carried in whole or in part by these walls. Normally this subclass is represented in California by pre-1933 buildings, which are typically found in the old downtown areas or historic centers of the older city cores located in the metropolitan San Francisco Bay area, such as the old downtown areas of San Francisco, Oakland, Richmond, San Jose, Berkeley, and Palo Alto, among others. As the Uniform Building Code no longer permits this subclass of construction in California, such buildings are not found in the tracts developed in recent years, and this has been reflected in the mapping.

There is a heavy concentration of this building type in the congested areas south of Market Street in San Francisco's urban core and old downtown section, and also in the high-density area of Oakland's city center. As a consequence, the results from mapping were increased by a factor of 3 for the mentioned areas in San Francisco and by a factor of 2 for Oakland in order to maintain an appropriately weighted relationship to the other areas. These increases also compensate for the fact that these areas include numerous multistory subclass V-E buildings.

Class V-Mixed construction; subclass V-F.--Buildings of this subclass are quite rare and of small value, and they have not been constructed in the San Francisco area for many decades. They do not warrant special attention in this study.

Class VI-Earthquake resistant construction.--Buildings in this class are structures having special damage control features. Identification requires on-site building inspections and structural analysis by professional engineers. Mapping would therefore require a building-by-building examination, which is clearly beyond the scope and resources budgeted for this study. Accordingly, no mapping has been attempted.

GROUND SHAKING-LOSS RELATIONSHIPS

Introduction and definitions

The estimation of losses resulting from earthquakes requires that relationships be known or developed between the intensity of ground shaking and some measure of the degree of damage to structures by class of construction.

The measure of the intensity of ground shaking used in this study is the Modified Mercalli (MM) intensity scale (Wood and Neumannn, 1931). The scale in its original form may be found in table 5. Limitations of the scale have been discussed in a number of papers (for example Voight and Byerly, 1949; Richter, 1958). The development of building loss-MM intensity scale relationships is discussed in the following sections.

The percent loss is defined here to mean the average percentage of the total actual cash value required to fully repair in kind any building of a particular class experiencing ground motion represented by a particular degree of the MM intensity scale.

Table 5.--Modified Mercalli intensity scale of 1931 (Wood and Neumann, 1931)

I. Not felt--or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt:

I[1] sometimes birds, animals, reported uneasy or disturbed;
R.F. sometimes dizziness or nausea experienced;
sometimes trees, structures, liquids, bodies of water, may sway--doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons.

Also, as in grade I, but often more noticeably:

I sometimes hanging objects may swing, especially when
to delicately suspended;
II sometimes trees, structures, liquids, bodies of water,
R.F. may sway, doors may swing, very slowly;
sometimes birds, animals, reported uneasy or disturbed;
sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases.

III Vibration like that due to passing of light, or lightly
R.F. loaded trucks, or heavy trucks some distance away.
Hanging objects may swing slightly.
Movements may be appreciable on upper levels of tall structures.

Table 5.--Modified Mercalli intensity scale of 1931 (Wood and Neumann, 1931)--Continued

		Rocked standing motor cars slightly.
IV.		Felt indoors by many, outdoors by few.
		Awakened few, especially light sleepers.
		Frightened no one, unless apprehensive from previous experience.
		Vibration like that due to passing of heavy, or heavily loaded trucks.
	IV to V R.F.	Sensation like heavy body striking building, or falling of heavy objects inside.
		Rattling of dishes, windows, doors; glassware and crockery clink and crash.
		Creaking of walls, frame, especially in the upper range of this grade.
		Hanging objects swung, in numerous instances.
		Disturbed liquids in open vessels slightly.
		Rocked standing motor cars noticeably.
V.		Felt indoors by practically all, outdoors by many or most: outdoors direction estimated.
		Awakened many, or most.
		Frightened few--slight excitement, a few ran outdoors.
		Buildings trembled throughout.
		Broke dishes, glassware, to some extent.
	V to VI	Cracked windows--in some cases, but not generally.
		Overturned vases, small or unstable objects, in many instances, with occasional fall.

Table 5.--Modified Mercalli intensity scale of 1931 (Wood and Neumann, 1931)--Continued

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R.F. Hanging objects, doors, swing generally or considerably.
Knocked pictures against walls, or swung them out of place.
Opened, or closed, doors, shutters, abruptly.
Pendulum clocks stopped, started, or ran fast, or slow.
Moved small objects, furnishings, the latter to slight extent.
Spilled liquids in small amounts from well-filled open containers.
Trees, bushes, shaken slightly.

VI. Felt by all, indoors and outdoors.
Frightened many, excitement general, some alarm, many ran outdoors.
Awakened all.
VI Persons made to move unsteadily.
to Trees, bushes, shaken slightly to moderately.
VII Liquid set in strong motion.
R.F. Small bells rang--church, chapel, school, etc.
Damage slight in poorly built buildings.
Fall of plaster in small amount.
Cracked plaster somewhat, especially fine cracks in chimneys in some instances.
Broke dishes, glassware, in considerable quantity, also some windows.

Table 5.--Modified Mercalli intensity scale of 1931 (Wood and Neumann, 1931)--Continued

	Fall of knick-knacks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.
VII.	Frightened all--general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver.
VII-R.F.	Damage negligible in buildings of good design and construction, to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows, furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs).

Table 5.--Modified Mercalli intensity scale of 1931 (Wood and Neumann, 1931)--Continued

	Fall of cornices from towers and high buildings.
	Dislodged bricks and stones.
	Overturned heavy furniture, with damage from breaking.
	Damage considerable to concrete irrigation ditches.
VIII.	Fright general--alarm approaches panic.
	Disturbed persons driving motor cars.
	Trees shaken strongly--branches, trunks, broken off, especially palm trees.
	Ejected sand and mud in small amounts.
	Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters.
	Damage slight in structures (brick) built especially to withstand earthquakes.
VIII+ to IX- R.F.	Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling.
	Fall of walls.
	Cracked, broke, solid stone walls seriously.
	Cracks in wet ground to some extent, also ground on steep slopes.
	Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers.

Table 5.--Modified Mercalli intensity scale of 1931 (Wood and Neumann, 1931)--Continued

---

IX. Panic general.

Cracked ground conspicuously.

Damage considerable in (masonry) structures built especially
to withstand earthquakes: threw out of plumb some wood-
IX+ frame houses built especially to withstand earthquakes;
R.F. great in substantial (masonry) buildings, some collapse in
large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures as much as a meter in width ran parallel to canal and stream banks.

Landslides considerable from river banks and steep coasts.

Shifted sand and mud horizontally on beaches and flat land.

X Changed level of water in wells.

R.F. Threw water on banks of canals, lakes, rivers, etc.

Damage serious to dams, dikes, embankments.

Severe to well-built wooden structures and bridges, some destroyed.

Developed dangerous cracks in excellent brick walls.

Destroyed most masonry and frame structures, also their foundations.

Table 5.--Modified Mercalli intensity scale of 1931 (Wood and Neumann, 1931)--Continued

---

Bent railroad rails slightly.

Tore apart, or crushed endwise, pipe lines buried in earth.

Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material.

Broad fissures, earth slumps, and land slips in soft, wet ground.

Ejected water in large amount charged with sand and mud.

Caused sea-waves ("tidal" waves) of significant magnitude.

Damage severe to wood-frame structures, especially near shock centers.

Great to dams, dikes, embankments, often for long distances.

Few if any (masonry) structures remained standing.

Destroyed large well-built bridges by the wrecking of supporting piers, or pillars.

Affected yielding wooden bridges less.

Bent railroad rails greatly, and thrust them endwise.

Put pipe lines buried in earth completely out of service.

XII. Damage total--practically all works of construction damaged greatly or destroyed.

Disturbances in ground great and varied, numerous shearing cracks.

Table 5.--Modified Mercalli intensity scale of 1931 (Wood and Neumann, 1931)--Continued

---

Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive.

Wrenched loose, tore off, large rock masses.

Fault slips in firm rock, with notable horizontal and vertical offset displacements.

Water channels, surface and underground, disturbed and modified greatly.

Dammed lakes, produced waterfalls, deflected rivers, etc.

Waves seen on ground surfaces (actually seen, probably, in some cases).

Distorted lines of sight and level.

Threw objects upward into the air.

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[1] Refers to equivalent degree of intensity in the Rossi-Forel intensity scale, a scale in common use until 1931.

Past and current insurance practices

As background for the discussion of ground shaking-loss relationships, it is instructive to review briefly the practice of the insurance industry in developing loss evaluation methods or rating methods. While numerous articles have been written on earthquake insurance in the trade press as well as in the scientific literature, few of them discuss in substantive detail the numerical basis for rating methods or loss evaluation methods. Loss ratios have been given by Chick (1934) and Freeman (1932). Loss ratios developed in 1925 to 1927 by what was then the Board of Fire Underwriters of the Pacific on a somewhat different classification system seem to be substantially higher than those given by Chick and Freeman, possibly due to significant differences in definitions. A description of the Board of Fire Underwriters of the Pacific's practices was written by E. W. Bannister (1927) and is worthy of review by anyone interested in this particular subject area.

All of the studies mentioned describe methodologies which are largely valid today; it is the numerical coefficients and judgment values which can be improved upon. Table 6 (modified from Bannister, 1927) represents an excellent apportionment of costs for that period. Bannister (1927) also included a calculation sheet for rating buildings, which was a reasonable working tool for damage evaluation at that time. On the rating sheet given by Bannister there is a column labeled "Percent of Damage," which came from a complicated schedule listing over 50 components, many involving a range of judgmentally derived

Table 6.--Cost percentages of different building types as used in earthquake risk survey (modified from Bannister, 1927)

[R.C., means reinforced-concrete frame; S., means steel frame; leaders (---), not applicable]

Components of structure	Percentages of total cost							
	Office building		Store or loft		Hotel or apartment		Warehouse	
Segregation-------------	R.C.	S.	R.C.	S.	R.C.	S.	R.C.	S.
Foundations-------------	5	5	7	7	5	5	9	9
Structural steel frame--	---	10	---	18	---	10	---	25
Floors and roof---------	---	8	---	15	---	8	---	20
Frame, floor and roof---	18	---	33	---	18	---	45	---
Walls, including exterior ornamentation----	12	12	8	8	10	10	9	9
Partitions--------------	2	2	---	---	4	4	---	---
Trim and finish---------	40	40	24	24	40	40	15	15
Equipment including plumbing, heating, ventilating, electrical work, but excluding elevators---------	13	13	16	16	17	17	10	10
Elevators---------------	10	10	12	12	6	6	12	12
Total--------------	100	100	100	100	100	100	100	100

values. The concept behind this complex schedule remains valid, but the complexity of its implementation probably was unwarranted by the quality of the "credits" and "charges" developed by the schedule. The methodology has been improved by simplifications over the years by the Board's successor organizations (Pacific Fire Rating Bureau and now the Insurance Services Office).

Methodology

The development of the loss-intensity relationships used in this study entailed three steps: (1) examination of loss experience in a number of earthquakes; (2) analysis of existing building cost data; and (3) integration of (1) and (2), using engineering judgment, into loss-intensity relationships. Because of the large number of classes of construction and the many construction components included in non-dwelling classes, the present attempt to develop loss-ground shaking relationships must be considered as only a first pilot effort.

(1) Actual loss experience:

Actual loss experience may exist in published or unpublished forms. Much of the useful loss data known has been published. However, substantial amounts of insurance data exist which cannot be easily related to classes of construction or for other reasons are not applicable.

One may cite hundreds of published studies wherein some sort of damage estimate exists for a given intensity. This is particularly true for nonreinforced unit masonry and other non-earthquake-resistive kinds of traditional construction. Unfortunately, these traditional construction types are not relevant with respect to new earthquake-resistive construction in California. Additionally, they are of decreasing importance in the evaluation of the older construction types usually found in the long-established city core areas since these older structures are decreasing in number due to redevelopment.

The most useful published sources are therefore found in the studies of the most recent earthquakes, although data extending back to the 1906 San Francisco shock still have substantial value. However, a review of a number of publications showed that the damage data are not usually compatible. Further, a more detailed review of all major sources shows that data are far from complete for all intensities for all building classes. It then follows that interpolation and judgment must be used with the known published record of actual losses to produce loss values.

(2) <u>Analysis of existing building cost data</u>

As examples, tables 7, 8, and 9 show summaries of data collected on the distribution of costs by construction component for construction classes III, IV, and V. These tables are principally applicable to current (1975) earthquake-resistive construction in California, except for the unreinforced brick walls in table 9. Tables 7, 8, and 9 do not include (a) all construction variants (such as walls of glass, metal, and precast concrete); (b) all occupancy variants (such as garages, mixed office-habitational, entertainment, and restaurants); (c) consequences of all zoning variants (such as building setback as a function of height, on-site parking); (d) all site conditions (such as difficult waterfront soil conditions or steep hillsides), and (e) all climatic conditions (as the need to insulate for temperature extremes not found along the California coastline). Future work requires the quality improvement of tables 7, 8, and 9, as well as the extension of these tables to include all significant variants. Unfortunately, from a cost standpoint as it applies to a study such as this, the variants within each building class are far more numerous than for dwellings--the class of construction considered in previous studies. The variations in the cost percentages among the construction components for any particular class suggest that only very approximate loss estimates are possible when applying loss averages to any specific structure.

Table 7.--Generalized cost breakdowns for selected types within class II-steel frame buildings

[25 ft-0 in. x 25 ft-0 in. bays, W18x96 primary beams, W16x31 secondary beams, 3 in. concrete fill on 1 1/2 in. ribbed 26 ga. metal deck. All tabular values in percent. Abbreviations are the following: Mfg./whse.-manufacturing plant or warehouse with minimum partitions and plain exterior; Merc.-mercantile with moderate number of partitions and average ornamentation; Habit.-habitational, as hotels, apartment buildings, and condominiums; Off.-office building. Leaders (---) indicate a very low percentage]

Construction component	1 through 3 stories				4 through 8 stories				Over 8 stories			
	Mfg./ whse.	Merc.	Habit.	Off.	Mfg./ whse.	Merc.	Habit.	Off.	Mfg./ whse.	Merc.	Habit.	Off.
General conditions[1]	3.9	3.2	4.4	3.9	3.8	2.9	3.5	4.1	3.7	2.5	2.7	5.0
Site work[2]	3.2	2.6	1.8	6.9	3.1	2.3	1.1	6.4	3.0	2.0	0.5	6.0
Concrete work	14.2	11.8	16.2	10.7	15.5	11.6	16.2	9.8	16.4	10.9	15.9	10.0
Masonry	4.9	3.3	----	----	4.0	3.0	----	---	3.8	2.6	----	----
Structural steel	29.0	24.0	19.8	17.7	29.0	21.6	17.7	15.8	31.2	20.8	17.5	15.6
Moisture protection	7.5	6.2	2.8	1.3	2.1	1.6	1.4	1.0	0.9	0.6	0.4	0.7
Doors, windows, glass[3]	1.2	1.0	10.6	18.5	1.2	0.9	8.3	17.8	1.2	0.8	6.4	17.2
Finishes[4]	5.3	17.0	13.7	8.9	5.3	20.7	16.9	10.5	5.0	22.6	19.0	12.0
Specialties[5]	1.0	0.8	1.9	2.3	1.0	0.7	1.7	1.3	1.0	0.6	1.5	0.3
Equipment[6]	1.8	1.5	0.8	---	1.8	1.3	1.6	---	1.7	1.0	2.1	---
Furnishings[7]	---	---	2.3	---	---	---	2.1	---	---	---	1.8	---
Special construction[8]	---	---	0.3	---	---	---	0.2	---	---	---	0.1	---
Conveying systems[9]	---	---	1.8	4.8	---	---	2.0	7.1	---	---	2.0	7.0
Mechanical	20.4	18.1	14.9	16.9	20.2	21.0	17.3	16.6	19.4	22.4	18.9	16.2
Electrical	8.5	10.5	8.7	8.1	13.0	12.4	10.0	9.6	12.7	13.2	11.2	10.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Includes contractor's site facilities, job equipment, and job supervision, but excludes home office expense.
[2] Includes excavation.
[3] Includes curtain walls where applicable.
[4] Includes partitions (lath and plaster or gypsum drywall), fireproofing, as well as floor, ceiling, and wall finishes.
[5] Includes items such as fire extinguishers, metal toilet partitions, door signs, and bulletin boards.
[6] Includes items such as pneumatic tubes, show, and display cases, and signal systems.
[7] Carpets and drapes in habitational structures only.
[8] Includes items such as swimming pools, saunas, and built-in refrigerated rooms.
[9] Includes elevators and window washing equipment.

Table 8.--Generalized cost breakdowns for selected types within Class IV-reinforced concrete buildings

[25 ft-0 in x 25 ft-0 in bays, concrete pan joist system. All tabular values in percent. Mfg./whse.-Manufacturing plant or warehouse with minimum partitions and plain exterior. Merc.-Mercantile with moderate number of partitions and average ornamentation. Habit.-Habitation, as hotels, apartment buildings, and condominiums. Off.-Office building. Leaders (---) indicate a very low percentage]

Construction component	1 through 3 stories				4 through 8 stories				Over 8 stories			
	Mfg./ whse.	Merc.	Habit.	Off.	Mfg./ whse.	Merc.	Habit.	Off.	Mfg./ whse.	Merc.	Habit.	Off.
General conditions[1]	3.9	3.2	4.5	3.9	3.9	2.8	3.5	4.1	3.8	2.4	2.7	5.0
Site work[2]	3.2	2.6	1.8	6.9	3.2	2.3	1.1	6.4	3.1	2.0	0.6	6.0
Concrete work	37.6	31.2	31.9	24.8	42.2	30.2	30.4	22.4	45.0	28.8	30.3	22.8
Masonry	4.0	3.3	---	---	4.1	2.9	---	---	4.0	2.5	---	---
Structural steel	5.6	4.6	3.8	3.4	5.6	4.0	3.4	3.0	5.5	3.5	3.0	2.6
Moisture protection	7.5	6.2	2.8	1.3	2.2	1.5	1.4	1.0	0.9	0.5	0.4	0.7
Doors, windows, glass[3]	1.2	1.0	10.6	18.5	1.3	0.9	8.3	17.8	1.2	0.8	6.4	17.1
Finishes[4]	5.3	17.0	14.0	8.9	5.4	20.4	17.0	10.5	5.2	22.4	19.0	12.1
Specialties[5]	1.0	0.8	1.9	2.3	1.0	0.7	1.7	1.4	1.0	0.6	1.5	0.3
Equipment[6]	1.8	1.5	0.8	---	1.8	1.3	1.6	---	1.8	1.2	2.1	---
Furnishings[7]	---	---	2.3	---	---	---	2.1	---	---	---	1.8	---
Special construction[8]	---	---	0.3	---	---	---	0.2	---	---	---	0.1	---
Conveying systems[9]	---	---	1.8	4.8	---	---	2.0	7.2	---	---	2.0	7.0
Mechanical	20.4	18.1	14.8	17.0	20.7	20.8	17.3	16.6	20.1	22.3	18.9	16.2
Electrical	8.5	10.5	8.7	8.2	8.6	12.2	10.0	9.6	8.4	13.0	11.2	10.2
Total building cost	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Includes contractor's site facilities, job equipment, and job supervision, but excludes home office expense.
[2] Includes excavation.
[3] Includes curtain walls where applicable.
[4] Includes partitions (lath and plaster or gypsum drywall), fireproofing, as well as floor, ceiling, and wall finishes.
[5] Includes items such as fire extinguishers, metal toilet partitions, door signs, and bulletin boards.
[6] Includes items such as pneumatic tubes, show and display cases, and signal systems.
[7] Carpets and drapes in habitational structures only.
[8] Includes items such as swimming pools, saunas, and built-in refrigerated rooms.
[9] Includes elevators and window washing equipment.

Table 9.--Generalized cost breakdowns for selected types within Class V-mixed construction buildings

[Data for one-story structures. Floor area, partitions, and air conditioning as listed. Walls as listed and as described in footnotes. Roof is plywood diaphragm on wood joist on 16 in. x 30 in. glulam beams. All tabular values in percent. AC-air conditioning. Pt.-partitions. Num. Pt.-numerous partitions. Leaders (---) indicate a very low percentage]

Construction component	Tilt-up walls[1]				Reinf. hollow conc. block walls[2]				Reinforced brick[3]				Nonreinforced brick[4]			
	100 ft x 200 ft		150 ft x 250 ft		100 ft x 200 ft		150 ft x 250 ft		100 ft x 200 ft		150 ft x 250 ft		100 ft x 200 ft		150 ft x 250 ft	
	No AC No pt.	AC Num. pt.	No AC No pt.	AC Num. pt.	No AC No pt.	AC Num. pt.	No AC No pt.	AC Num. pt.	No AC No pt.	AC Num. pt.	No AC No pt.	AC Num. pt.	No AC No pt.	AC Num. pt.	No AC No pt.	AC Num. pt.
General conditions[5]---	4.4	3.4	4.5	3.5	4.2	3.3	4.4	3.4	3.9	3.1	4.1	3.2	4.0	3.1	4.2	3.3
Site work[6]------------	3.6	2.8	3.7	2.8	3.4	2.7	3.6	2.8	3.2	2.5	3.4	2.6	3.3	2.6	3.4	2.7
Concrete work---------	20.7	16.0	19.4	14.8	13.8	10.7	14.3	11.0	12.7	10.1	13.5	10.5	13.1	10.3	13.8	10.7
Masonry---------------	---	---	---	---	10.1	7.9	7.3	5.7	16.9	13.3	12.7	9.9	14.6	11.4	10.9	8.5
Rough carpentry-------	17.3	13.3	17.8	13.6	16.6	12.9	17.3	13.3	15.4	12.2	16.3	12.8	15.8	12.4	16.6	12.9
Moisture protection---	8.5	6.5	8.7	6.7	8.2	6.3	8.5	6.5	7.5	6.0	8.0	6.2	7.8	6.1	8.2	6.3
Doors, windows glass[7]--------------	3.0	2.3	2.2	1.7	2.9	2.2	2.1	1.6	2.6	2.1	2.0	1.6	2.7	2.1	2.0	1.6
Finishes[8]-------------	6.0	17.9	6.2	18.3	5.8	17.4	6.0	17.9	5.4	16.3	5.7	17.2	5.5	16.7	5.8	17.4
Specialties[9]----------	1.2	0.9	1.2	0.9	1.1	0.8	1.1	0.9	1.0	0.8	1.1	0.8	1.0	0.8	1.1	0.8
Equipment[10]-----------	2.0	1.6	2.1	1.6	1.9	1.5	2.0	1.6	1.8	1.4	1.9	1.5	1.8	1.5	2.0	1.5
Mechanical[11]----------	23.6	24.2	24.3	24.8	22.7	23.5	23.6	24.2	21.0	22.1	22.2	23.1	21.6	22.6	22.7	23.5
Electrical------------	9.7	11.1	9.9	11.3	9.3	10.8	9.7	11.1	8.6	10.1	9.1	10.6	8.8	10.4	9.3	10.8
Total building cost	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Walls 7.5 in. thick and 20 ft high.

[2] Walls 8 in. thick and 20 ft high.

[3] Walls 10 in. thick and 20 ft high. 2 ea. 4 in. brick w/2 in reinforcing space.

[4] Walls 8 in. thick and 20 ft high. Not reinforced and not earthquake resistive. (Typical of pre-1933 construction.)

[5] Includes contractor's site facilities, job equipment, and job supervision, but excludes home office expense.

[6] Includes excavation.

[7] Includes curtain wall where applicable.

[8] Includes partitions (lath and plaster or gypsum drywall), fireproofing, as well as floor, ceiling, and wall finishes.

[9] Includes items such as fire extinguishers, metal toilet partitions, door signs, and bulletin boards.

[10] Includes items such as pneumatic tubes, show and display cases, and signal systems.

[11] Air conditioning is minimal when included, being simple systems commonly used in northern coastal California.

(3) Loss-intensity relationships

The development of loss-intensity relationships, as previously pointed out, requires the integration of actual earthquake loss experience with current cost data. It also requires the interpretation of earthquake loss data and its relation to each class of construction in terms of the Modified Mercalli intensity (MM) scale.

The most important element in the development of loss-intensity relationships is the interpretation of actual loss experience (and construction component costs) in terms of the degrees of the MM scale. This means analysis of losses with relationship to MM intensity maps (isoseismal maps) prepared for recent earthquakes. This step essentially amounts to a more definitive description of losses at each intensity level than exist in the original MM scale. In this sense, development of loss-intensity relationships for the various construction classes represents a further definition or refinement of the MM scale based on an analysis of loss experience and cost. It is believed that, at the present time, MM intensity maps together with the damage-intensity relationships developed are the best basis for this kind of study when used with experienced judgment. Indeed, it is the only basis for which extensive data are available.

The MM intensities are one kind of a summary record of what happened in an earthquake. Additional basic observed engineering loss data can be used as backup material. In any study of this type, "what actually happened" far outweighs a theoretical model which describes "what might have happened," if there are any discrepancies between results. Restated, actuality (as represented by observed effects) is the basis for these studies.

A review of the Modified Mercalli scale shows that the lower intensities are based principally on human reactions, such as "felt indoors by few," since other effects, such as damage, are minimal. The highest effects are largely measured by geological effects, such as broad fissures in wet ground, numerous and extensive landslides, and major surface faulting. The middle intensity range is based largely on the degree of damage to buildings and other manmade structures. For analysis purposes, the lower intensity limit is the threshold of damage, with this threshold varying with the kind of building as well as the kind of ground motion. The threshold normally includes "imaginary" damage which may decrease the actual lower limit by one intensity unit. By "imaginary" damage is meant damage which the owner/occupant believes occurred during the shock, but which was actually in existence before the earthquake. The upper intensity limit is determined by that intensity where ground vibration effects to buildings are overshadowed by geologic effects such as landsliding, faulting, and failures of structurally poor ground. This upper limit is normally given as MM intensity IX for insurance practice. The cutoff at IX is somewhat arbitrary since vibrational effects on buildings will increase with increasing intensity, but become overshadowed by building damage due to faulting, and so forth.

Figure 9 shows some characteristic loss patterns for selected building classes. Consider curve nos. 1 and 2 in figure 9 which show the characteristic damage patterns for certain kinds of flexible-frame multistory buildings. Both buildings are considered to be equally earthquake resistive from a design standpoint, with certain nonstructural elements being the only construction variable. The lower loss vs. intensity values are represented by a flattened curved line to represent, in part, "imaginary" losses. If the largest loss is less than 100 percent (such as, no collapse), then the curve flattens out at the top. In this case, the curve flattens, since increasing nonstructural damage no longer requires proportionate repair costs; for example, patching and painting may cost little more for the repair of a badly cracked wall as compared with a less severely cracked wall.

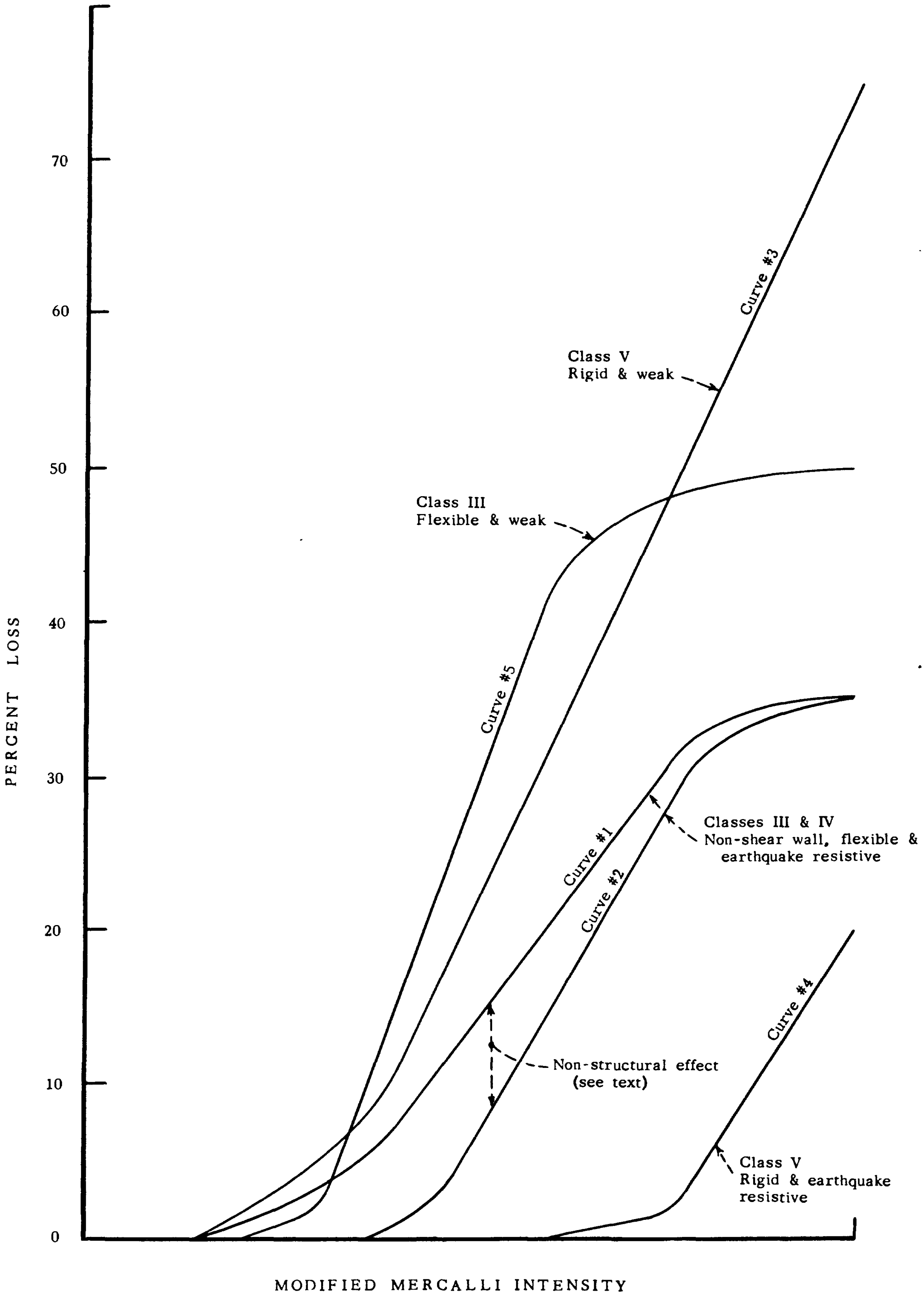

Figure 9.--Characteristic loss M.M. intensity patterns for selected building classes.

A possible effect of occupancy can be seen by comparing curve nos. 1 and 2 in figure 9. A warehouse or manufacturing structure might have a minimal number of partitions (curve no. 2) whereas a hotel would have numerous partitions (curve no. 1). The vertical spread between the curves represents the difference in loss due to occupancy-related construction. Significant exceptions may exist to this vertical spread between curves. For example, if the partitions are of a high value type which are subject to little damage prior to building collapse, then the two curves may essentially coincide. It should be added that these two curves are principally applicable to Class II and Class IV structures which do not have shear walls.

Curve nos. 3 and 4 in figure 9 have the characteristic shapes for loss to rigid unit masonry buildings, and these curves are generally applicable to Class V structures as well as to some Class III and IV buildings. The beginning of the curves at low loss levels represents hairline cracks at partition-masonry wall intersections and similar kinds of minor damage. The steepness of the straight line represents brittle failure of the walls and/or roof-to-wall connections. Actually, for a specific building, the straight line could be replaced by a jagged line, since loss would really be a series of step functions, with each step representing another brittle failure. Numerous acceptable variants exist.

Curve no. 5 is representative of an older steel frame multistory building which is not expected to collapse despite heavy damage. For the lower intensities, it is quite possible that the steel frame building may have significantly more damage than a "collapse hazard" unreinforced brick bearing wall structure with lime mortar, but the pattern would reverse at higher intensities.

The pilot nature of this study precluded the determination of the shape of the characteristic intensity-loss curves to the degree shown in figure 9. As usable approximations, linear relationships were developed as given in figure 10. The lower and upper intensity limits were determined by one of the authors (K. V. Steinbrugge) with the advice of consultants, and are based on the data and engineering judgments previously discussed. In figure 10, percent losses from 0 percent to 10 percent have been estimated to the nearest 1 percent. Percent losses above 10 percent are estimated to the nearest 5 percent.

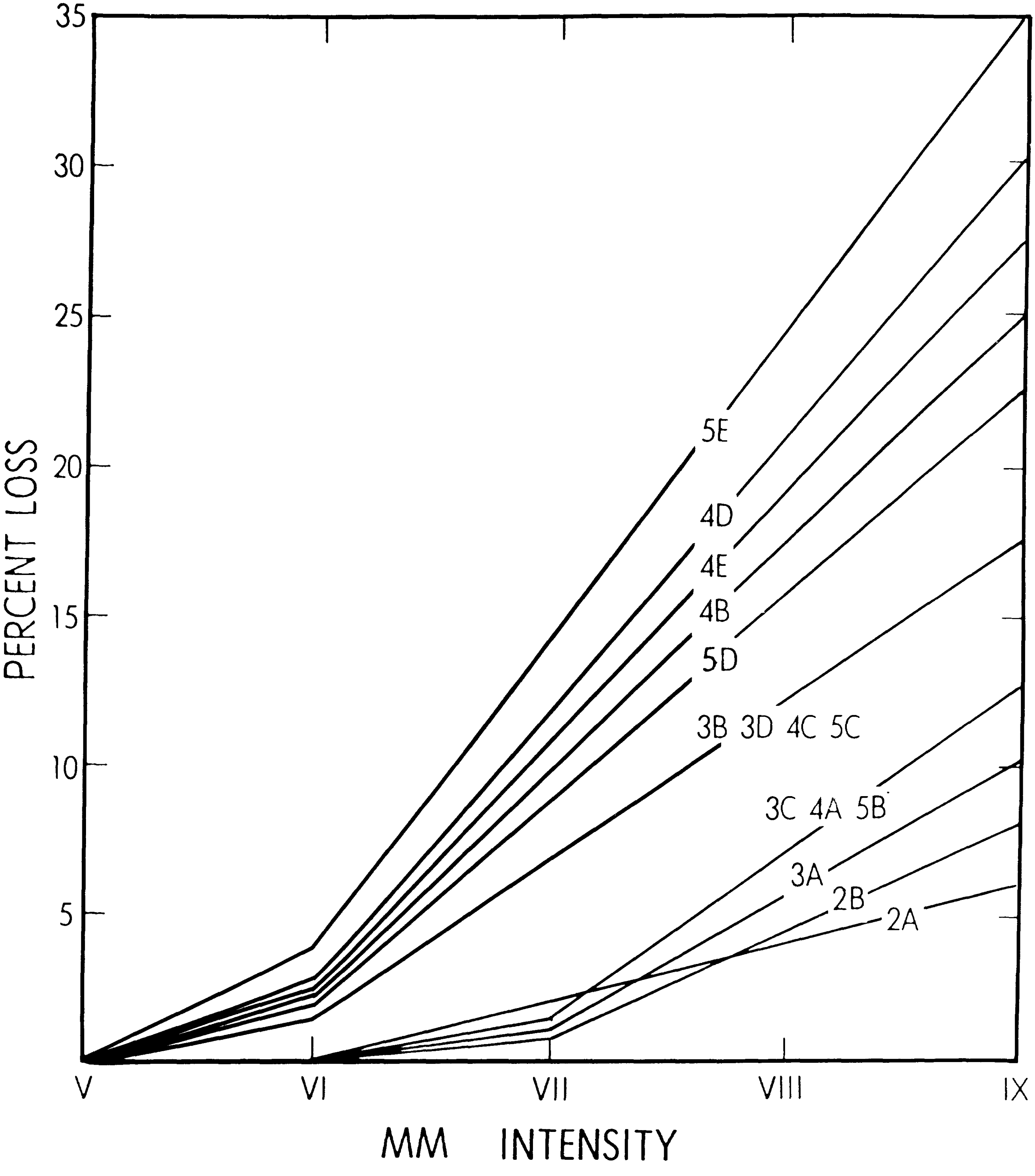

Figure 10.--Modified Mercalli intensity--loss relationship (by class of construction) used in this study. Descriptions of the various calsses may be found in tables 1 and 10.

LOSS CALCULATIONS

Objective

The objective of the loss calculations is to estimate the percent losses* to 24 subclasses of construction (in five classes) for: (1) a repetition of the historical record of seismicity in the nine bay-area counties, and (2) certain selected earthquakes affecting the same area. The notation used to identify building subclasses in loss tables and figures is given in table 10.

General description of the calculations

The principal steps in the loss calculations are:

(1) Establish MM intensity in each census tract in the study area resulting from all known earthquakes 1800-1974 with $I_o \geq V$ affecting the study area.

(2) Calculate losses* in each census tract by class of construction using intensity-loss relationships (fig. 10) and inventory of buildings in each census tract.

(3) Calculate (a) average percentage of monetary loss for each construction class in each county of the study area based on the geographic distribution of the building inventory as described on pages 28 through 42; (b) same as foregoing, except for entire study area; and (c) calculate (a) and (b) above for selected earthquakes and for various time spans using the known historical seismicity.

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*Defined on p. 43.

Table 10.--Notation used to identify building classes and brief description of building classes

Notation used in loss tables	Brief description of building subclass (see p. 12-25 for complete description)
2A	One story all metal; floor area less than 20,000 ft^2
2B	All metal buildings not under 2A
3LA	Steel frame, superior damage control features; less than 4 stories
3LB	Steel frame; ordinary damage control features; less than 4 stories
3LC	Steel frame; intermediate damage control features (between 3LA and 3LB); less than 4 stories
3LD	Floors and roofs not concrete; less than 4 stories
3HA 3HB 3HC 3HD	Descriptions of 3HA, 3HB, 3HC, and 3HD are the same as 3LA, 3LB, 3LC, and 3LD except that they designate buildings with 4 stories and over
4LA	Reinforced concrete; superior damage control features; less than 4 stories
4LB	Reinforced concrete; ordinary damage control features, less than 4 stories
4LC	Reinforced concrete; intermediate damage control features (between 4LA and 4LB), less than 4 stories
4LD	Precast reinforced concrete, lift slab, less than 4 stories
4LE	Floors and roofs not concrete, less than 4 stories
4HA 4HB 4HC 4HD 4HE	Descriptions of 4HA, 4HB, 4HC, 4HD, and 4HE are the same as 4LA, 4LB, 4LC, 4LD, and 4LE except that they designate buildings with 4 stories and over

Table 10.--Notation used to identify building classes and brief description of building classes--Continued

Notation used in loss tables	Brief description of building subclass (see p. 12-25 for complete description)
5B	Mixed construction, see table 1
5C	Do.
5D	Do.
5E	Do.

Steps and assumptions in the calculations

The previous description is brief and gives the general approach used to simulate losses to various classes of construction. The loss computations depend on a number of assumptions and techniques that will now be discussed.

Step 1

Intensities are assigned to all census tracts for all earthquakes of interest. Two techniques were used to assign intensities to census tracts. For earthquakes $VI \leq I_o \leq VIII$, average isoseismal maps were used. For earthquakes $I_o > VIII$, isoseismal maps were constructed which are based on special studies (Algermissen, Rinehart, Dewey, and others, 1972). Figure 11 is an example of an isoseismal map developed for a maximum intensity IX earthquake located on the San Andreas fault. The average isoseismal maps (for earthquakes $VI \leq I_o \leq VIII$) were constructed in the following manner:

A. The average areas shaken at each intensity level were determined for earthquakes in the San Francisco Bay area for which isoseismal maps are available. The same general approach was used in an earlier study of single family dwellings (Algermissen and others, 1969; Steinbrugge and others, 1969), and all of the intensity data used earlier was used together with additional new material.

B. Isoseismal patterns were considered to be elongated in the direction of faulting. This is true in the San Francisco Bay area because earthquakes are shallow

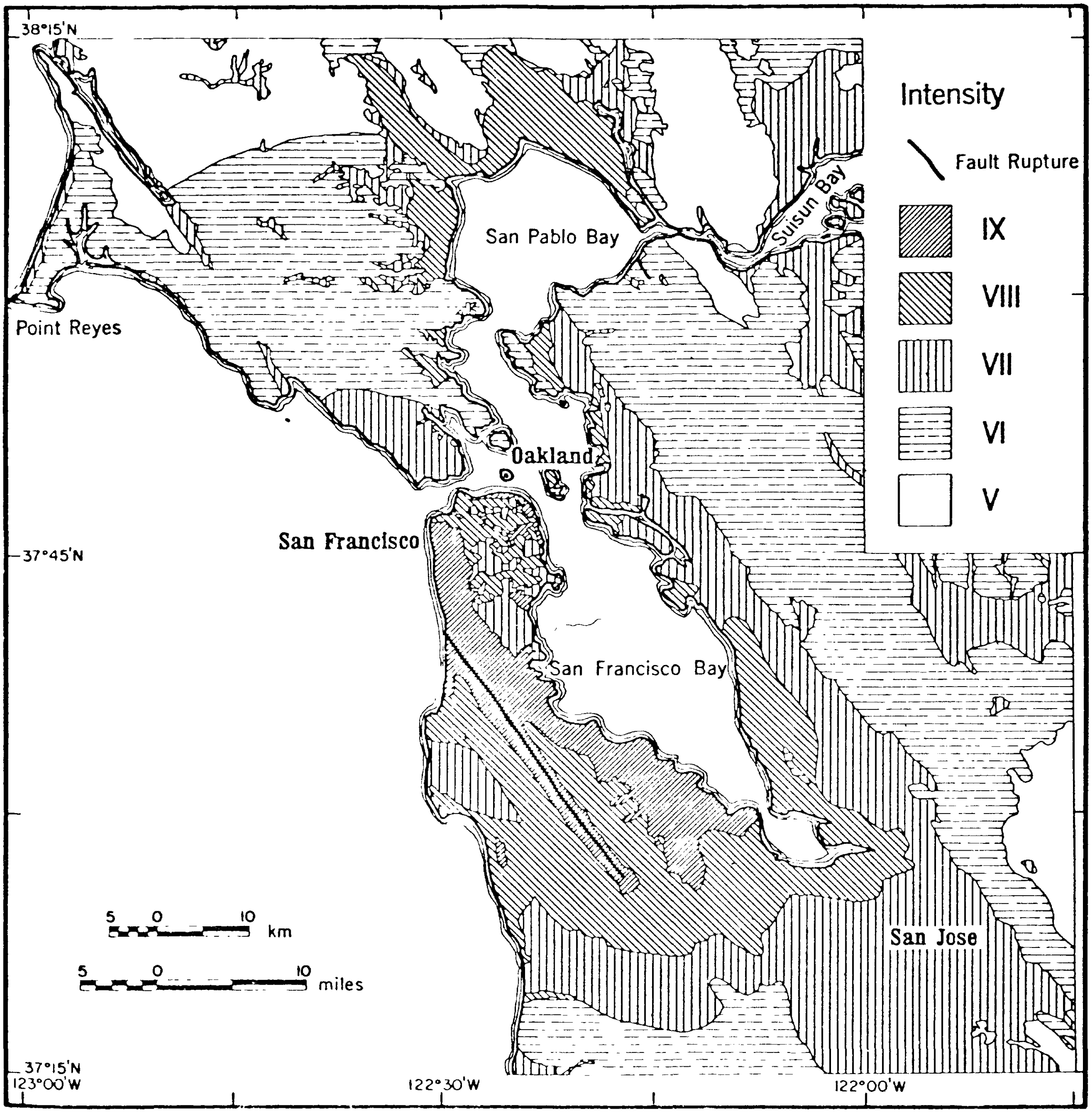

Figure 11.--Isoseismal map for a maximum intensity IX earthquake on the San Andreas fault.

(<15 km) and strike-slip faulting predominates, at least in the larger earthquakes of most interest to this study.

C. Using $M_L=1+2/3\ I_o$ where I_o is the maximum MM intensity and M_L is the original Richter magnitude and the relationship $\text{Log } L=-0.39+0.34\ M_L$ where L is in km (developed for length of fault rupture vs. earthquake magnitude for strike slip faults (Algermissen and others, 1969)), the shapes of average isoseismal maps were constructed using:

$$A_{I_o}=2W_{I_o}L+\pi W^2_{I_o} \qquad \text{(see fig. 12)}$$

where A_{I_o}=area of maximum intensity

L=length of faulting determined from a fault rupture length-magnitude relationship

W_{I_o}=width of the zone of maximum intensity

for any intensity I

$$A_I=2W_IL+\pi W^2_I$$

where A_I=area of any intensity I plus higher intensities up to $I=I_o$

W_I= width of zone of any intensity I plus higher intensities up to $I=I_o$.

D. The orientation of the isoseismals (the strike of L in fig. 12) for any particular historical earthquake was taken to be the same as the strike of faulting in the San Francisco Bay area near the earthquake epicenter known to have been active at least during or since

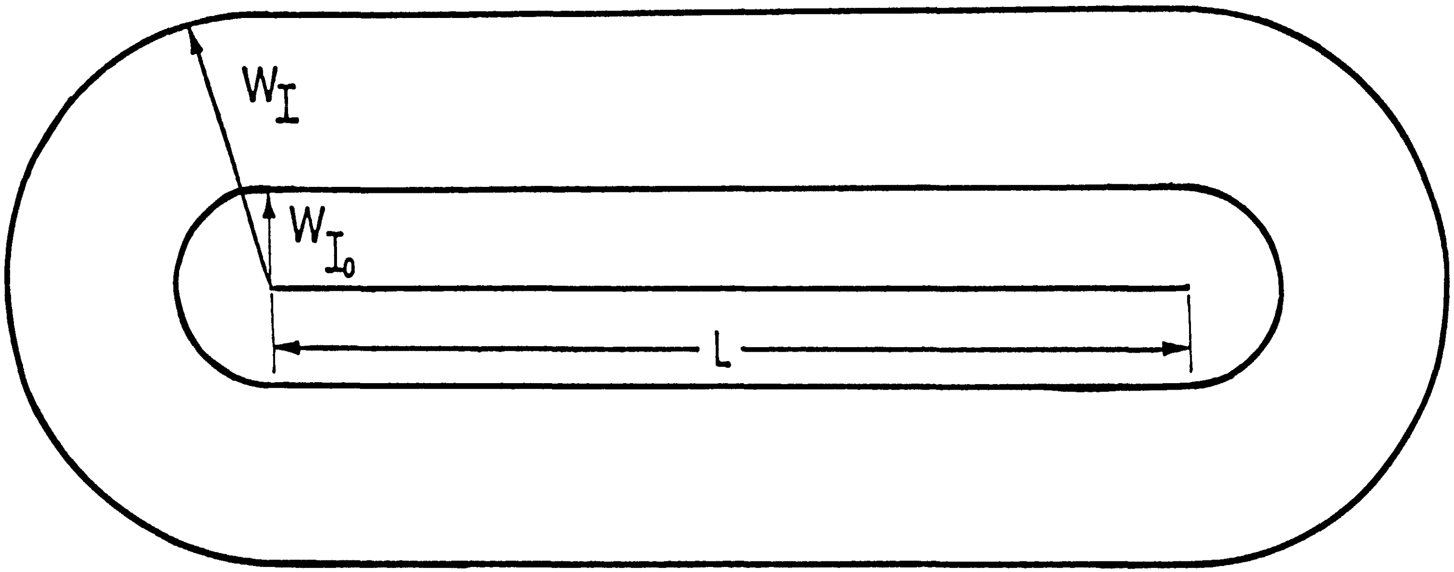

Figure 12.--Schematic showing the construction of average isoseismal maps (see text for discussion).

Quaternary time (Wesson and others, 1975; also see fig. 13). The strike of L was taken parallel to the strike of the known faulting if the earthquake epicenter was within 10 km of the fault. Earthquakes that could not be associated with specific faults were assumed to have circular isoseismals. Table 11 gives the values of W (see fig. 12) and L for elongated isoseismals and the radius R for circular isoseismals for all intensities associated with earthquakes of maximum intensity VI through VIII.

E. The isoseismals constructed for earthquakes I_0=VI to VIII obviously average the effects of surficial materials over broad areas. Consequently the intensity of shaking at individual sites may differ considerably from the average intensity map. The effect of site geology was taken into account by digitizing and storing on magnetic tape the average surficial geology of each census-tract in the study area. Surficial geology was divided into five classes as shown in table 12, and the incremental intensities +1, 0, -1 were either added to or subtracted from the intensity determined for the census tract using the average isoseismal map previously described. An argument can be made that the site corrections should be different, probably larger, perhaps in the range +2 to -2 degrees of intensity. It should be kept in mind that the

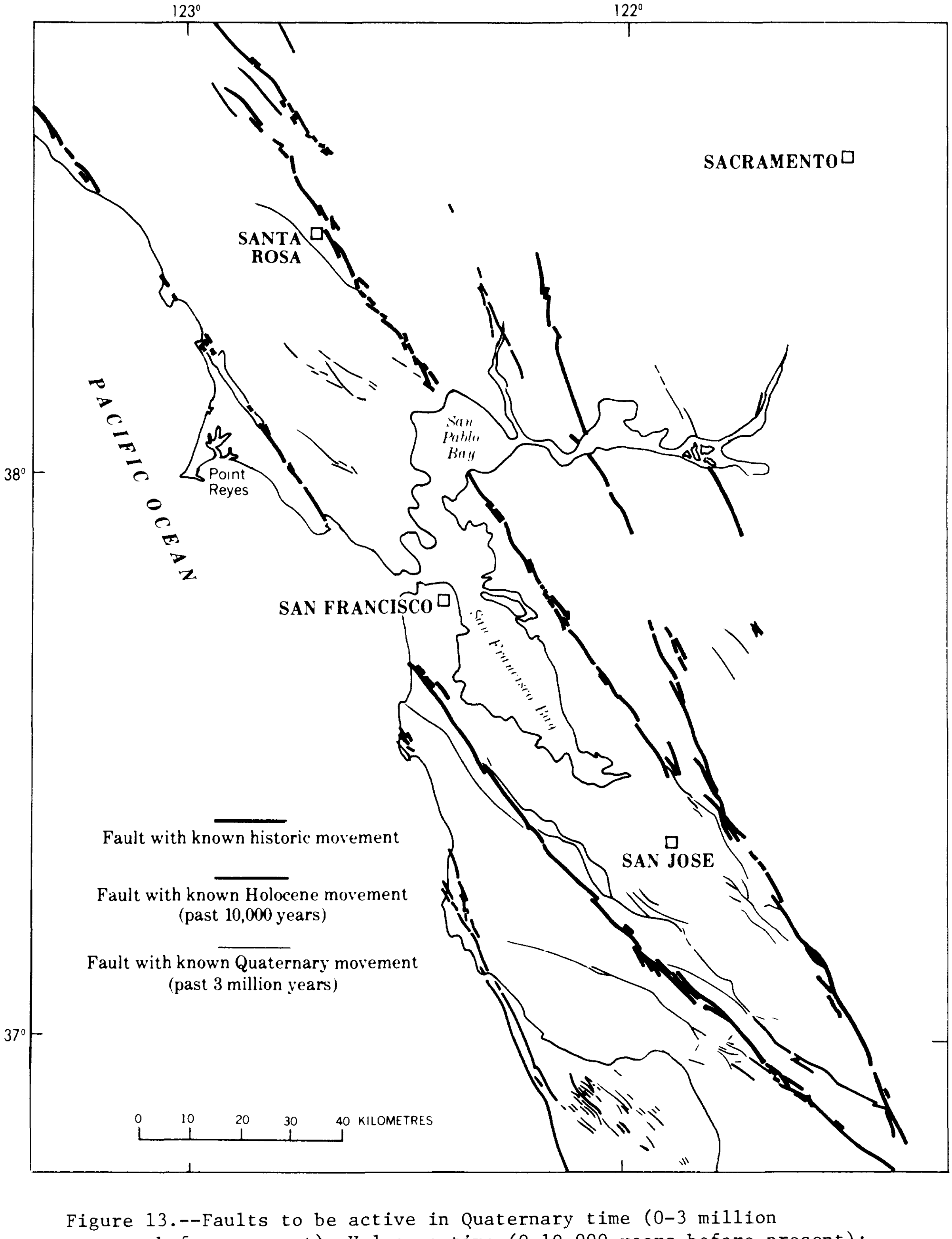

Figure 13.--Faults to be active in Quaternary time (0-3 million years before present); Holocene time (0-10,000 years before present); or during historic time (past 150 years) after Wesson and others (1975).

Table 11.--Parameters for construction of average isoseismals for $VI \leq I_0 \leq VIII$

Maximum intensity I_0	Associated intensities I	Fault length L (km)	Width[1] W (km)	Radius[2] R (km)
VIII		58	2.30	8.00
	VII		5.90	15.55
	VI		17.54	30.90
VII		35	3.17	8.92
	VI		9.98	17.84
VI		20	3.95	8.18

[1] The widths (W) and radii (R) given are to the outer limit of each intensity.

[2] The radius (R) is for the circular isoseismals, which are assigned to earthquakes not associated with specific faults.

Table 12.--Site amplifications and classification of surficial materials

Material	Intensity increment
Alluvium	1
Tertiary marine sediments	0
Pre-Tertiary marine and nonmarine sediments	0
Franciscan Formation	-1
Igneous rocks	-1

correlation between intensity and surficial geology (defined as a mappable geologic unit) is not particularly high because ground shaking depends on a number of factors other than the lithologic and gross physical characteristics used to define geologic formations. Additional perturbation of the average isoseismal maps to account for local site amplification was not considered to be particularly useful. At any rate, losses to structures were computed using isoseismal maps with site corrections. The isoseismal maps for larger earthquakes (I_o=IX and X) on the San Andreas and Hayward faults included the effect of the site geology as estimated from special studies (Algermissen and others, 1972).

Step 2

Intensities for specific earthquakes are assigned to each census tract in the study area. The input to the computer program for earthquakes with maximum intensities VI through VIII was the location of the earthquake, its maximum intensity, the fault system to which the earthquake was assigned, the coordinates of the center of population of each census tract, the surficial geology of each census tract. The computer assigns an intensity to every census tract for each earthquake including corrections for surficial geology.

For earthquakes with maximum intensities of IX and X, intensities were assigned manually to all census tracts.

Step 3

Percent losses for each year are computed and stored on magnetic disk. The percent losses are computed using the intensities for each census tract, the loss curves shown in figure 10, and the inventory of buildings in each census tract.

Step 4

The result of this step is a data set that contains tables for each year that an earthquake occurred. Each table contains the losses in each building subclass for all nine counties. This step in the analysis permits examination of the losses in any given year and the contribution of any particular year to total losses over various periods of time.

Step 5

A final group of computer programs uses the data set from Step 4 to compute average percent losses for a wide range of earthquake input data. Examples are average yearly percent losses based on earthquake input data from 1 to 175 years in yearly increments, and moving yearly average losses based on 5 to 15 year samples of earthquake data. These results are discussed in the following section.

LOSS ESTIMATES

Introduction

All percent losses were computed using the historical record of earthquakes from 1800 through 1974 with maximum Modified Mercalli intensities VI-X in the nine-county study area. A list of these earthquakes may be found in table 13.

Average Annual Percent Losses

Average percent losses per year for the 24 building subclasses were computed using four different time spans of seismicity:

(1) 1800-1974 (175-year average)

(2) 1800-1899 (100-year average)

(3) 1900-1974 (75-year average)

(4) 1907-1974 (68-year average)

Table 13.--Earthquakes with maximum Modified Mercalli intensities greater than V in the nine-county study area (1800-1974 inclusive)

Year	°N. lat.	°W. long.	I_o	Year	°N. lat.	°W. long.	I_o
1800	36.9	121.6	7	1888	38.2	122.7	7
1808	38.0	122.3	7	1888	37.8	122.2	7
1829	37.8	122.6	6	1888	37.3	121.6	6
1836	38.0	122.3	9	1889	37.7	121.9	7
1838	37.7	122.5	9	1889	38.0	122.1	7
1840	38.0	122.1	8	1890	36.9	121.7	7
1851	37.5	122.5	6	1891	38.5	122.5	7
1852	37.5	122.5	7	1891	37.5	122.5	6
1855	37.5	122.5	7	1892	38.5	122.5	9
1856	37.5	122.5	7	1892	38.5	122.5	9
1856	37.8	122.6	6	1892	37.3	121.6	6
1858	37.2	121.7	7	1893	38.5	122.5	7
1859	37.8	122.6	6	1897	37.0	121.5	8
1861	37.7	121.9	8	1898	38.0	122.1	7
1864	37.8	122.6	6	1899	36.9	121.8	7
1865	38.5	122.5	7	1899	38.5	122.5	7
1865	37.1	121.9	9	1899	36.8	121.9	6
1868	37.8	122.2	9	1899	37.5	122.5	6
1876	38.4	123.1	6	1902	38.5	122.0	7
1881	38.0	121.0	7	1903	37.7	121.9	7
1882	36.8	121.4	6	1903	37.7	121.9	7
1883	37.0	121.5	6	1906	38.1	122.8	10
1885	36.5	121.0	7	1911	37.2	121.7	8
1885	39.0	123.0	6	1911	36.8	121.4	6

Table 13.--Earthquakes with maximum Modified Mercalli intensities greater than V in the nine-county study area (1800-1974 inclusive)--Continued

Year	°N. lat.	°W. long.	I_o	Year	°N. lat.	°W. long.	I_o
1914	37.1	121.9	7	1948	37.4	121.8	6
1915	37.7	121.9	6	1948	36.7	121.3	6
1916	36.5	121.0	7	1949	36.9	121.6	7
1924	36.7	121.6	6	1949	37.0	121.5	7
1927	37.3	121.8	6	1949	37.0	121.5	6
1927	37.1	121.9	6	1949	37.3	121.7	6
1937	37.8	122.2	7	1949	37.9	122.3	6
1939	36.8	121.4	7	1951	37.7	122.1	6
1941	37.1	121.9	6	1951	36.6	121.2	6
1941	36.8	121.8	6	1951	36.6	121.2	6
1942	37.7	122.1	6	1951	36.9	121.6	6
1943	37.4	121.7	6	1951	37.9	122.3	6
1943	37.7	122.2	6	1953	36.9	121.7	6
1944	37.8	122.0	6	1953	39.3	123.3	6
1945	36.8	121.4	6	1954	36.9	121.7	8
1945	36.6	121.3	6	1954	37.7	122.1	6
1945	37.2	121.8	6	1954	36.9	121.7	6
1946	37.6	121.9	6	1955	37.4	121.8	7
1946	37.6	121.7	6	1955	38.0	122.1	7
1947	36.9	121.6	6	1955	38.9	122.0	6
1947	37.0	121.8	6	1955	38.9	122.9	6
1948	38.0	121.0	6	1956	38.5	122.5	6
1948	39.1	123.2	6	1957	37.7	122.5	7
1948	36.8	121.5	7	1957	37.7	122.5	6

Table 13.--Earthquakes with maximum Modified Mercalli intensities greater than V in the nine-county study area (1800-1974 inclusive)--Continued

Year	°N. lat.	°W. long.	I_o	Year	°N. lat.	°W. long.	I_o
1958	37.5	121.8	6	1967	37.1	121.8	6
1958	37.7	122.5	6	1967	37.0	121.8	6
1959	39.4	123.0	6	1969	38.5	122.7	7
1959	36.2	121.6	6	1969	38.5	122.6	6
1959	36.9	121.6	6	1969	38.5	122.7	7
1959	36.9	121.5	6	1970	37.8	122.0	6
1960	36.8	121.4	6	1970	37.8	122.0	6
1961	36.7	121.3	7	1972	36.6	121.2	6
1961	36.7	121.3	7	1972	36.8	121.5	6
1962	39.1	123.2	7	1972	36.6	121.5	6
1963	36.9	121.6	7	1973	39.3	123.3	6
1963	38.0	121.8	6	1974	36.9	121.6	6
1964	36.9	121.8	7				
1965	37.7	121.9	6				
1966	37.0	121.7	6				
1967	37.0	121.8	6				

The above average percent losses were computed for:

(1) Each building subclass for each county. This means the loss in percent of the cash value of all buildings of a particular building subclass in each county (tables 14-17). Some of these results are displayed in figure 14.

(2) Each building subclass for the nine-county area (table 18). This means the loss in percent of the cash value of all buildings of a particular subclass in the nine-county study area. Some of these results are displayed in figure 15.

Three other different types of average percent losses were also here computed.

(1) Annual average losses computed using a 10-year moving time filter (figs. 1-24, appendix A). An example for building subclass IIA for filters of 5, 10, and 15 years is shown in figure 16. The average loss plotted at year Y is

$$\text{Average loss}_Y = \frac{L_Y + L_{Y-1} \ldots L_{Y-n+1}}{n}$$

and n is the number of years considered.

Table 14.--Average annual percent losses in each county based on a 175 year seismicity record (1800-1974)

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano
2A	0.182	0.121	0.151	0.104	0.146	0.119	0.135	0.129	0.043
2B	0.182	0.156	0.196	0.139	0.110	0.096	*	0.167	0.025
3HA	0.186	0.286	*	0.121	*	*	*	*	*
3HB	0.588	0.500	*	0.898	*	*	*	*	*
3HC	0.232	0.357	*	0.151	*	*	*	*	*
3HD	0.588	0.500	*	0.898	*	*	*	*	*
3LA	0.217	0.183	0.224	0.119	0.149	0.112	0.142	0.175	0.029
3LB	0.974	0.697	0.793	0.877	0.687	0.581	0.695	0.805	0.317
3LC	0.271	0.229	0.280	0.149	0.187	0.140	0.178	0.219	0.036
3LD	0.974	0.697	0.793	0.877	0.687	0.581	0.695	0.805	0.317
4HA	0.232	0.357	*	0.151	*	*	*	*	*
4HB	0.840	0.714	*	1.283	*	*	*	*	*
4HC	0.588	0.500	*	0.896	*	*	*	*	*
4HD	1.008	0.857	*	1.539	*	*	*	*	*
4HE	0.924	0.786	*	1.411	*	*	*	*	*
4LA	0.271	0.229	0.280	0.149	0.187	0.140	0.178	0.219	0.036
4LB	1.391	0.995	1.133	1.253	0.961	0.830	0.993	1.150	0.453
4LC	0.380	0.320	0.393	0.209	0.262	0.196	0.249	0.307	0.051
4LD	1.669	1.195	1.360	1.504	1.177	0.996	1.192	1.380	0.543
4LE	1.530	1.095	1.247	1.378	1.079	0.913	1.093	1.265	0.498
5B	0.271	0.229	0.280	0.149	0.187	0.140	0.178	0.219	0.036
5C	0.974	0.697	0.793	0.877	0.687	0.581	0.695	0.805	0.317
5D	1.252	0.896	1.020	1.128	0.883	0.747	0.894	1.035	0.407
5E	1.871	1.667	1.380	1.731	1.110	0.900	1.330	1.613	0.559

Table 15.--Average annual percent losses in each county based on a 100 year seismicity record (1800-1899)

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano
2A	0.208	0.157	0.195	0.107	0.184	0.170	0.176	0.194	0.052
2B	0.226	0.203	0.260	0.143	0.150	0.136	*	0.243	*
3HA	0.252	0.400	*	0.067	*	*	*	*	*
3HB	0.731	0.700	*	0.700	*	*	*	*	*
3HC	0.315	0.500	*	0.084	*	*	*	*	*
3HD	0.731	0.700	*	0.700	*	*	*	*	*
3LA	0.267	0.234	0.288	0.108	0.195	0.145	0.185	0.259	0.035
3LB	0.975	0.814	0.864	0.727	0.770	0.712	0.820	0.996	0.369
3LC	0.334	0.292	0.360	0.135	0.244	0.181	0.231	0.324	0.043
3LD	0.975	0.814	0.864	0.727	0.770	0.712	0.820	0.996	0.369
4HA	0.315	0.500	*	0.084	*	*	*	*	*
4HB	1.045	1.000	*	1.001	*	*	*	*	*
4HC	0.731	0.700	*	0.700	*	*	*	*	*
4HD	1.254	1.200	*	1.201	*	*	*	*	*
4HE	1.149	1.100	*	1.101	*	*	*	*	*
4LA	0.334	0.292	0.360	0.135	0.244	0.181	0.231	0.324	0.043
4LB	1.393	1.163	1.235	1.039	1.099	1.017	1.172	1.423	0.527
4LC	0.468	0.409	0.504	0.189	0.342	0.254	0.324	0.454	0.061
4LD	1.672	1.396	1.482	1.246	1.319	1.221	1.406	1.708	0.632
4LE	1.533	1.279	1.358	1.142	1.209	1.119	1.289	1.566	0.580
5B	0.334	0.292	0.360	0.135	0.244	0.181	0.231	0.324	0.043
5C	0.975	0.814	0.864	0.727	0.770	0.712	0.820	0.996	0.369
5D	1.254	1.047	1.111	0.935	0.990	0.916	1.054	1.281	0.474
5E	1.950	1.926	1.566	1.405	1.209	1.076	1.522	2.011	0.610

Table 16.--Average annual percent losses in each county based on a 75 year seismicity record (1900-1974)

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano
2A	0.147	0.073	0.093	0.099	0.095	0.052	0.079	0.043	0.031
2B	0.122	0.092	0.111	0.134	0.057	0.043	*	0.067	0.059
3HA	0.097	0.133	*	0.192	*	*	*	*	*
3HB	0.396	0.233	*	1.161	*	*	*	*	*
3HC	0.121	0.167	*	0.240	*	*	*	*	*
3HD	0.396	0.233	*	1.161	*	*	*	*	*
3LA	0.150	0.115	0.140	0.135	0.088	0.068	0.085	0.064	0.021
3LB	0.971	0.540	0.699	1.077	0.576	0.407	0.529	0.550	0.247
3LC	0.187	0.144	0.175	0.168	0.110	0.085	0.107	0.080	0.027
3LD	0.971	0.540	0.699	1.077	0.576	0.407	0.529	0.550	0.247
4HA	0.121	0.167	*	0.240	*	*	*	*	*
4HB	0.566	0.333	*	1.659	*	*	*	*	*
4HC	0.396	0.233	*	1.161	*	*	*	*	*
4HD	0.679	0.400	*	1.991	*	*	*	*	*
4HE	0.623	0.367	*	1.825	*	*	*	*	*
4LA	0.187	0.144	0.175	0.168	0.110	0.085	0.107	0.080	0.027
4LB	1.387	0.772	0.998	1.539	0.824	0.581	0.756	0.786	0.353
4LC	0.262	0.201	0.245	0.235	0.154	0.120	0.150	0.112	0.037
4LD	1.665	0.926	1.198	1.847	0.988	0.697	0.907	0.943	0.424
4LE	1.526	0.849	1.098	1.693	0.906	0.639	0.832	0.865	0.389
5B	0.187	0.144	0.175	0.168	0.110	0.085	0.107	0.080	0.027
5C	0.971	0.540	0.699	1.077	0.576	0.407	0.529	0.550	0.247
5D	1.249	0.695	0.898	1.385	0.741	0.523	0.680	0.707	0.318
5E	1.765	1.323	1.132	2.165	0.978	0.666	1.073	1.082	0.491

Table 17.--Average annual percent losses in each county based on a 68 year seismicity record (1907-1974)

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano
2A	0.079	0.006	0.016	0.043	0.043	*	0.037	0.029	0.001
2B	.040	*	.005	.050	.015	*	*	.011	*
3HA	.026	*	*	.064	*	*	*	*	*
3HB	.239	*	*	.971	*	*	*	*	*
3HC	.033	*	*	.080	*	*	*	*	*
3HD	.239	*	*	.971	*	*	*	*	*
3LA	.051	.001	.009	.041	.030	*	.032	.013	*
3LB	.781	.316	.487	.928	.418	.224	.350	.404	.129
3LC	.064	.002	.012	.051	.038	*	.040	.016	.001
3LD	.781	.316	.487	.928	.418	.224	.350	.404	.129
4HA	.033	*	*	.080	*	*	*	*	*
4HB	.342	*	*	1.387	*	*	*	*	*
4HC	.239	*	*	.971	*	*	*	*	*
4HD	.410	*	*	1.664	*	*	*	*	*
4HE	.376	*	*	1.525	*	*	*	*	*
4LA	.064	.002	.012	.051	.038	*	.040	.016	.001
4LB	1.116	.452	.695	1.326	.597	.320	.500	.577	.184
4LC	.090	.003	.016	.072	.053	*	.056	.022	.001
4LD	1.339	.542	.834	1.592	.717	.384	.600	.692	.221
4LE	1.227	.497	.765	1.459	.657	.352	.550	.635	.203
5B	.064	.002	.012	.051	.038	*	.040	.016	.001
5C	.781	.316	.487	.928	.418	.224	.350	.404	.129
5D	1.004	.407	.626	1.194	.537	.288	.450	.519	.166
5E	1.399	.841	.698	1.842	.739	.313	.669	.801	.218

Table 18.--Average annual percent losses for the nine county study area based on the seismicity during four time intervals

(* indicates a very low percentage)

Bldg. Subclass	175 years (1800-1874)	100 years (1800-1899)	75 years (1900-1974)	68 years (1907-1974)
2A	0.131	0.153	0.102	0.043
2B	0.160	0.201	0.106	0.028
3HA	0.260	0.357	0.132	0.008
3HB	0.539	0.705	0.317	0.098
3HC	0.325	0.446	0.165	0.010
3HD	0.539	0.705	0.317	0.098
3LA	0.166	0.198	0.123	0.032
3LB	0.822	0.820	0.826	0.652
3LC	0.208	0.248	0.154	0.040
3LD	0.822	0.820	0.826	0.652
4HA	0.325	0.446	0.165	0.010
4HB	0.769	1.007	0.453	0.139
4HC	0.539	0.705	0.317	0.098
4HD	0.923	1.208	0.543	0.167
4HE	0.846	1.108	0.498	0.153
4LA	0.208	0.248	0.154	0.040
4LB	1.175	1.171	1.180	0.931
4LC	0.291	0.347	0.215	0.056
4LD	1.410	1.406	1.416	1.117
4LE	1.292	1.288	1.298	1.024
5B	0.208	0.248	0.154	0.040
5C	0.822	0.820	0.826	0.652
5D	1.057	1.054	1.062	0.838
5E	1.521	1.589	1.430	1.083

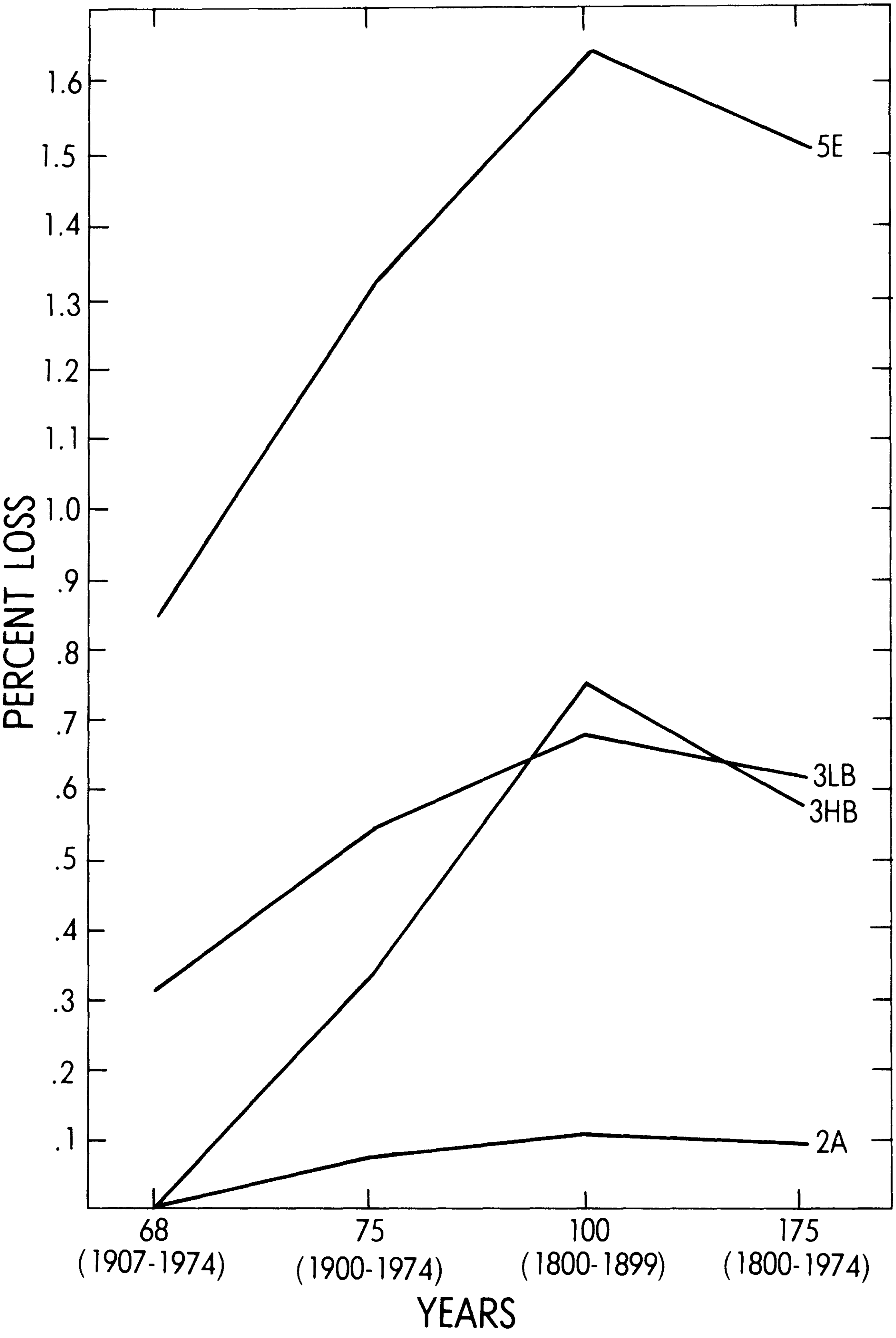

Figure 14.--Average annual percent losses for several different time spans of historical seismicity for selected building subclasses for San Francisco County.

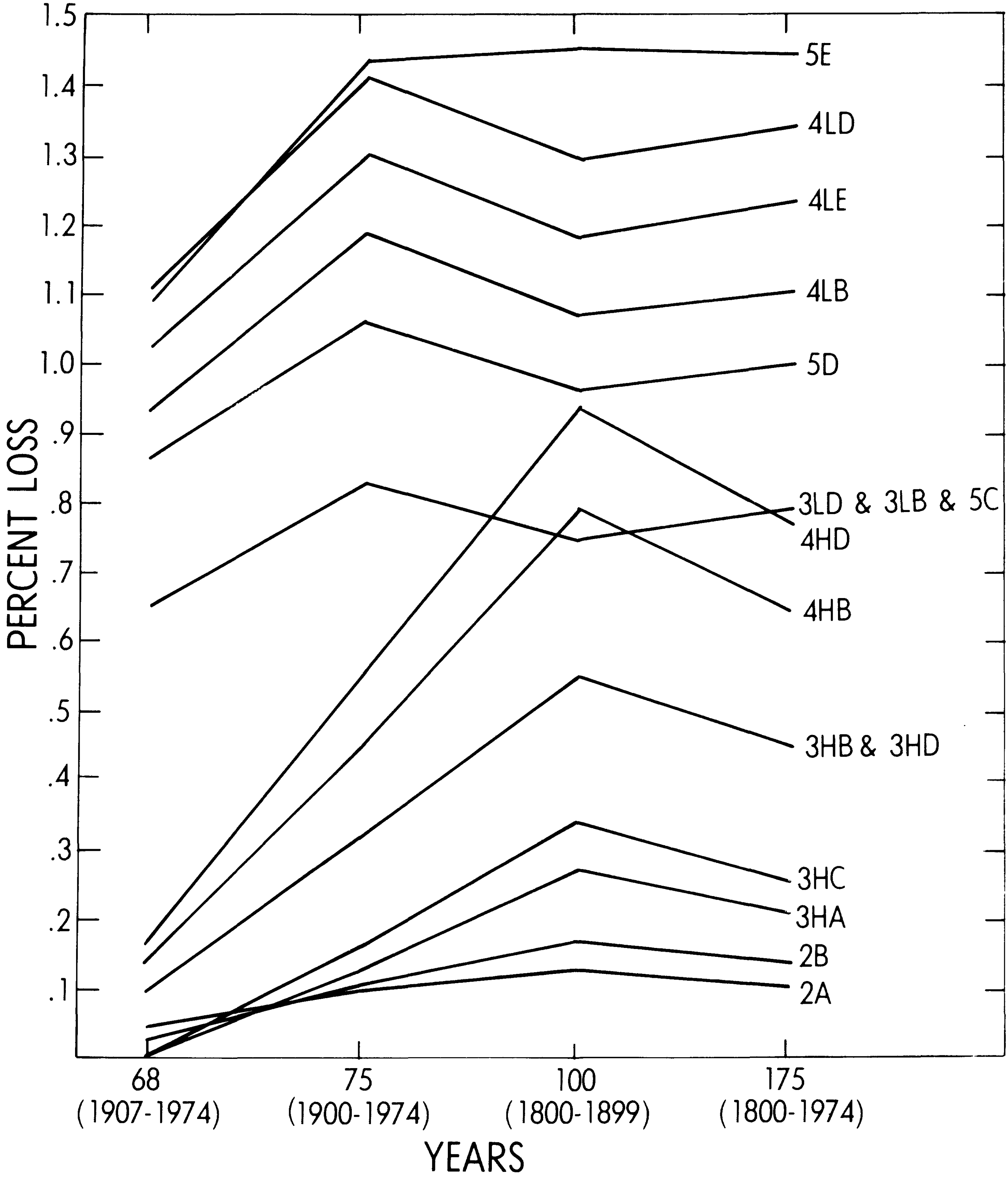

Figure 15.--Average annual percent losses in the nine-county study area for several different time spans of historical seismicity for selected subclasses.

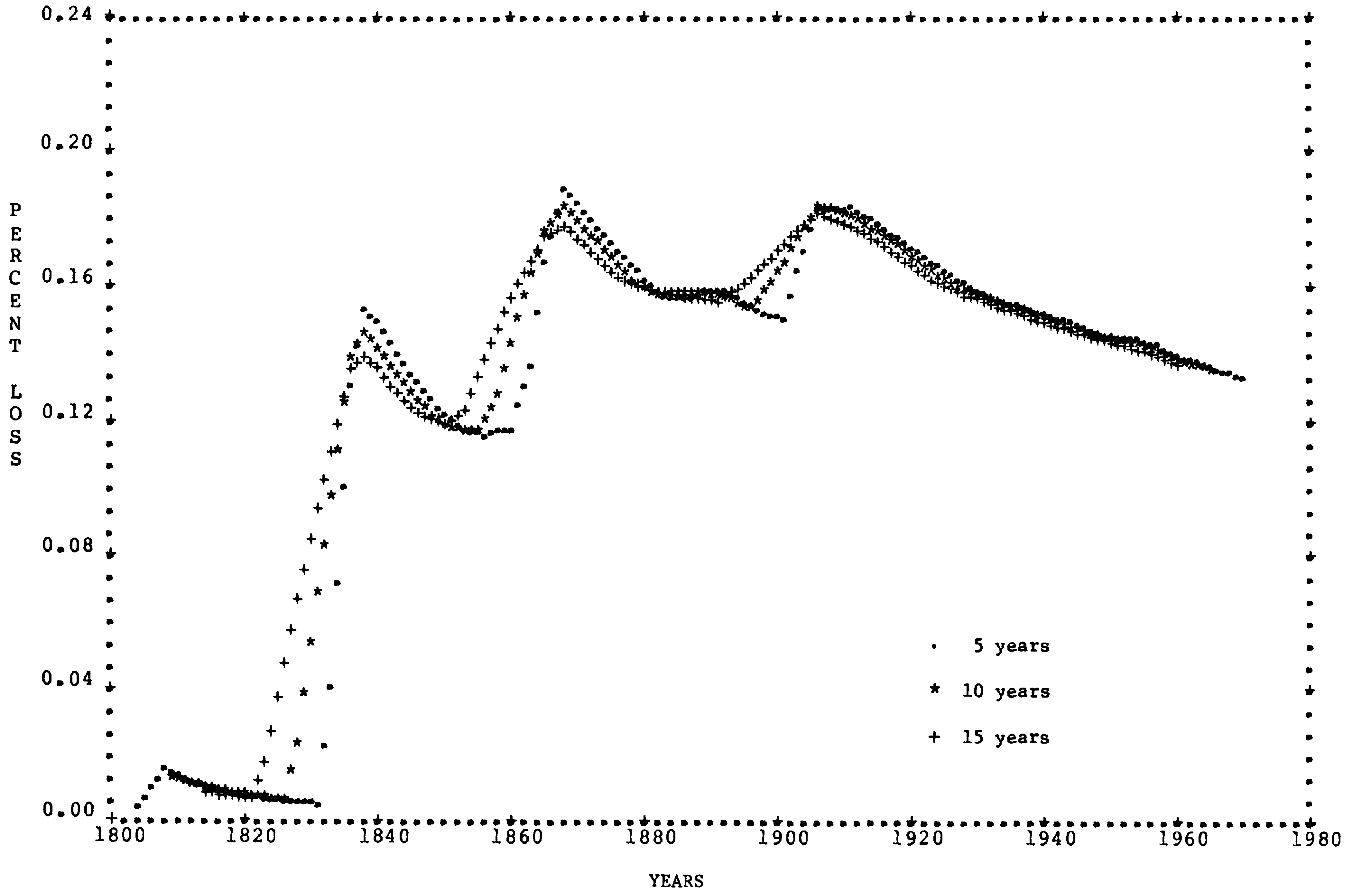

Figure 16.--Average percent losses, subclass 2A. The averages were computed using running averages of 5, 10, and 15 years of data (see text).

(2) Average annual percent losses computed using seismicity data samples from 1 to 1,000 years in length in yearly increments (figs. 17-40). This means that losses were averaged first for one year of seismicity (1800), then two years (1800 and 1801), then three years (1800, 1801, 1802) and so on up to 175 years (a seismicity record of 175 years, 1800-1974). The seismic history was then repeated starting with 1800 again. Thus, the average loss for 200 years would be:

$$\frac{\text{Sum of annual losses 1800-1974 plus the sum of annual losses 1800-1824}}{200}$$

Therefore the 1,000-year seismicity record was simulated by repeating the 175-year historical seismicity 5.71 times. Table 19 gives the average annual percent losses for each subclass obtained from the 1,000-year simulated seismicity record discussed above.

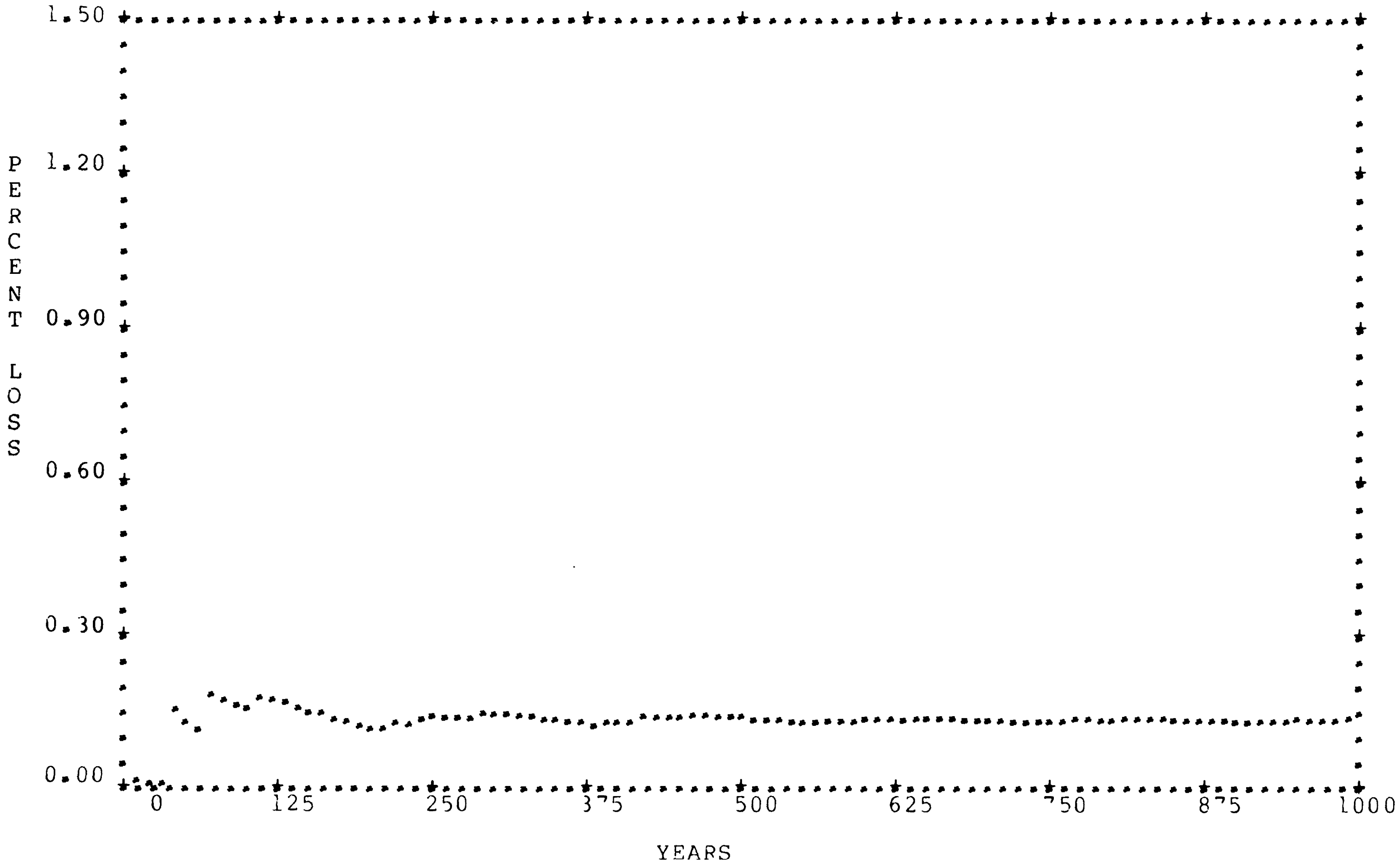

Figure 17.--Annual percent losses for subclass 2A based on losses averaged over from one to 1,000 years.

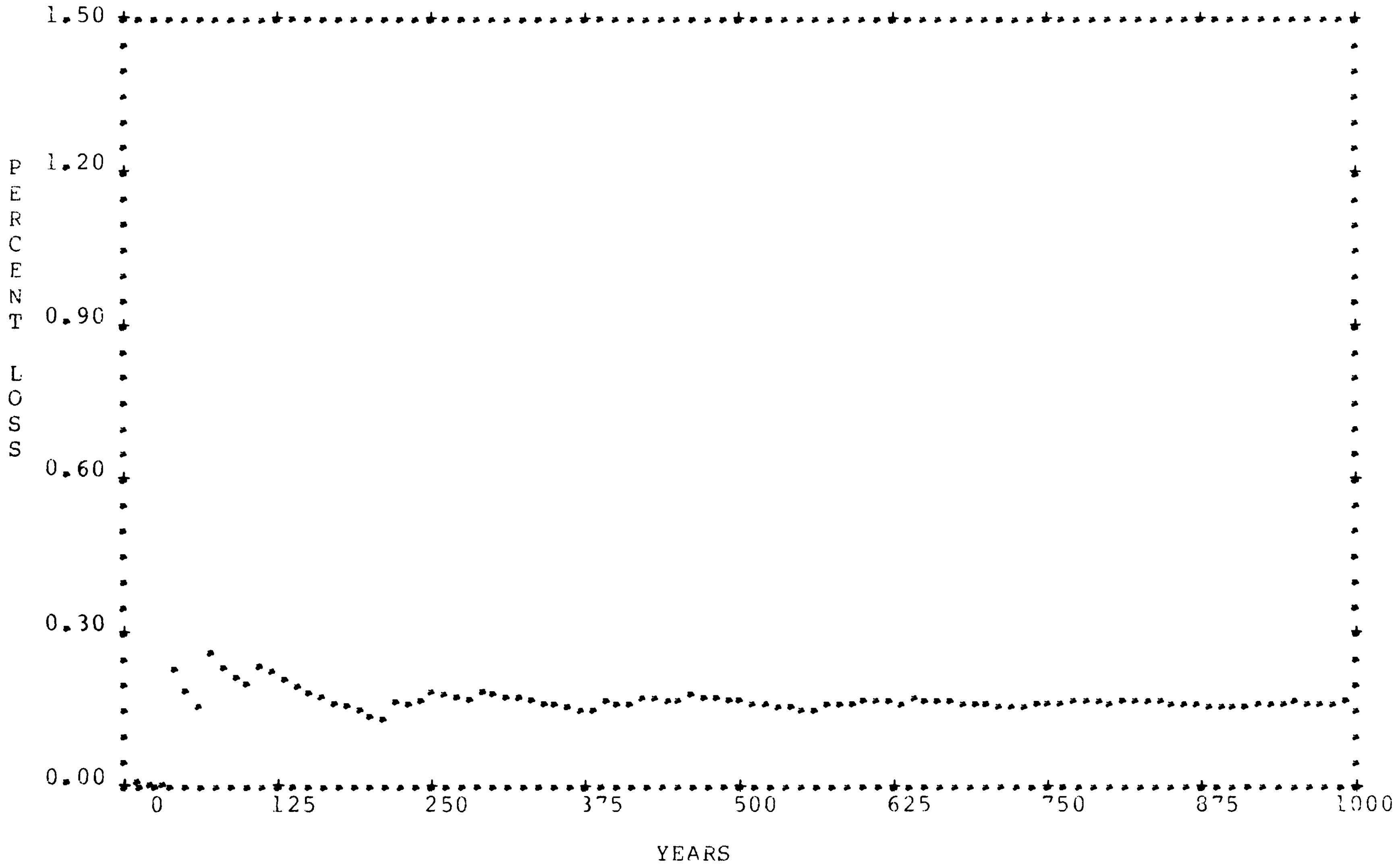

Figure 18.--Annual percent losses for subclass 2B based on losses averaged over from one to 1,000 years.

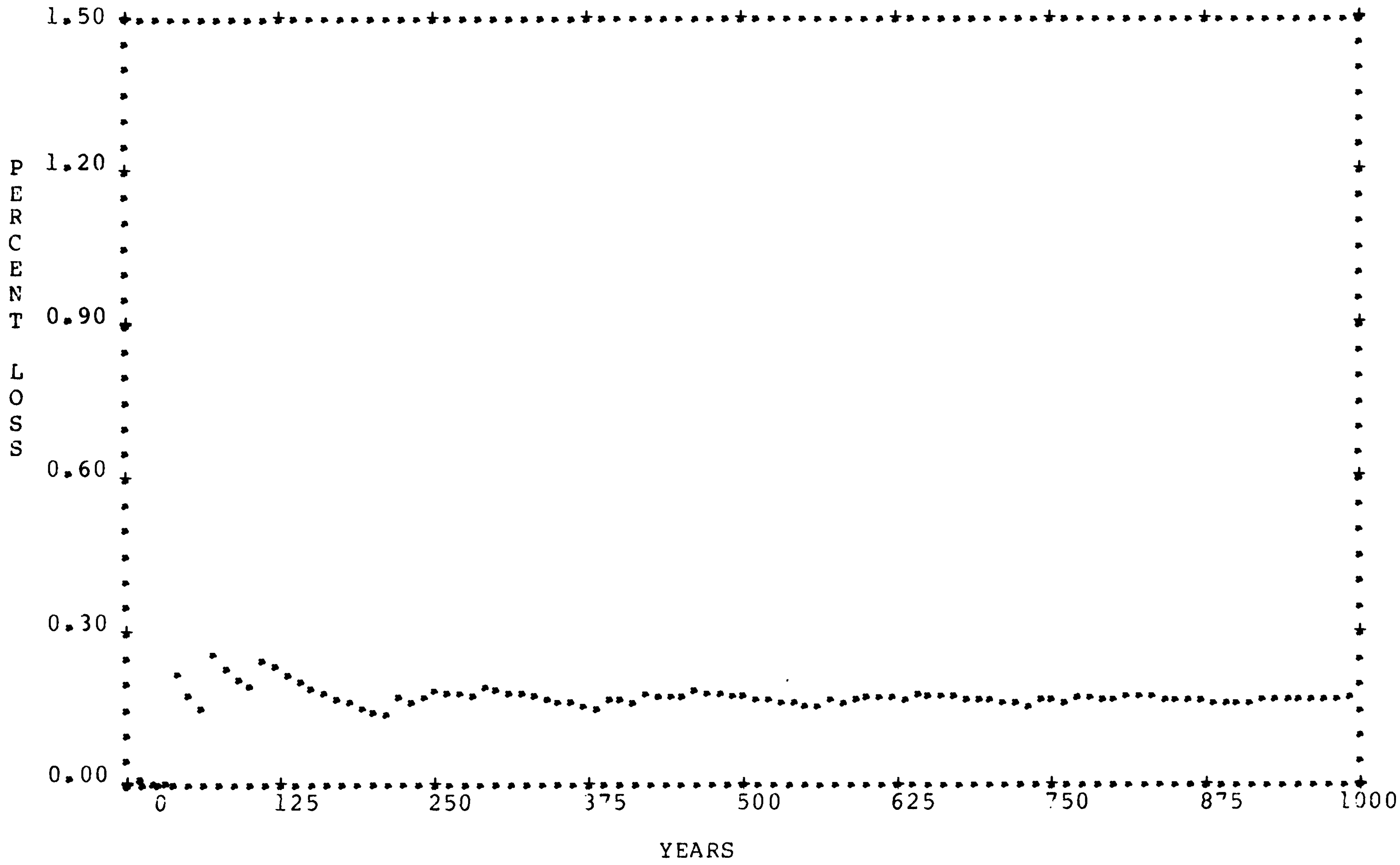

Figure 19.--Annual percent losses for subclass 3LA based on losses averaged over from one to 1,000 years.

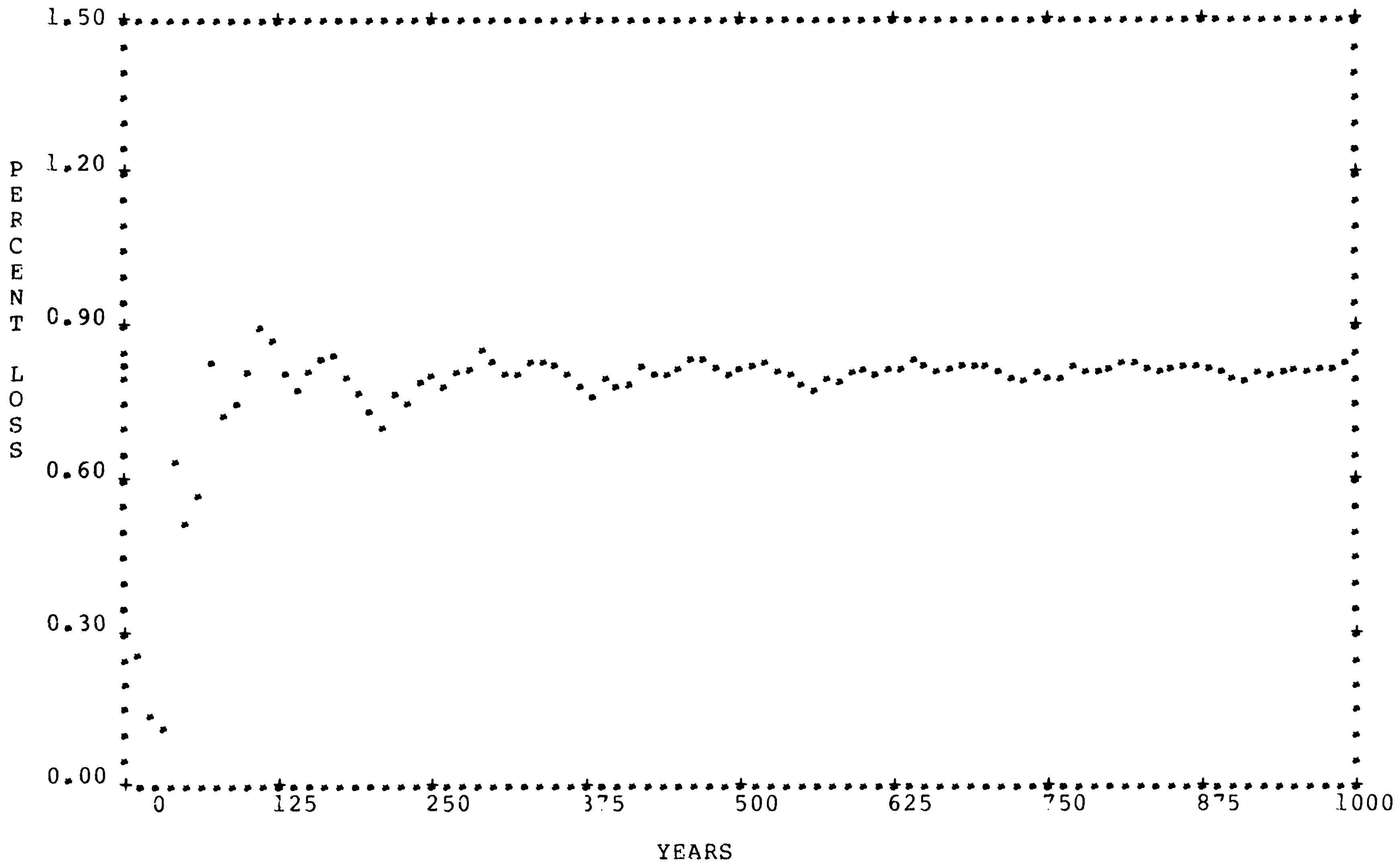

Figure 20.--Annual percent losses for subclass 3LB based on losses averaged over from one to 1,000 years.

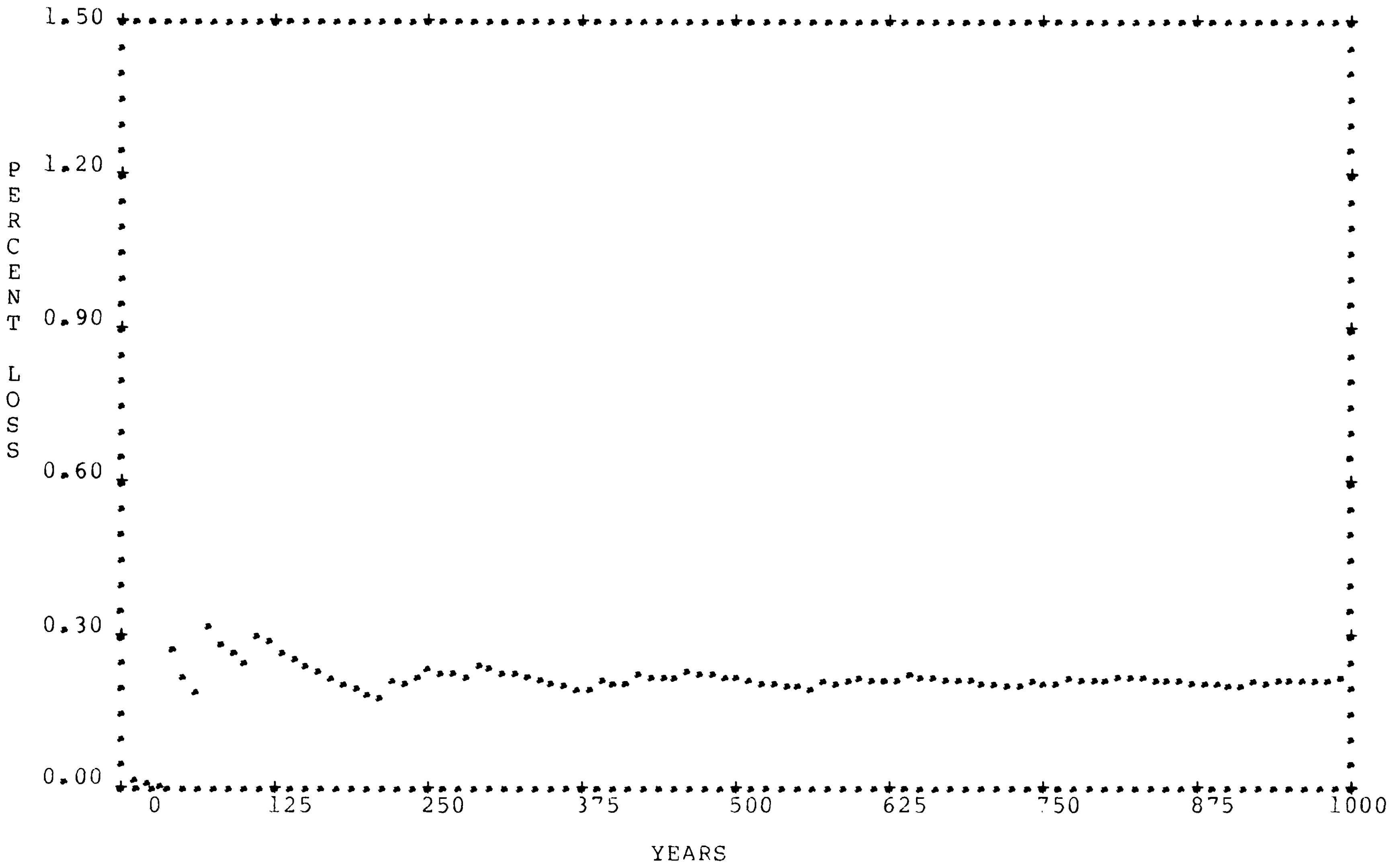

Figure 21.--Annual percent losses for subclass 3LC based on losses averaged over from one to 1,000 years.

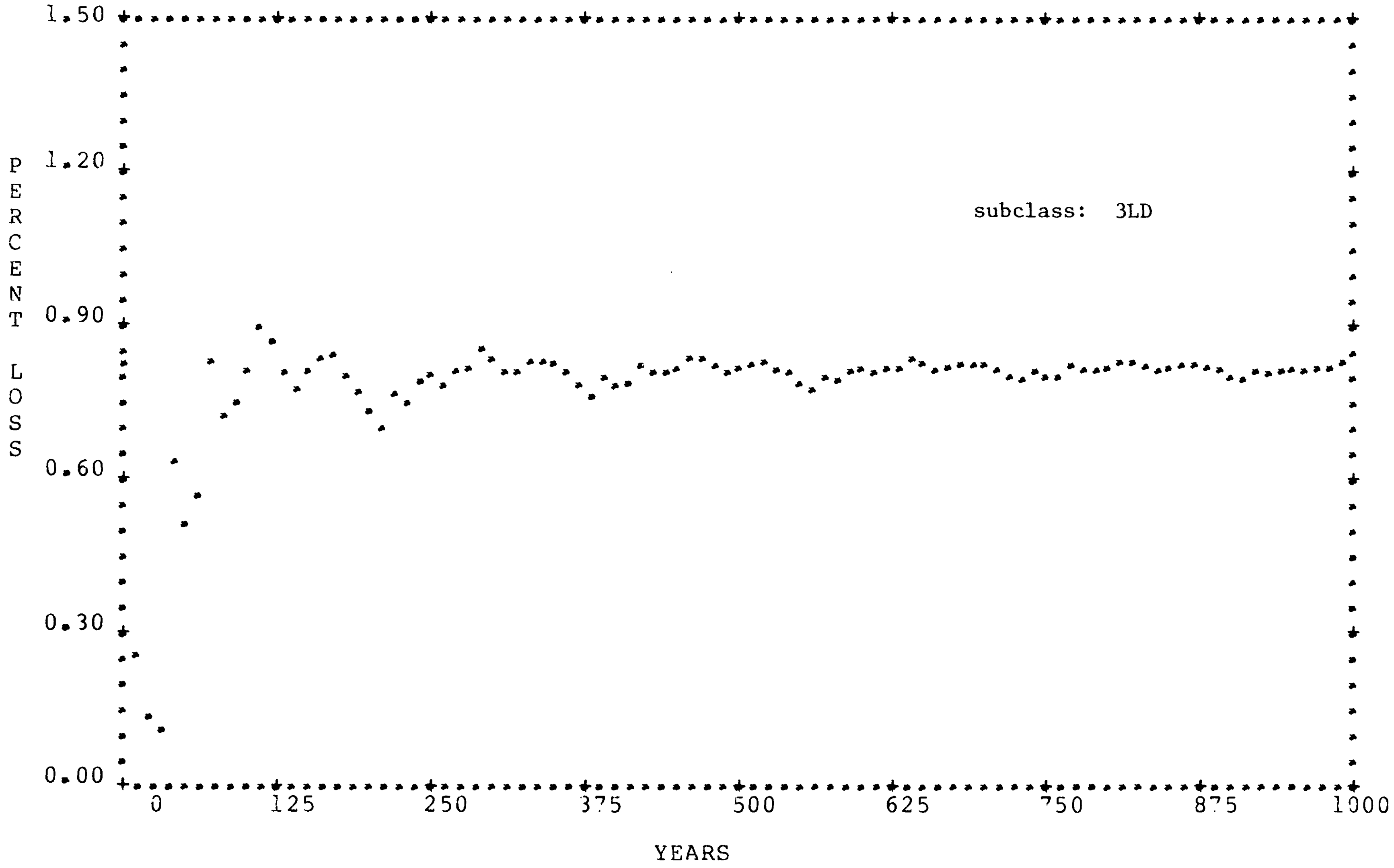

Figure 22.--Annual percent losses for subclass 3LD based on losses averaged over from one to 1,000 years.

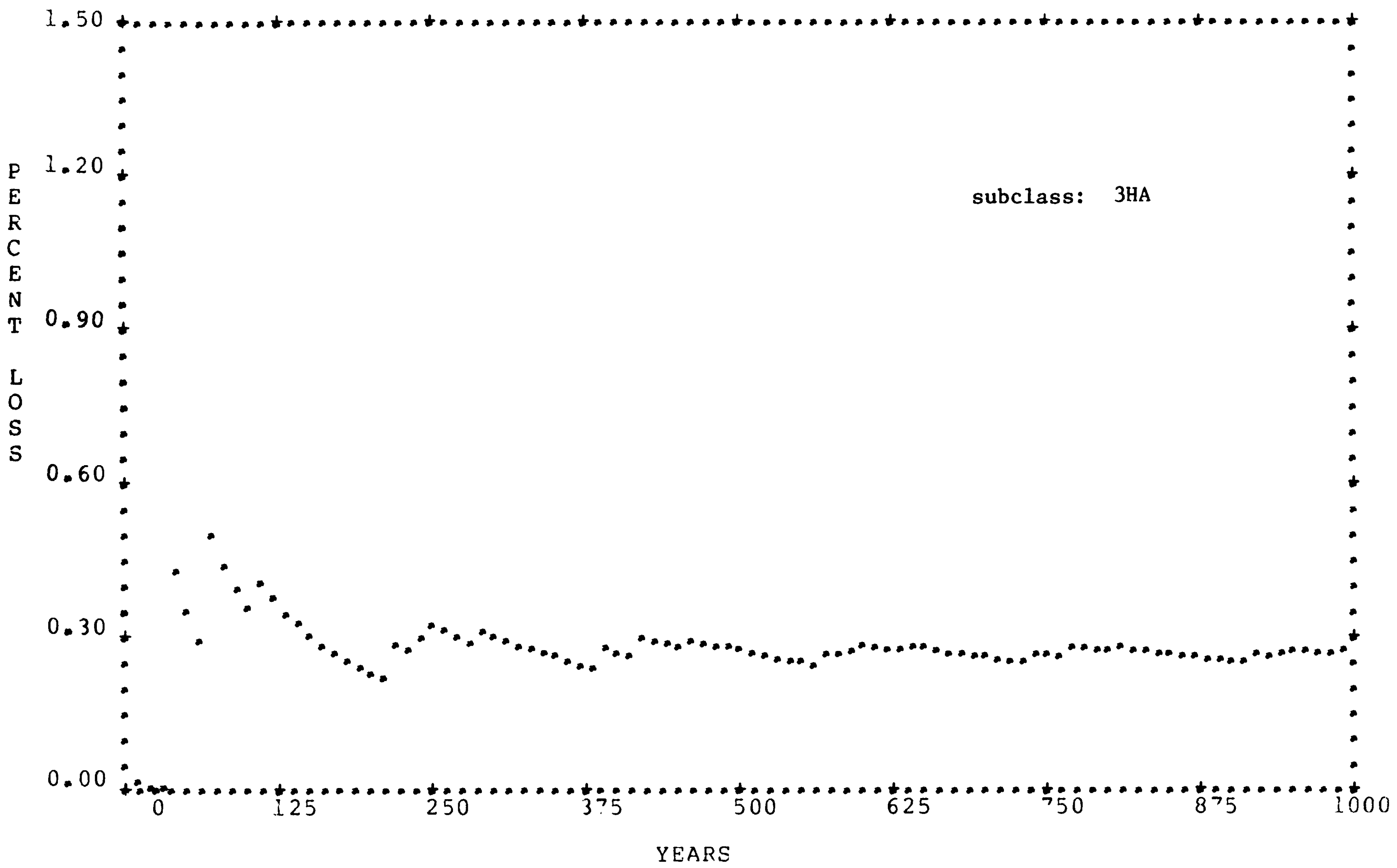

Figure 23.--Annual percent losses for subclass 3HA based on losses averaged over from one to 1,000 years.

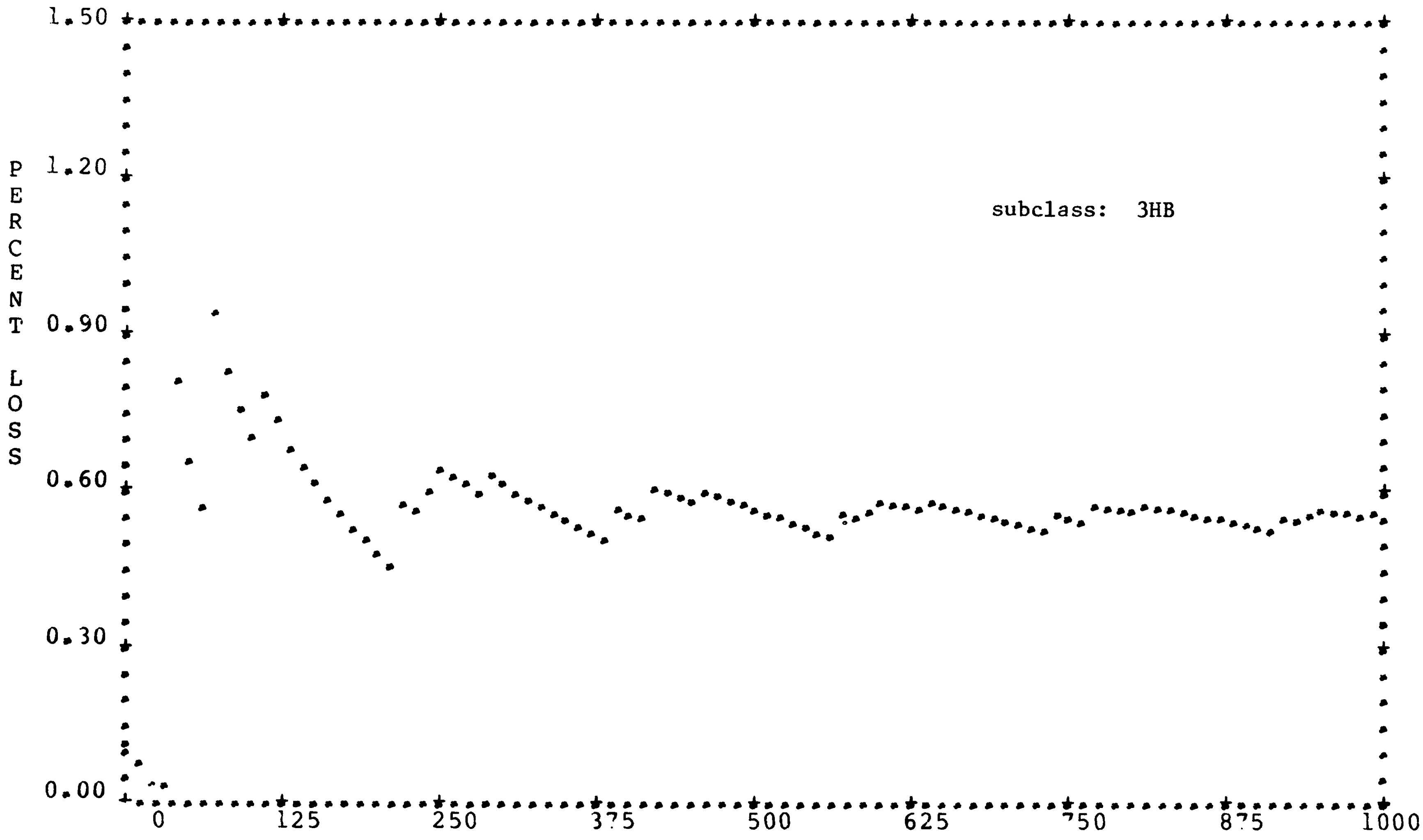

Figure 24.--Annual percent losses for subclass 3HB based on losses averaged over from one to 1,000 years.

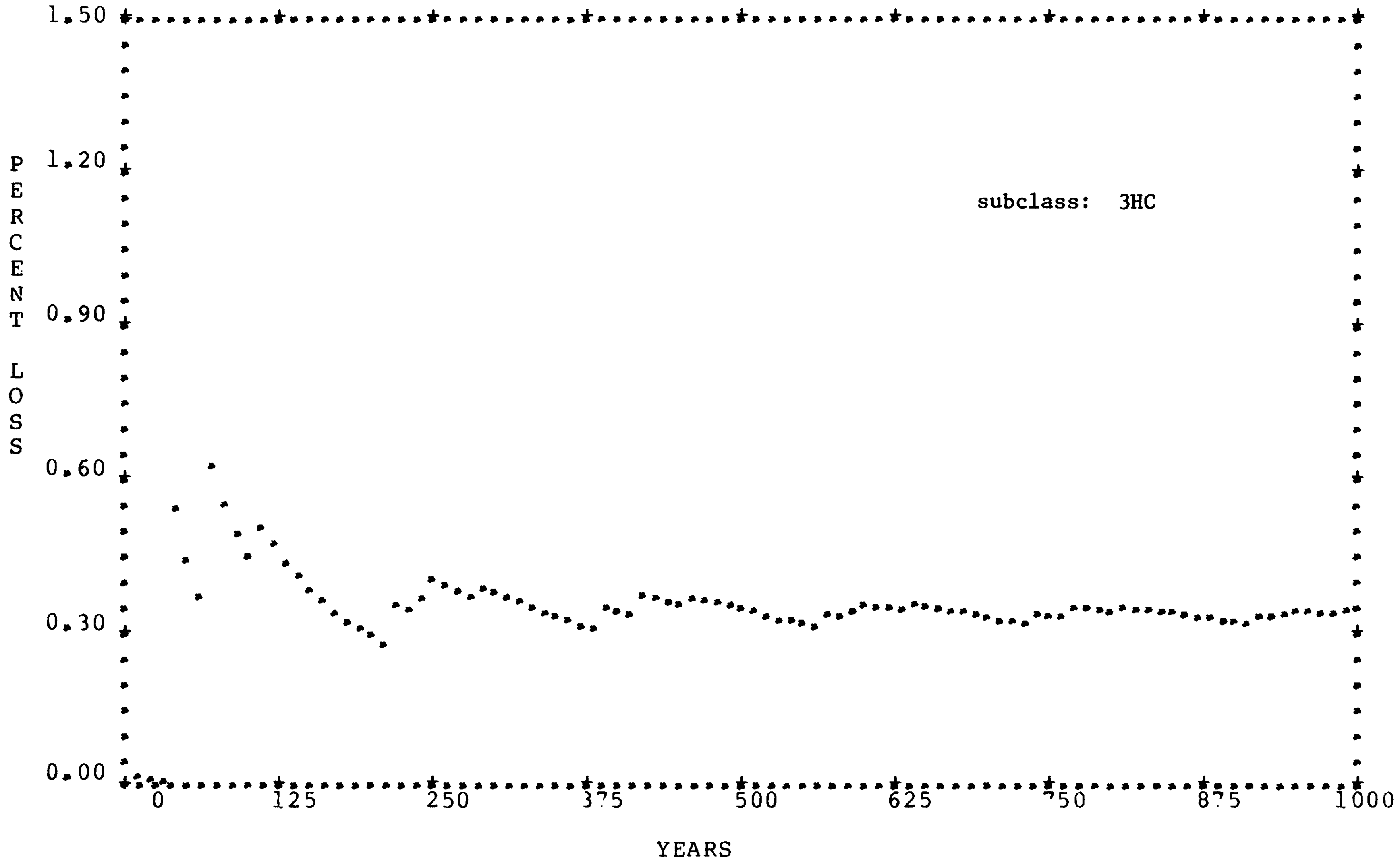

Figure 25.--Annual percent losses for subclass 3HC based on losses averaged over from one to 1,000 years.

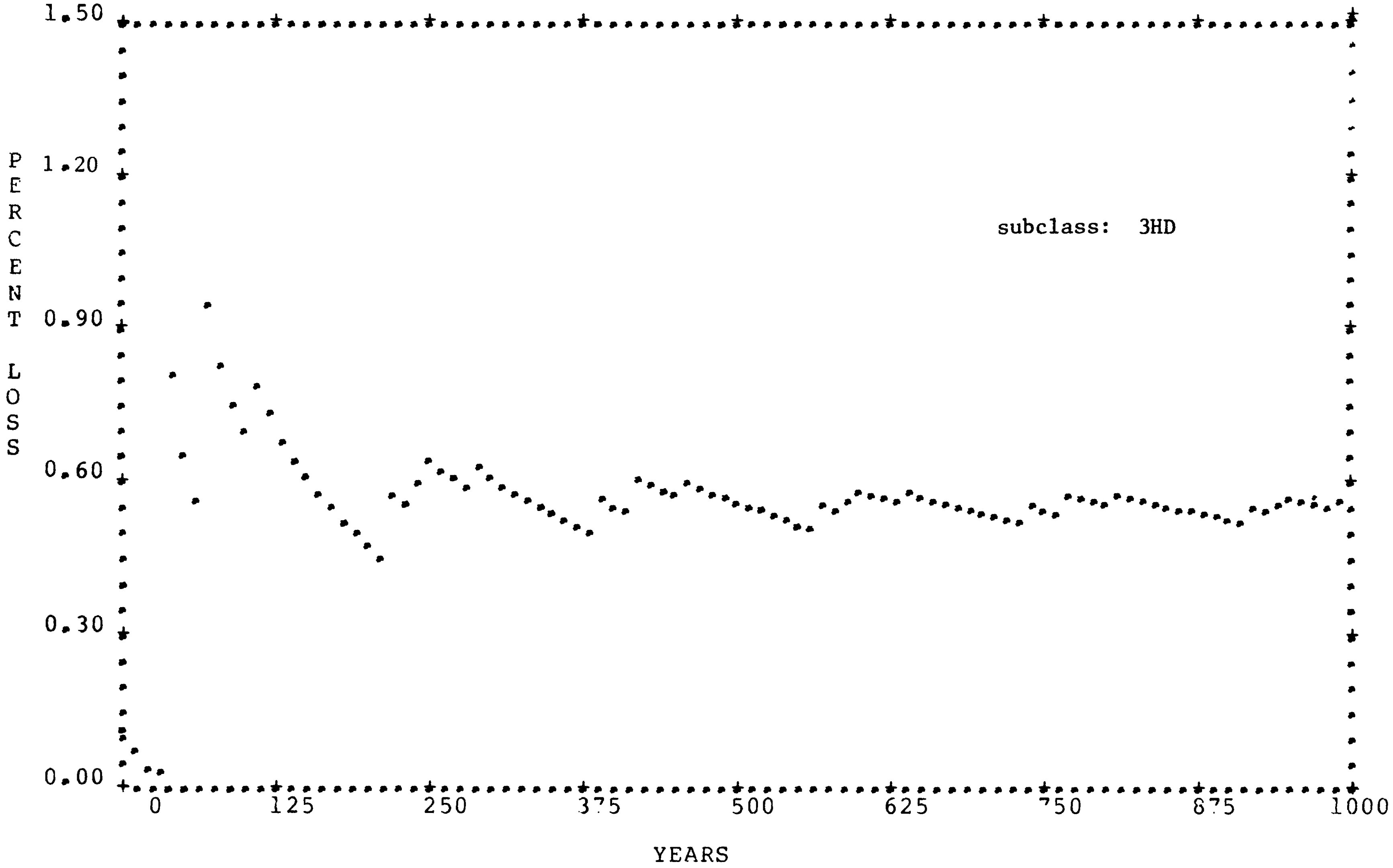

Figure 26.--Annual percent losses for subclass 3HD based on losses averaged over from one to 1,000 years.

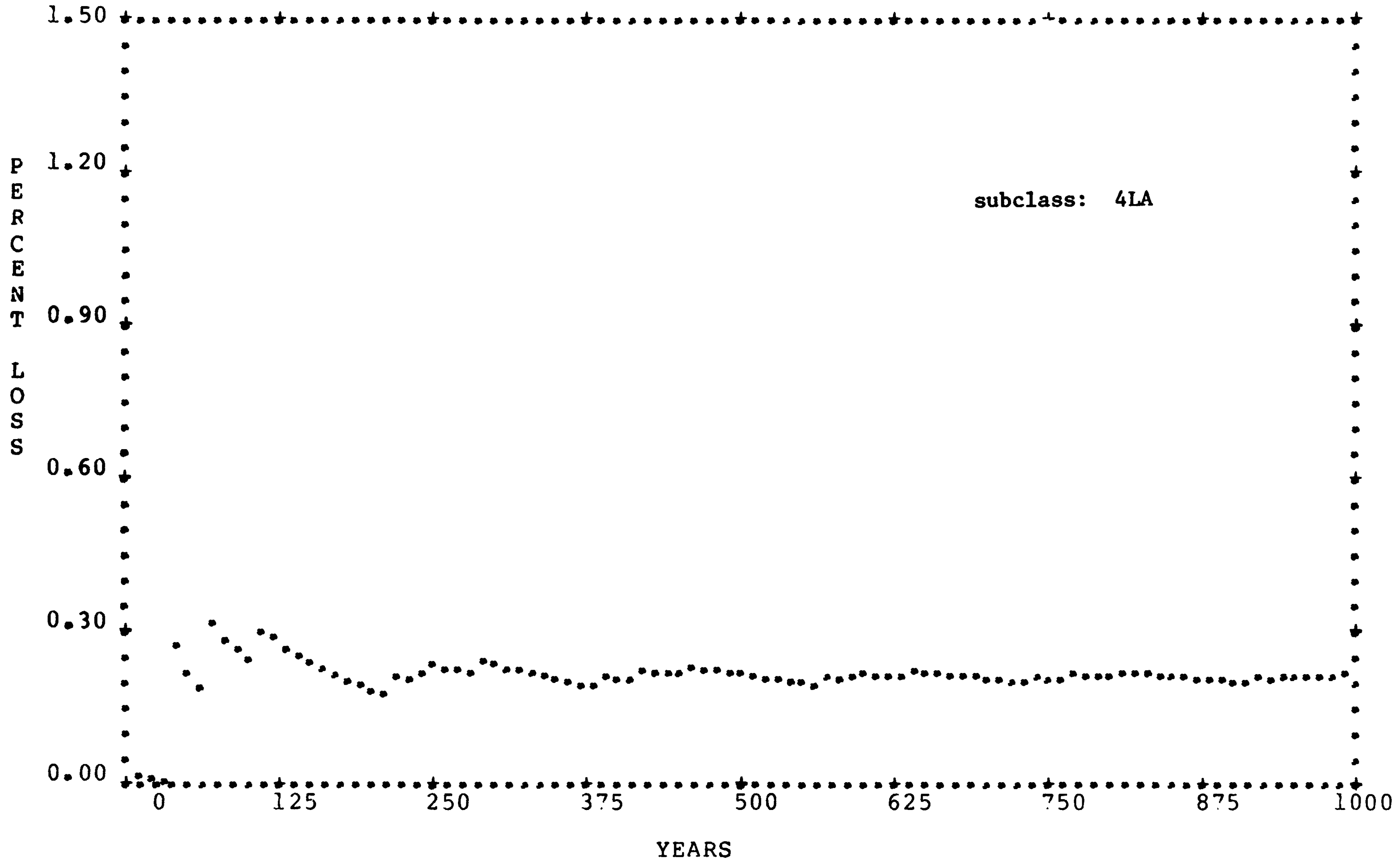

Figure 27.--Annual percent losses for subclass 4LA based on losses averaged over from one to 1,000 years.

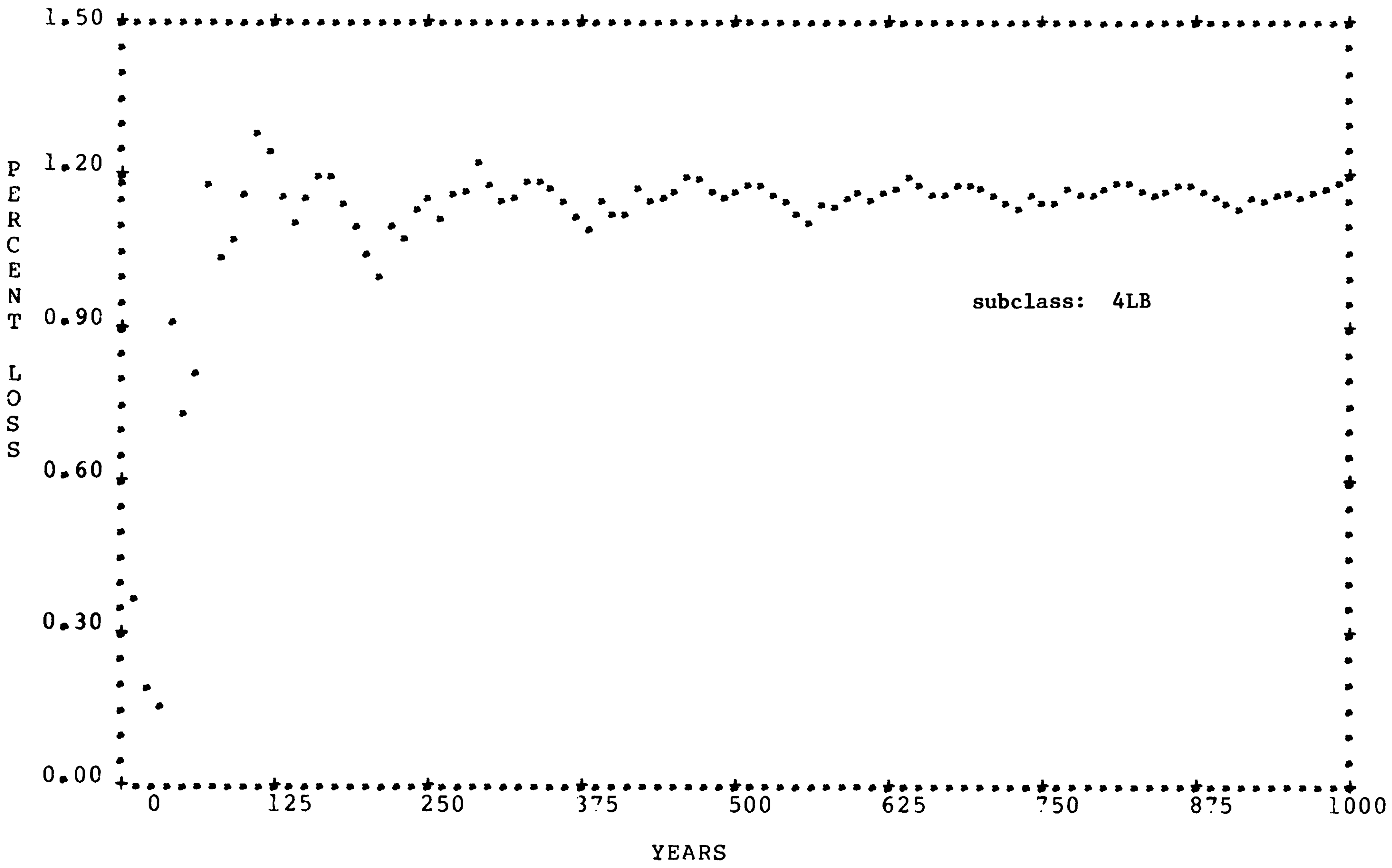

Figure 28.--Annual percent losses for subclass 4LB based on losses averaged over from one to 1,000 years.

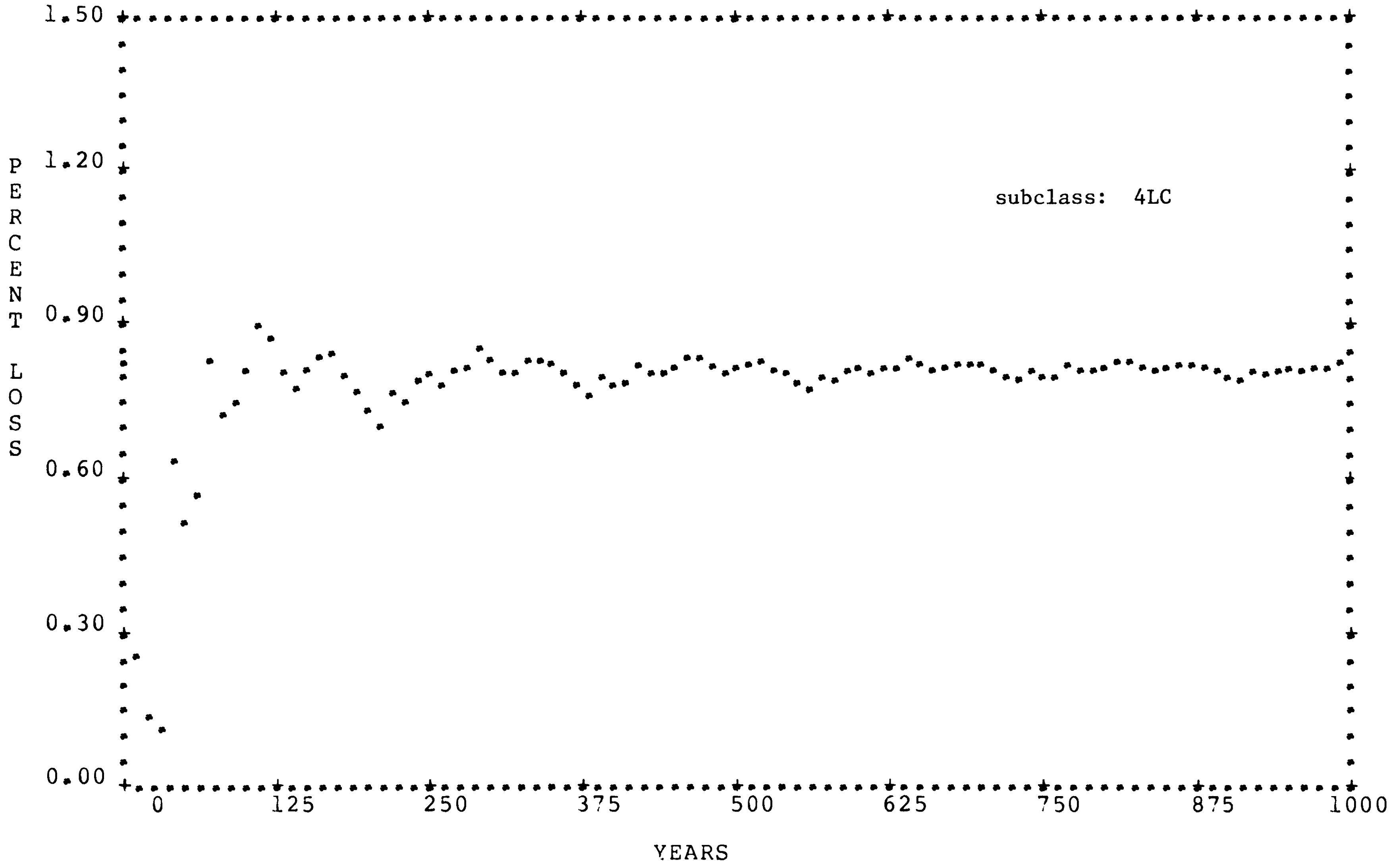

Figure 29.--Annual percent losses for subclass 4LC based on losses averaged over from one to 1,000 years.

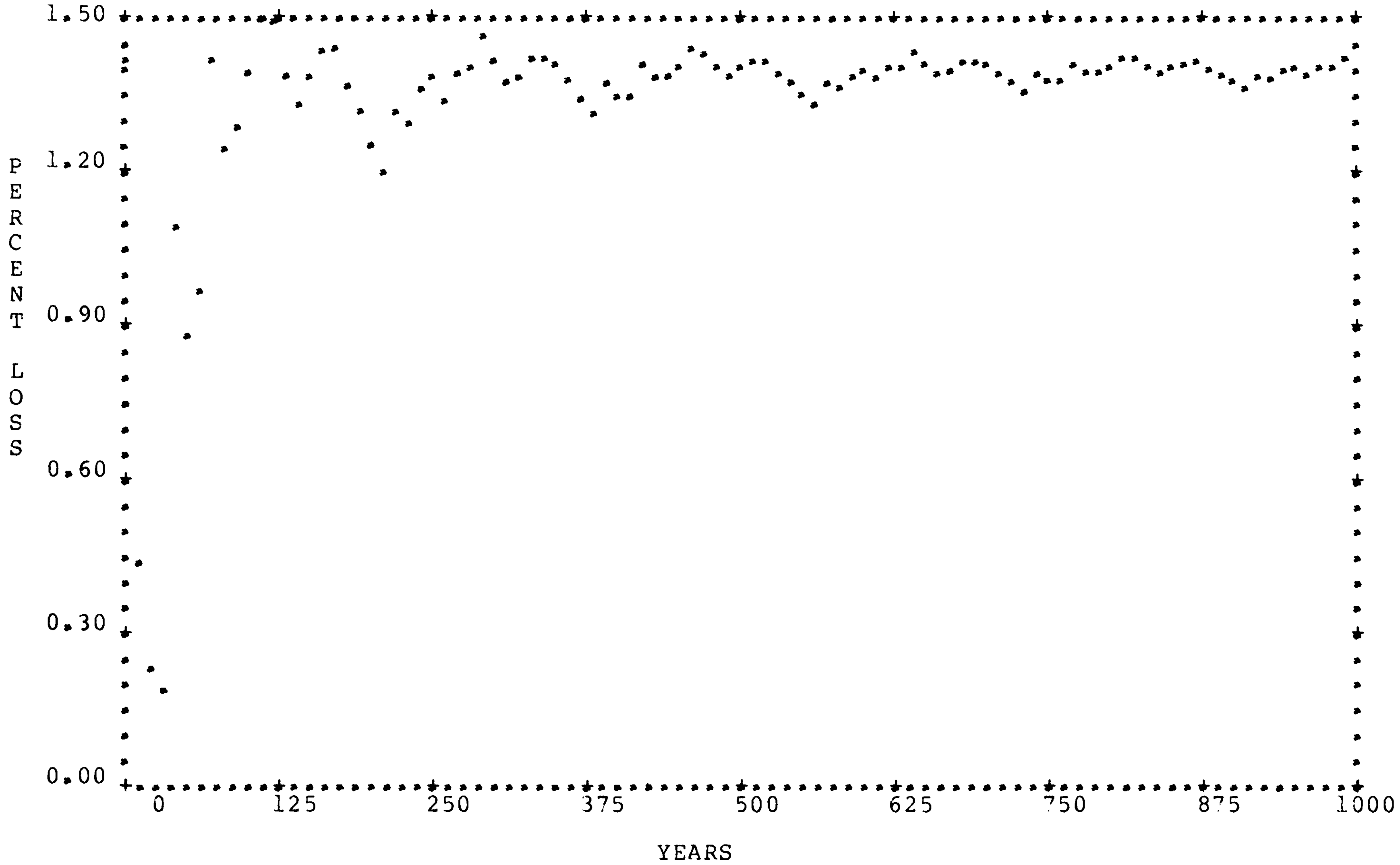

Figure 30.--Annual percent losses for subclass 4LD based on losses averaged over from one to 1,000 years.

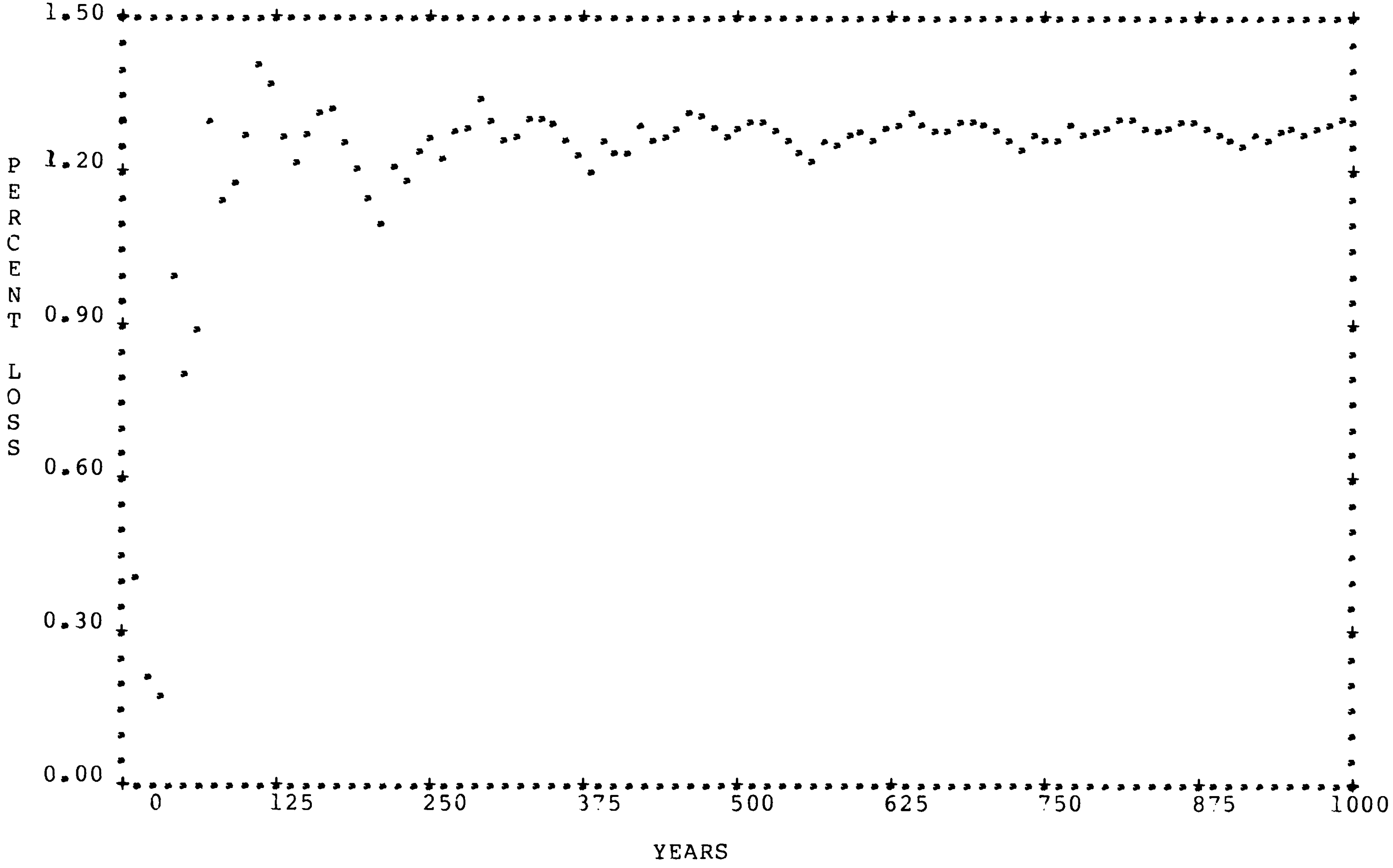

Figure 31.--Annual percent losses for subclass 4LE based on losses averaged over from one to 1,000 years.

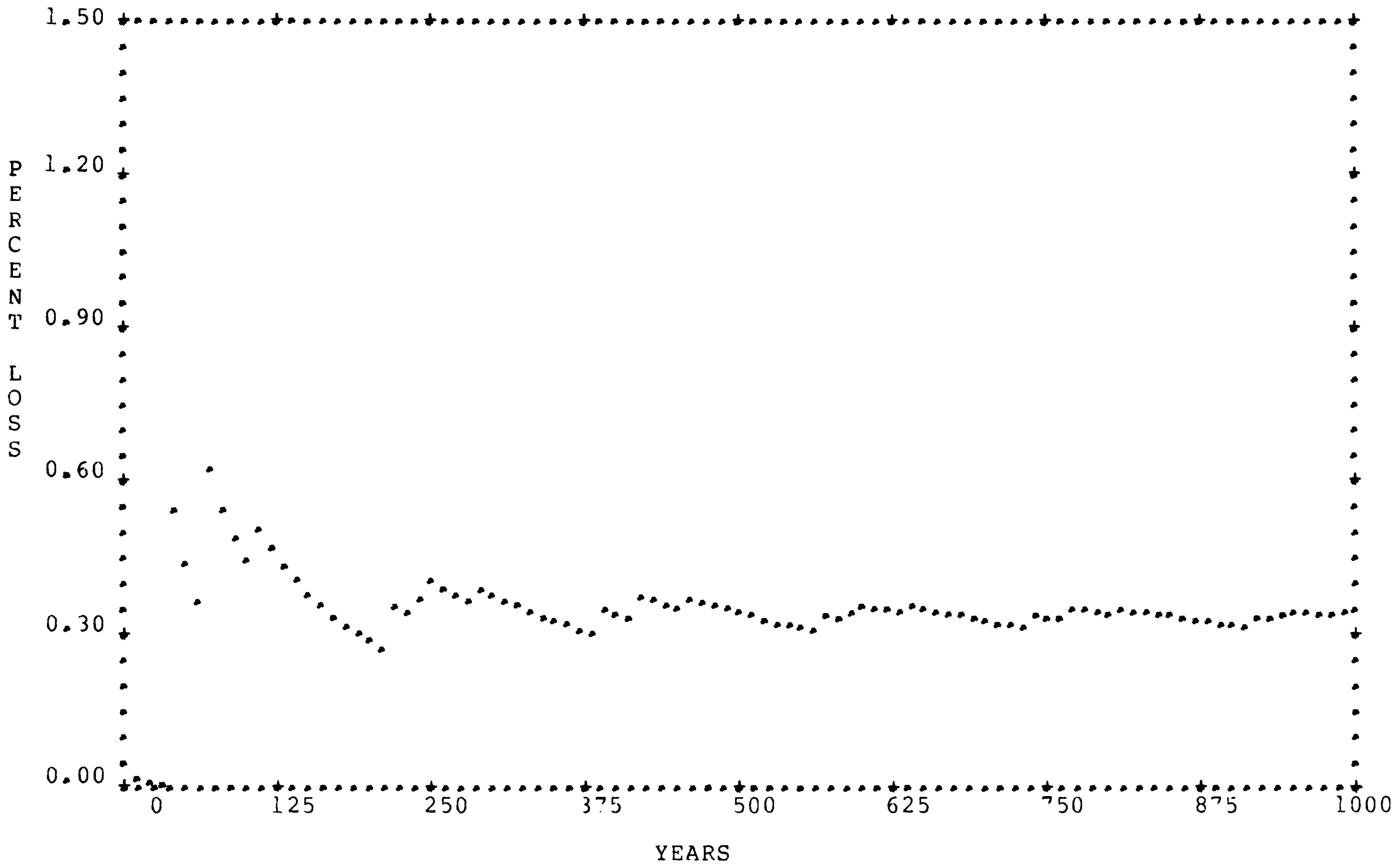

Figure 32.--Annual percent losses for subclass 4HA based on losses averaged over from one to 1,000 years.

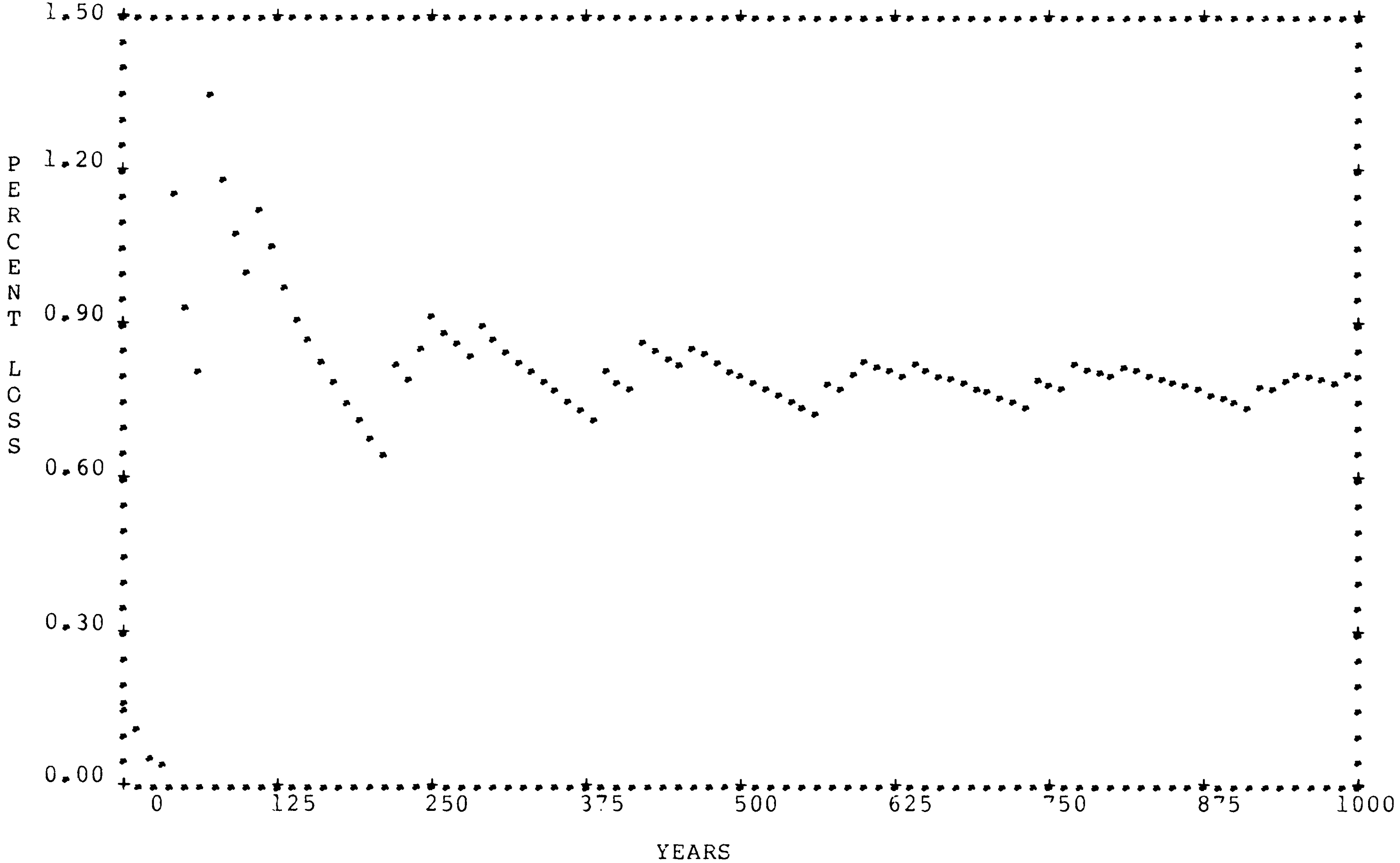

Figure 33.--Annual percent losses for subclass 4HB based on losses averaged over from one to 1,000 years.

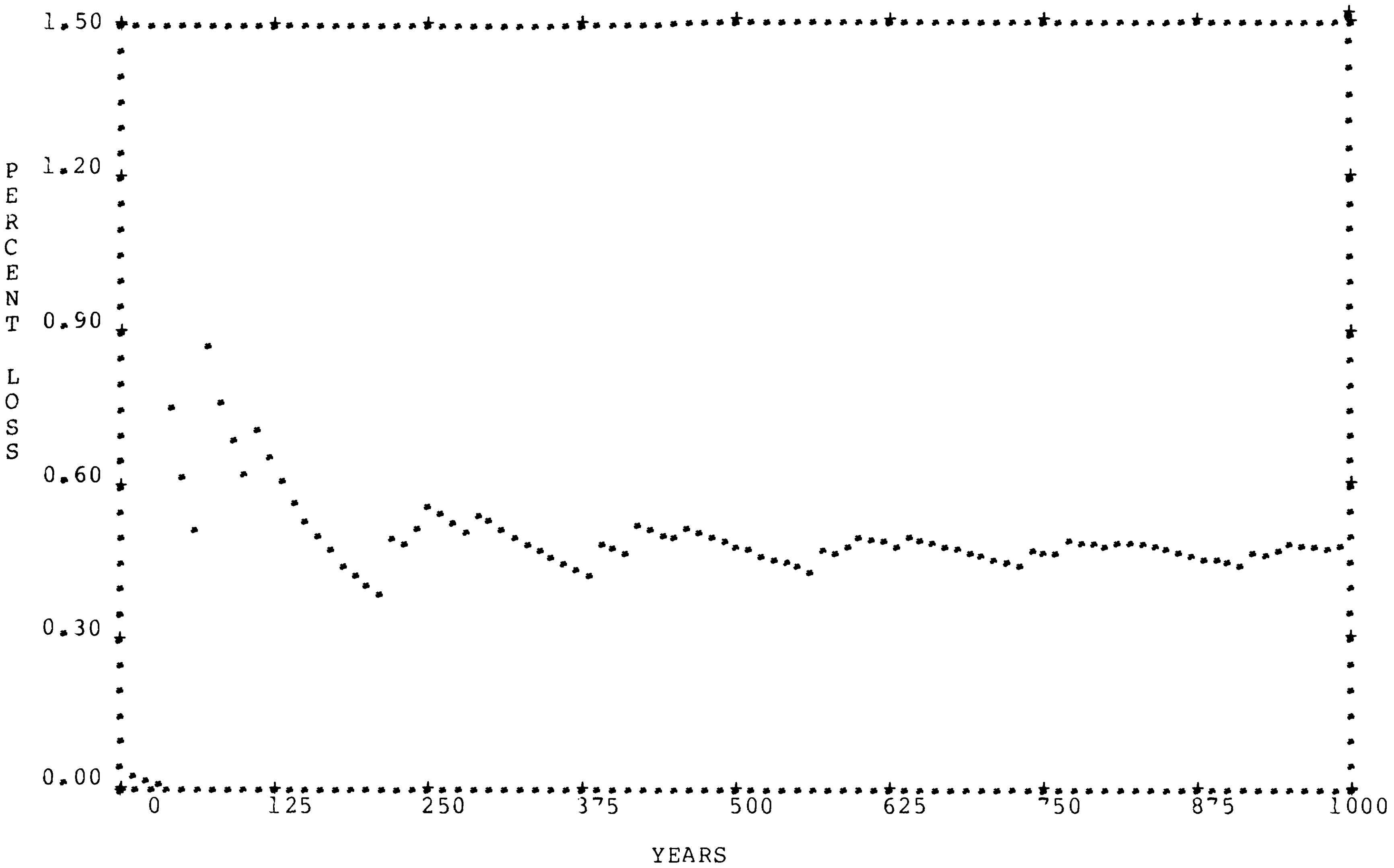

Figure 34.--Annual percent losses for subclass 4HC based on losses averaged over from one to 1,000 years.

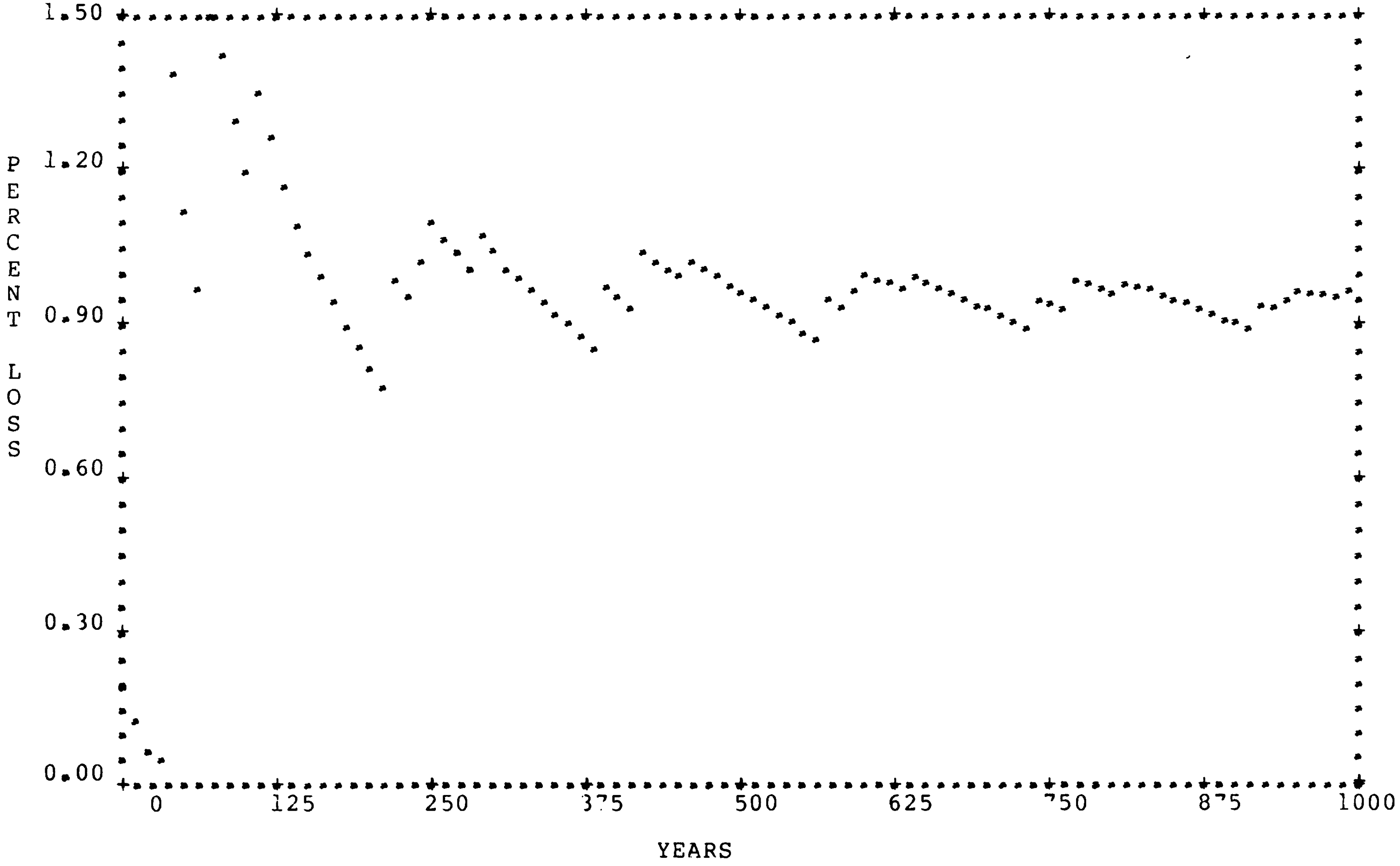

Figure 35.--Annual percent losses for subclass 4HD based on losses averaged over from one to 1,000 years.

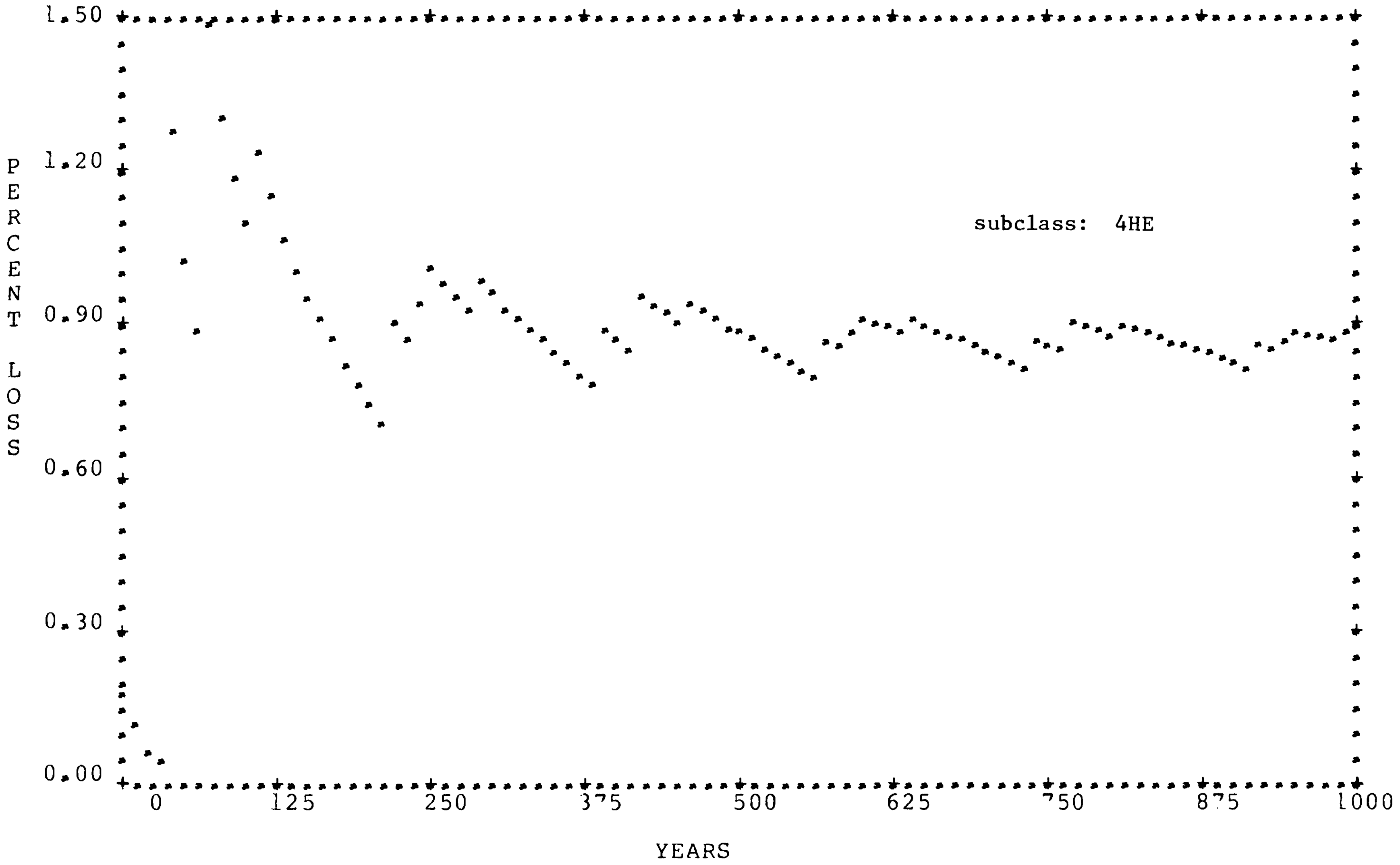

Figure 36.--Annual percent losses for subclass 4HE based on losses averaged over from one to 1,000 years.

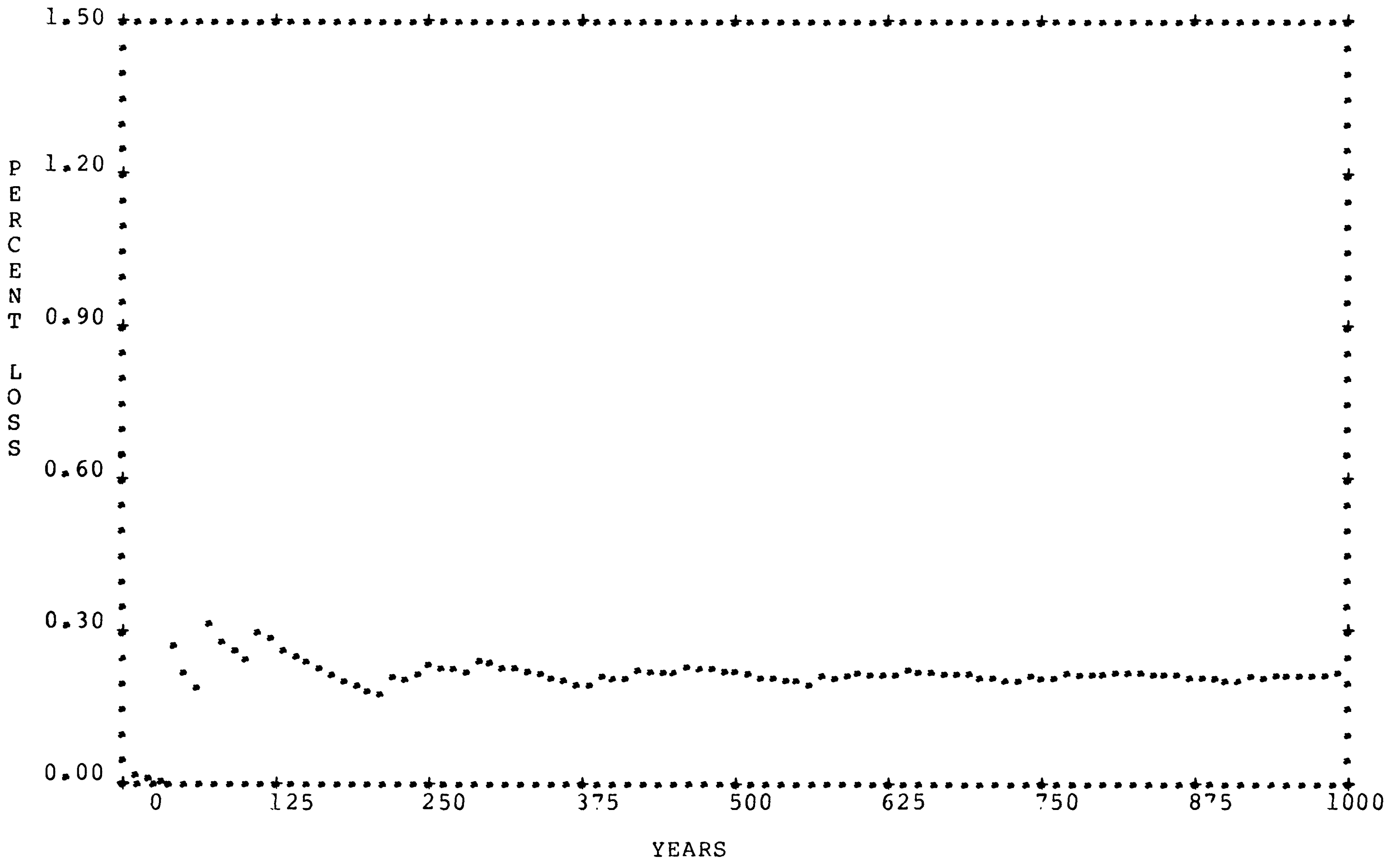

Figure 37.--Annual percent losses for subclass 5B based on losses averaged over from one to 1,000 years.

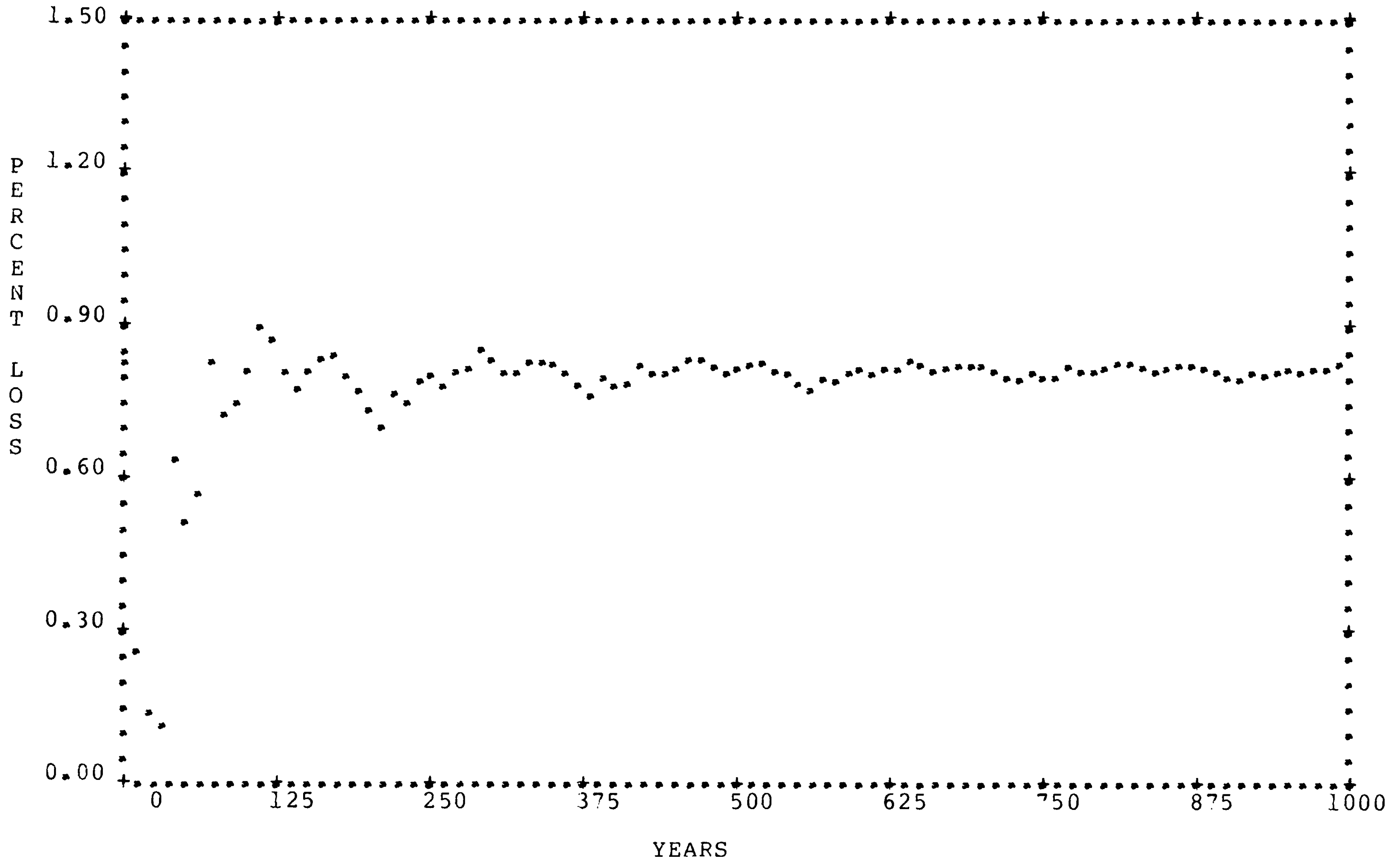

Figure 38.--Annual percent losses for subclass 5C based on losses averaged over from one to 1,000 years.

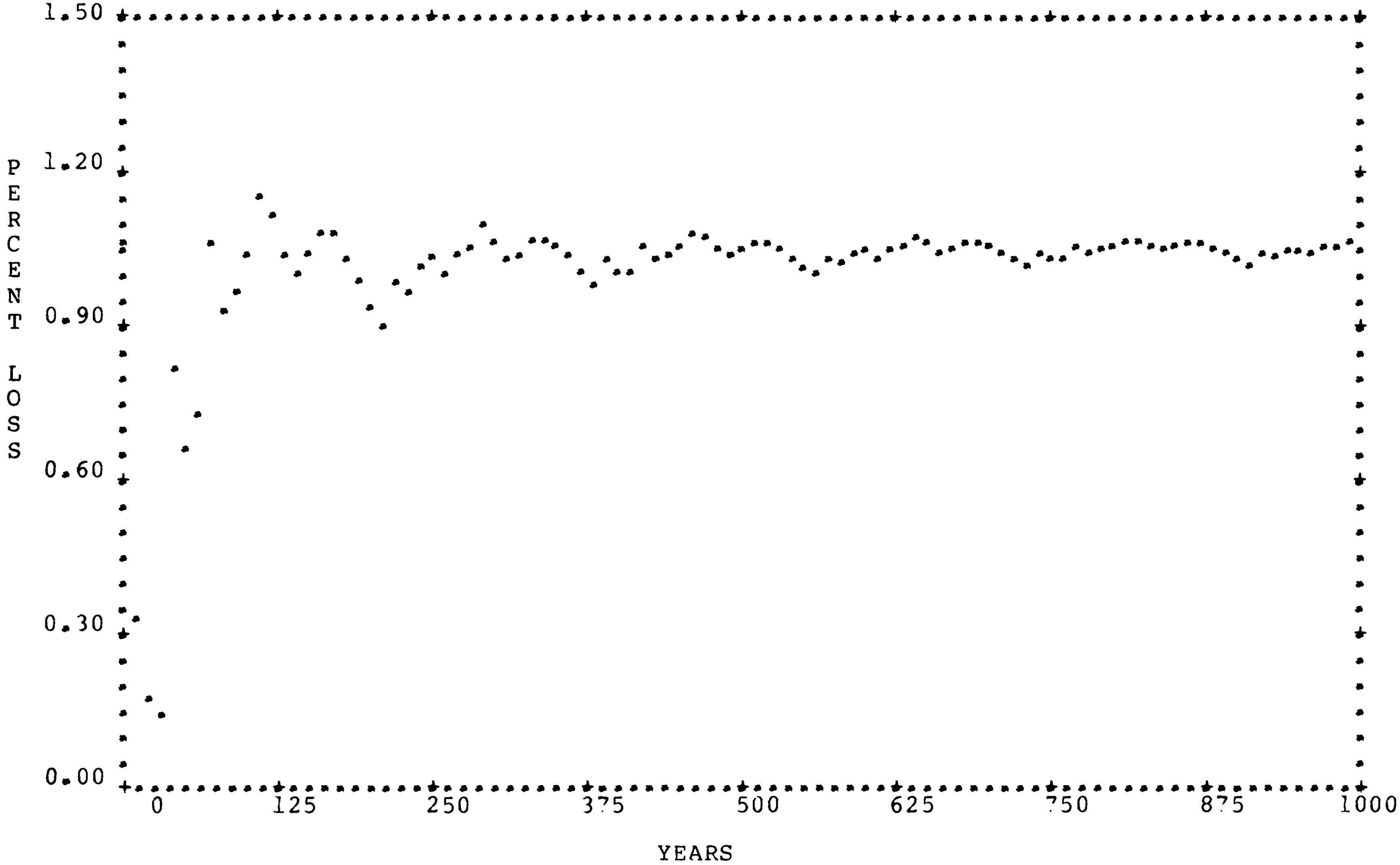

Figure 39.--Annual percent losses for subclass 5D based on losses averaged over from one to 1,000 years.

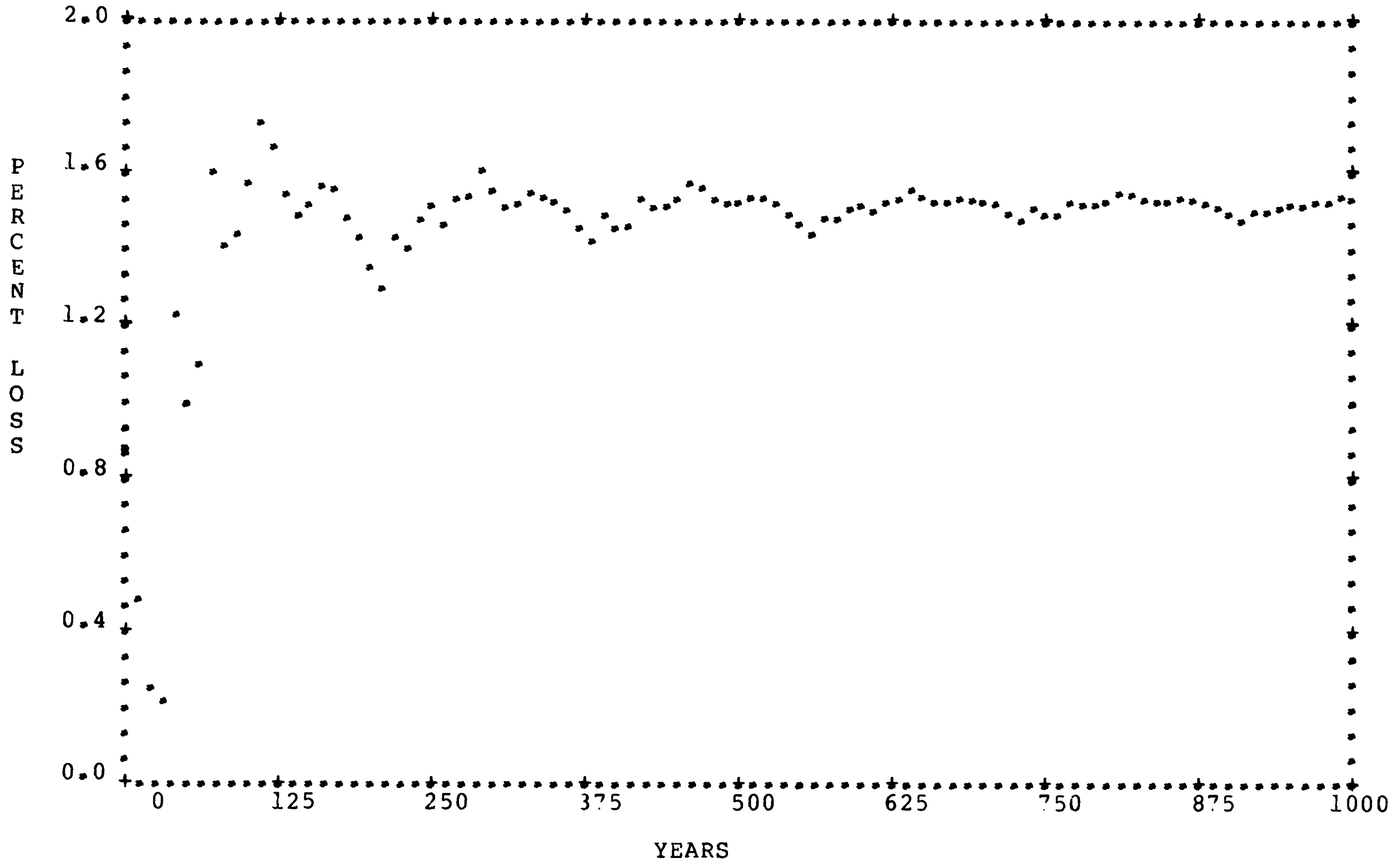

Figure 40.--Annual percent losses for subclass 5E based on losses averaged over from one to 1,000 years.

Table 19.--Average annual percent losses for each building subclass obtained from the 1,000-yr simulated seismicity record

Building subclass	Annual percent loss
2A	0.12
2B	.15
3LA	.15
3LB	.78
3LC	.18
3LD	.78
3HA	.22
3HB	.46
3HC	.28
3HD	.46
4LA	.18
4LB	1.12
4LC	.78
4LD	1.34
4LE	1.23
4HA	.28
4HB	.66
4HC	.46
4HD	.79
4HE	.74
5B	.18
5C	.78
5D	1.01
5E	1.44

Simulated Losses--Individual Earthquakes

Percent losses were simulated for nine individual earthquakes. Five of these earthquakes were located on the San Andreas fault with their epicenters located at the epicenter of the 1957 Daly City earthquake. Percent losses were computed for simulated earthquakes having maximum intensities of X, IX, VIII, VII, and VI. The remaining four simulated earthquakes were located on the Hayward fault at the approximate epicenter of the 1868 (maximum intensity IX) earthquake on the Hayward fault. Percent losses were computed for earthquakes having maximum intensities of IX, VIII, VII, and VI with identical epicenters on the Hayward fault. The results appear in tables 20 through 28. Losses to selected building subclasses in a few representative counties are shown in figures 41 through 44.

DISCUSSION OF RESULTS

Seismicity

The seismicity used in this report is the known historical earthquakes in the study areas from 1800 through 1974. The seismicity becomes progressively less well known going back into the 19th century. Large shocks (magnitude 7 and above) are probably completely known for the entire period; earthquakes of lesser magnitude are completely known for progressively shorter periods of time, as the magnitude decreases, until a magnitude threshold is reached below which earthquakes are not located even at the present. Thus use of the historical record for 1800-1974 will always result in loss estimates that are too low for the period considered. This is one reason for computing average earthquake losses using shorter (and more recent) segments of the seismic history. The disadvantage of using shorter segments of the seismic history is that large shocks are less well represented in the seismicity record, because their recurrence times are long compared with the recurrence times of small earthquakes.

For one set of results, the 175-year seismicity record was repeated a sufficient number of times (5.71 times) to permit the computation of average losses over a long period of time--1,000 years in this particular case. The basic assumption is that the future seismicity of the area will be the same as the past. This is a reasonable assumption, the principal difficulty being the uncertain recurrence intervals of the larger shocks.

Table 20.--Percent losses by county for a maximum intensity X earthquake on the San Andreas fault (similar to 1906 California earthquake)

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano	
2A	4.1581	5.0285	5.9211	4.4751	3.1059	3.8773	3.4400	1.2030	0.8361	2A
2B	6.4670	5.8816	8.0000	6.6336	3.2514	3.2490	*	4.2235	4.4000	2B
3HA	5.4814	10.0025	*	10.0469	*	*	*	*	*	3HA
3HB	12.2086	17.5044	*	17.5820	*	*	*	*	*	3HB
3HC	6.8568	12.5032	*	12.5586	*	*	*	*	*	3HC
3HD	12.2086	17.5044	*	17.5820	*	*	*	*	*	3HD
3LA	6.5634	8.5297	9.8546	7.3025	4.0080	5.1225	4.2361	3.9092	0.9529	3LA
3LB	13.3010	15.7722	17.2785	14.3141	9.2834	11.7764	10.6944	8.8469	3.0776	3LB
3LC	8.2074	10.6627	12.3183	9.1310	5.0136	6.4077	5.2987	4.8901	1.1917	3LC
3LD	13.3010	15.7722	17.2785	14.3141	9.2834	11.7764	10.6944	8.8469	3.0776	3LD
4HA	6.8568	12.5032	*	12.5586	*	*	*	*	*	4HA
4HB	17.4409	25.0063	*	25.1172	*	*	*	*	*	4HB
4HC	12.2086	17.5044	*	17.5820	*	*	*	*	*	4HC
4HD	20.9291	30.0076	*	30.1406	*	*	*	*	*	4HD
4HE	19.1850	27.5070	*	27.6289	*	*	*	*	*	4HE
4LA	8.2074	10.6627	12.3183	9.1310	5.0136	6.4077	5.2987	4.8901	1.1917	4LA
4LB	19.0014	22.5318	24.6836	20.4487	13.2620	16.8234	15.2778	12.6385	4.3966	4LB
4LC	13.3010	15.7722	17.2785	14.3141	9.2834	11.7764	10.6944	8.8469	3.0776	4LC
4LD	22.8017	27.0381	29.6203	24.5385	15.9144	20.1880	18.3333	15.1662	5.2759	4LD
4LE	20.9015	24.7850	27.1519	22.4936	14.5882	18.5057	16.8056	13.9023	4.8362	4LE
5B	8.2074	12.6627	12.3183	9.1310	5.0136	6.4077	5.2987	4.8901	1.1917	5B
5C	13.3010	15.7722	17.2785	14.3141	9.2834	11.7764	10.6944	8.8469	3.0776	5C
5D	17.1013	20.2786	22.2152	18.4039	11.9358	15.1410	13.7500	11.3746	3.9569	5D
5E	26.0544	33.4685	34.7881	30.5992	15.0768	23.9278	24.5000	16.3178	14.2283	5E

Table 21.--Percent losses by county for a maximum intensity IX earthquake on the San Andreas fault
(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano	
2A	2.2927	4.7368	5.7432	2.3480	1.1466	3.0507	1.7280	0.6015	0.1774	2A
2B	2.7235	5.3670	7.5658	2.2942	1.4245	2.9932	*	0.7679	*	2B
3HA	0.9966	10.0025	*	1.9469	*	*	*	*	*	3HA
3HB	6.9764	17.5044	*	8.1320	*	*	*	*	*	3HB
3HC	1.2458	12.5032	*	2.4346	*	*	*	*	*	3HC
3HD	6.9764	17.5044	*	8.1320	*	*	*	*	*	3HD
3LA	2.2323	7.5286	9.3316	2.3726	1.0817	2.9957	2.3681	0.7108	0.0782	3LA
3LB	8.2322	14.6043	16.6684	8.5626	4.9893	8.4110	5.7361	4.9754	0.8609	3LB
3LC	2.7918	9.4128	11.6650	2.9673	1.3528	3.7471	2.9622	0.8885	0.0977	3LC
3LD	8.2322	14.6043	16.6684	8.5626	4.9893	8.4110	5.7361	4.9754	0.8609	3LD
4HA	1.2458	12.5032	*	2.4346	*	*	*	*	*	4HA
4HB	9.9662	25.0063	*	11.6172	*	*	*	*	*	4HB
4HC	6.9764	17.5044	*	8.1320	*	*	*	*	*	4HC
4HD	11.9595	30.0076	*	13.9406	*	*	*	*	*	4HD
4HE	10.9628	27.5070	*	12.7789	*	*	*	*	*	4HE
4LA	2.7918	9.4128	11.6650	2.9673	1.3528	3.7471	2.9622	0.8885	0.0977	4LA
4LB	11.7603	20.8633	23.8120	12.2323	7.1276	12.0157	8.1944	7.1077	1.2299	4LB
4LC	8.2322	14.6043	16.6684	8.5626	4.9893	8.4110	5.7361	4.9754	0.8609	4LC
4LD	14.1124	25.0360	28.5744	14.6788	8.5531	14.4188	9.8333	8.5292	1.4759	4LD
4LE	12.9363	22.9497	26.1932	13.4556	7.8403	13.2172	9.0139	7.8185	1.3529	4LE
5B	2.7918	9.4128	11.6650	2.9673	1.3528	3.7471	2.9622	0.8885	0.0977	5B
5C	8.2322	14.6043	16.6684	8.5626	4.9893	8.4110	5.7361	4.9754	0.8609	5C
5D	10.5843	18.7770	21.4308	11.0091	6.4148	10.8141	7.3750	6.3969	1.1069	5D
5E	15.4025	30.7231	33.3898	17.1477	6.9514	13.8283	14.4375	8.8356	2.5996	5E

Table 22.--Percent losses by county for a maximum intensity VIII earthquake on the San Andreas fault

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano	
2A	*	1.3126	3.1786	0.2138	*	0.1760	*	*	*	2A
2B	*	0.4816	2.1062	0.0384	*	*	*	*	*	2B
3HA	*	*	*	0.2094	*	*	*	*	*	3HA
3HB	0.4127	*	*	2.8574	*	*	*	*	*	3HB
3HC	*	*	*	0.2617	*	*	*	*	*	3HC
3HD	0.4127	*	*	2.8574	*	*	*	*	*	3HD
3LA	*	0.6557	3.4752	0.1921	*	0.0940	*	*	*	3LA
3LB	1.4782	4.4232	9.5972	2.6911	1.0655	1.6603	1.7257	1.6531	1.1224	3LB
3LC	*	0.8197	4.3463	0.2401	*	0.1175	*	*	*	3LC
3LD	1.4782	4.4232	9.5972	2.6911	1.0655	1.6603	1.7257	1.6531	1.1224	3LD
4HA	*	*	*	0.2617	*	*	*	*	*	4HA
4HB	0.5895	*	*	4.0820	*	*	*	*	*	4HB
4HC	0.4127	*	*	2.8574	*	*	*	*	*	4HC
4HD	0.7074	*	*	4.8984	*	*	*	*	*	4HD
4HE	0.6485	*	*	4.4902	*	*	*	*	*	4HE
4LA	*	0.8197	4.3463	0.2401	*	0.1175	*	*	*	4LA
4LB	2.1117	6.3189	13.7102	3.8445	1.5222	2.3718	2.4653	2.3615	1.6034	4LB
4LC	1.4782	4.4232	9.5972	2.6911	1.0655	1.6603	1.7257	1.6531	1.1224	4LC
4LD	2.5340	7.5826	16.4523	4.6134	1.8266	2.8462	2.9583	2.8338	1.9241	4LD
4LE	2.3228	6.9507	15.0812	4.2289	1.6744	2.6090	2.7118	2.5977	1.7638	4LE
5B	*	0.8197	4.3463	0.2401	*	0.1175	*	*	*	5B
5C	1.4782	4.4232	9.5972	2.6911	1.0655	1.6603	1.7257	1.6531	1.1224	5C
5D	1.9005	5.6870	12.3392	3.4600	1.3699	2.1346	2.2188	2.1254	1.4431	5D
5E	2.7038	10.4626	19.0565	5.8023	2.1134	3.6144	3.5000	3.4533	1.2047	5E

Table 23.--Percent losses by county for a maximum intensity VII earthquake on the San Andreas fault

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano	
2A	*	0.3614	1.0241	*	*	*	*	*	*	2A
2B	*	*	0.3389	*	*	*	*	*	*	2B
3HA	*	*	*	*	*	*	*	*	*	3HA
3HB	0.4127	*	*	1.7582	*	*	*	*	*	3HB
3HC	*	*	*	*	*	*	*	*	*	3HC
3HD	0.4127	*	*	1.7582	*	*	*	*	*	3HD
3LA	*	0.0996	0.6240	*	*	*	*	*	*	3LA
3LB	1.4782	1.6351	4.3174	1.6826	1.0655	1.1667	1.7257	1.6531	0.2213	3LB
3LC	*	0.1245	0.7802	*	*	*	*	*	*	3LC
3LD	1.4782	1.6351	4.3174	1.6826	1.0655	1.1667	1.7257	1.6531	0.2213	3LD
4HA	*	*	*	*	*	*	*	*	*	4HA
4HB	0.5895	*	*	2.5117	*	*	*	*	*	4HB
4HC	0.4127	*	*	1.7582	*	*	*	*	*	4HC
4HD	0.7074	*	*	3.0141	*	*	*	*	*	4HD
4HE	0.6485	*	*	2.7629	*	*	*	*	*	4HE
4LA	*	0.1245	0.7802	*	*	*	*	*	*	4LA
4LB	2.1117	2.3358	6.1677	2.4038	1.5222	1.6667	2.4653	2.3615	0.3161	4LB
4LC	1.4782	1.6351	4.3174	1.6826	1.0655	1.1667	1.7257	1.6531	0.2213	4LC
4LD	2.5340	2.8030	7.4012	2.8845	1.8266	2.0000	2.9583	2.8338	0.3793	4LD
4LE	2.3228	2.5694	6.7844	2.6442	1.6744	1.8333	2.7118	2.5977	0.3477	4LE
5B	*	0.1245	0.7802	*	*	*	*	*	*	5B
5C	1.4782	1.6351	4.3174	1.6826	1.0655	1.1667	1.7257	1.6531	0.2213	5C
5D	1.9005	2.1022	5.5509	2.1634	1.3699	1.5000	2.2188	2.1254	0.2845	5D
5E	2.7038	2.9733	11.5226	3.2811	2.1134	1.5831	3.5000	3.4533	1.1413	5E

Table 24.--Percent losses by county for a maximum intensity VI earthquake on the San Andreas fault

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano	
2A	*	0.0507	0.0366	*	*	*	*	*	*	2A
2B	*	*	*	*	*	*	*	*	*	2B
3HA	*	*	*	*	*	*	*	*	*	3HA
3HB	0.4127	*	*	0.3664	*	*	*	*	*	3HB
3HC	*	*	*	*	*	*	*	*	*	3HC
3HD	0.4127	*	*	0.3664	*	*	*	*	*	3HD
3LA	*	*	0.0104	*	*	*	*	*	*	3LA
3LB	1.2741	1.0826	1.5699	0.5480	0.5495	1.0620	*	*	*	3LB
3LC	*	*	0.0130	*	*	*	*	*	*	3LC
3LD	1.2741	1.0826	1.5699	0.5480	0.5495	1.0620	*	*	*	3LD
4HA	*	*	*	*	*	*	*	*	*	4HA
4HB	0.5895	*	*	0.5234	*	*	*	*	*	4HB
4HC	0.4127	*	*	0.3664	*	*	*	*	*	4HC
4HD	0.7074	*	*	0.6281	*	*	*	*	*	4HD
4HE	0.6485	*	*	0.5758	*	*	*	*	*	4HE
4LA	*	*	0.0130	*	*	*	*	*	*	4LA
4LB	1.8202	1.5466	2.2428	0.7829	0.7850	1.5171	*	*	*	4LB
4LC	1.2741	1.0826	1.5699	0.5480	0.5495	1.0620	*	*	*	4LC
4LD	2.1842	1.8559	2.6913	0.9395	0.9419	1.8205	*	*	*	4LD
4LE	2.0022	1.7013	2.4671	0.8612	0.8634	1.6688	*	*	*	4LE
5B	*	*	0.0130	*	*	*	*	*	*	5B
5C	1.2741	1.0826	1.5699	0.5480	0.5495	1.0620	*	*	*	5C
5D	1.6382	1.3919	2.0185	0.7046	0.7065	1.3654	*	*	*	5D
5E	2.3706	2.8613	3.2542	0.9033	0.9294	1.3447	*	*	*	5E

Table 25.--Percent losses by county for a maximum intensity IX earthquake on the Hayward fault

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano	
2A	5.5389	2.3589	3.1752	2.4832	2.9674	3.3173	2.2560	2.6165	1.9519	2A
2B	8.0000	4.3184	5.3142	4.5589	4.5863	2.9932	*	4.2556	*	2B
3HA	9.9662	10.0025	*	1.0047	*	*	*	*	*	3HA
3HB	17.4409	17.5044	*	7.0328	*	*	*	*	*	3HB
3HC	12.4578	12.5032	*	1.2559	*	*	*	*	*	3HC
3HD	17.4409	17.5044	*	7.0328	*	*	*	*	*	3HD
3LA	9.2839	3.6462	4.7591	2.6599	4.6757	3.4103	2.6319	4.1862	1.3023	3LA
3LB	16.5741	9.2097	11.1101	8.8835	9.9251	8.8597	7.1215	10.6454	6.4086	3LB
3LC	11.6055	4.5604	5.9519	3.3256	5.8469	4.2658	3.2921	5.2362	1.6285	3LC
3LD	16.5741	9.2097	11.1101	8.8835	9.9251	8.8597	7.1215	10.6454	6.4086	3LD
4HA	12.4578	12.5032	*	1.2559	*	*	*	*	*	4HA
4HB	24.9155	25.0063	*	10.0469	*	*	*	*	*	4HB
4HC	17.4409	17.5044	*	7.0328	*	*	*	*	*	4HC
4HD	29.8986	30.0076	*	12.0563	*	*	*	*	*	4HD
4HE	27.4071	27.5070	*	11.0516	*	*	*	*	*	4HE
4LA	11.6055	4.5604	5.9519	3.3256	5.8469	4.2658	3.2921	5.2362	1.6285	4LA
4LB	23.6774	13.1568	15.8716	12.6907	14.1788	12.6567	10.1736	15.2077	9.1552	4LB
4LC	16.5741	9.2097	11.1101	8.8835	9.9251	8.8597	7.1215	10.6454	6.4086	4LC
4LD	28.4128	15.7881	19.0459	15.2288	17.0145	15.1880	12.2083	18.2492	10.9862	4LD
4LE	26.0451	14.4725	17.4587	13.9598	15.5966	13.9224	11.1910	16.7285	10.0707	4LE
5B	11.6055	4.5604	5.9519	3.3256	5.8469	4.2658	3.2921	5.2362	1.6285	5B
5C	16.5741	9.2097	11.1101	8.8835	9.9251	8.8597	7.1215	10.6454	6.4086	5C
5D	21.3096	11.8411	14.2844	11.4216	12.7609	11.3910	9.1563	13.6869	8.2397	5D
5E	33.2516	20.1446	21.0763	15.7286	15.5641	15.2875	14.4375	22.3067	10.9819	5E

Table 26.--Percent losses by county for a maximum intensity VIII earthquake on the Hayward fault

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano	
2A	3.1558	*	0.0576	0.0178	1.5234	1.3760	*	*	0.0632	2A
2B	3.2722	*	0.0645	*	3.0245	0.8000	*	*	*	2B
3HA	3.1189	*	*	*	*	*	*	*	*	3HA
3HB	9.4524	*	*	1.7582	*	*	*	*	*	3HB
3HC	3.8986	*	*	*	*	*	*	*	*	3HC
3HD	9.4524	*	*	1.7582	*	*	*	*	*	3HD
3LA	4.0763	0.1695	0.0429	0.0066	2.7743	0.6068	*	*	0.0276	3LA
3LB	10.2756	2.1133	1.2409	1.7175	6.0682	4.3526	1.7257	1.6531	1.2672	3LB
3LC	5.0977	0.2119	0.0537	0.0083	3.4683	0.7585	*	*	0.0345	3LC
3LD	10.2756	2.1133	1.2409	1.7175	6.0682	4.3526	1.7257	1.6531	1.2672	3LD
4HA	3.8986	*	*	*	*	*	*	*	*	4HA
4HB	13.5034	*	*	2.5117	*	*	*	*	*	4HB
4HC	9.4524	*	*	1.7582	*	*	*	*	*	4HC
4HD	16.2041	*	*	3.0141	*	*	*	*	*	4HD
4HE	14.8537	*	*	2.7629	*	*	*	*	*	4HE
4LA	5.0977	0.2119	0.0537	0.0083	3.4683	0.7585	*	*	0.0345	4LA
4LB	14.6795	3.0191	1.7728	2.4536	8.6688	6.2179	2.4653	2.3615	1.8103	4LB
4LC	10.2756	2.1133	1.2409	1.7175	6.0682	4.3526	1.7257	1.6531	1.2672	4LC
4LD	17.6154	3.6229	2.1273	2.9444	10.4026	7.4615	2.9583	2.8338	2.1724	4LD
4LE	16.1474	3.3210	1.9500	2.6990	9.5357	6.8397	2.7118	2.5977	1.9914	4LE
5B	5.0977	0.2119	0.0537	0.0083	3.4683	0.7585	*	*	0.0345	5B
5C	10.2756	2.1133	1.2409	1.7175	6.0682	4.3526	1.7257	1.6531	1.2672	5C
5D	13.2115	2.7172	1.5955	2.2083	7.8019	5.5962	2.2188	2.1254	1.6293	5D
5E	21.1097	7.8853	1.3164	3.2811	9.7397	5.6172	3.5000	3.4533	1.2047	5E

Table 27.--Percent losses by county for a maximum intensity VII earthquake on the Hayward fault

(* indicates a very low percentage)

Bldg. Subclass	Ala-meda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano	
2A	1.5358	*	*	*	0.7373	*	*	*	*	2A
2B	1.2232	*	*	*	0.8329	*	*	*	*	2B
3HA	1.2970	*	*	*	*	*	*	*	*	3HA
3HB	4.2201	*	*	1.7582	*	*	*	*	*	3HB
3HC	1.6224	*	*	*	*	*	*	*	*	3HC
3HD	4.2201	*	*	1.7582	*	*	*	*	*	3HD
3LA	1.7052	*	*	*	0.9568	*	*	*	*	3LA
3LB	6.0538	1.0826	1.0155	1.6826	3.5615	1.1667	1.7257	1.6531	1.1224	3LB
3LC	2.1327	*	*	*	1.1968	*	*	*	*	3LC
3LD	6.0538	1.0826	1.0155	1.6826	3.5615	1.1667	1.7257	1.6531	1.1224	3LD
4HA	1.6224	*	*	*	*	*	*	*	*	4HA
4HB	6.0287	*	*	2.5117	*	*	*	*	*	4HB
4HC	4.2201	*	*	1.7582	*	*	*	*	*	4HC
4HD	7.2345	*	*	3.0141	*	*	*	*	*	4HD
4HE	6.6316	*	*	2.7629	*	*	*	*	*	4HE
4LA	2.1327	*	*	*	1.1968	*	*	*	*	4LA
4LB	8.6483	1.5466	1.4508	2.4038	5.0879	1.6667	2.4653	2.3615	1.6034	4LB
4LC	6.0538	1.0826	1.0155	1.6826	3.5615	1.1667	1.7257	1.6531	1.1224	4LC
4LD	10.3780	1.8559	1.7409	2.8845	6.1054	2.0000	2.9583	2.8338	1.9241	4LD
4LE	9.5131	1.7013	1.5959	2.6442	5.5966	1.8333	2.7118	2.5977	1.7638	4LE
5B	2.1327	*	*	*	1.1968	*	*	*	*	5B
5C	6.0538	1.0826	1.0155	1.6826	3.5615	1.1667	1.7257	1.6531	1.1224	5C
5D	7.7835	1.3919	1.3057	2.1634	4.5791	1.5000	2.2188	2.1254	1.4431	5D
5E	14.0854	2.8613	1.3164	3.2811	6.5529	1.5831	3.5000	3.4533	1.2047	5E

Table 28.--Percent losses by county for a maximum intensity VI earthquake on the Hayward fault

(* indicates a very low percentage)

Bldg. Subclass	Alameda	San Fran.	San Mateo	Santa Clara	Contra Costa	Marin	Sonoma	Napa	Solano	
2A	0.5633	*	*	*	*	*	*	*	*	2A
2B	0.2396	*	*	*	*	*	*	*	*	2B
3HA	0.2358	*	*	*	*	*	*	*	*	3HA
3HB	1.6507	*	*	0.3664	*	*	*	*	*	3HB
3HC	0.2948	*	*	*	*	*	*	*	*	3HC
3HD	1.6507	*	*	0.3664	*	*	*	*	*	3HD
3LA	0.3057	*	*	*	0.0092	*	*	*	*	3LA
3LB	3.0938	1.0826	1.0155	0.8321	0.9759	1.1667	*	1.2438	0.0483	3LB
3LC	0.3822	*	*	*	0.0115	*	*	*	*	3LC
3LD	3.0938	1.0826	1.0155	0.8321	0.9759	1.1667	*	1.2438	0.0483	3LD
4HA	0.2948	*	*	*	*	*	*	*	*	4HA
4HB	2.3581	*	*	0.5234	*	*	*	*	*	4HB
4HC	1.6507	*	*	0.3664	*	*	*	*	*	4HC
4HD	2.8297	*	*	0.6281	*	*	*	*	*	4HD
4HE	2.5939	*	*	0.5758	*	*	*	*	*	4HE
4LA	0.3822	*	*	*	0.0115	*	*	*	*	4LA
4LB	4.4197	1.5466	1.4508	1.1888	1.3942	1.6667	*	1.7769	0.0690	4LB
4LC	3.0938	1.0826	1.0155	0.8321	0.9759	1.1667	*	1.2438	0.0483	4LC
4LD	5.3036	1.8559	1.7409	1.4265	1.6730	2.0000	*	2.1323	0.0828	4LD
4LE	4.8617	1.7013	1.5959	1.3076	1.5336	1.8333	*	1.9546	0.0759	4LE
5B	0.3822	*	*	*	0.0115	*	*	*	*	5B
5C	3.0938	1.0826	1.0155	0.8321	0.9759	1.1667	*	1.2438	0.0483	5C
5D	3.9777	1.3919	1.3057	1.0699	1.2548	1.5000	*	1.5992	0.0621	5D
5E	7.5420	2.8613	1.3164	1.2329	1.7165	1.5831	*	2.2089	*	5E

Losses-Individual Earthquakes

Figures 41-44 show selected results for earthquakes on the San Andreas and Hayward faults. Losses to all building subclasses may be found in tables 20-28. Consider the losses resulting from an intensity X earthquake on the San Andreas fault--equivalent to an earthquake of the 1906 San Francisco type. Table 20 shows that San Francisco, Alameda, and Santa Clara Counties show losses to all building subclasses. This is a result of the *presence* of all building subclasses in these counties plus their proximity to the area of strong ground shaking. It is interesting to compare percent losses to subclass 3HB structures (steel frame four stories and over with ordinary damage control features) in San Francisco County with losses to dwellings resulting from the simulation of the same earthquake in an earlier study (Rinehart and others, 1976).

Table 29 shows the distribution of subclass 3HB buildings by county. The percent loss of 3HB buildings in the nine-county area from an earthquake of maximum intensity X on the San Andreas fault is (from tables 20 and 29):

12.2 percent x 12.5 percent (Alameda County)+
17.5 percent x 85.5 percent (San Francisco County)+
17.6 percent x 2.0 percent (Santa Clara County)=16.8 percent

The percent loss to dwellings for the same earthquake was estimated to be 3.0 percent (Rinehart and others, 1976, table 16, p. 52). Similar comparisons can be made between other classes of structures.

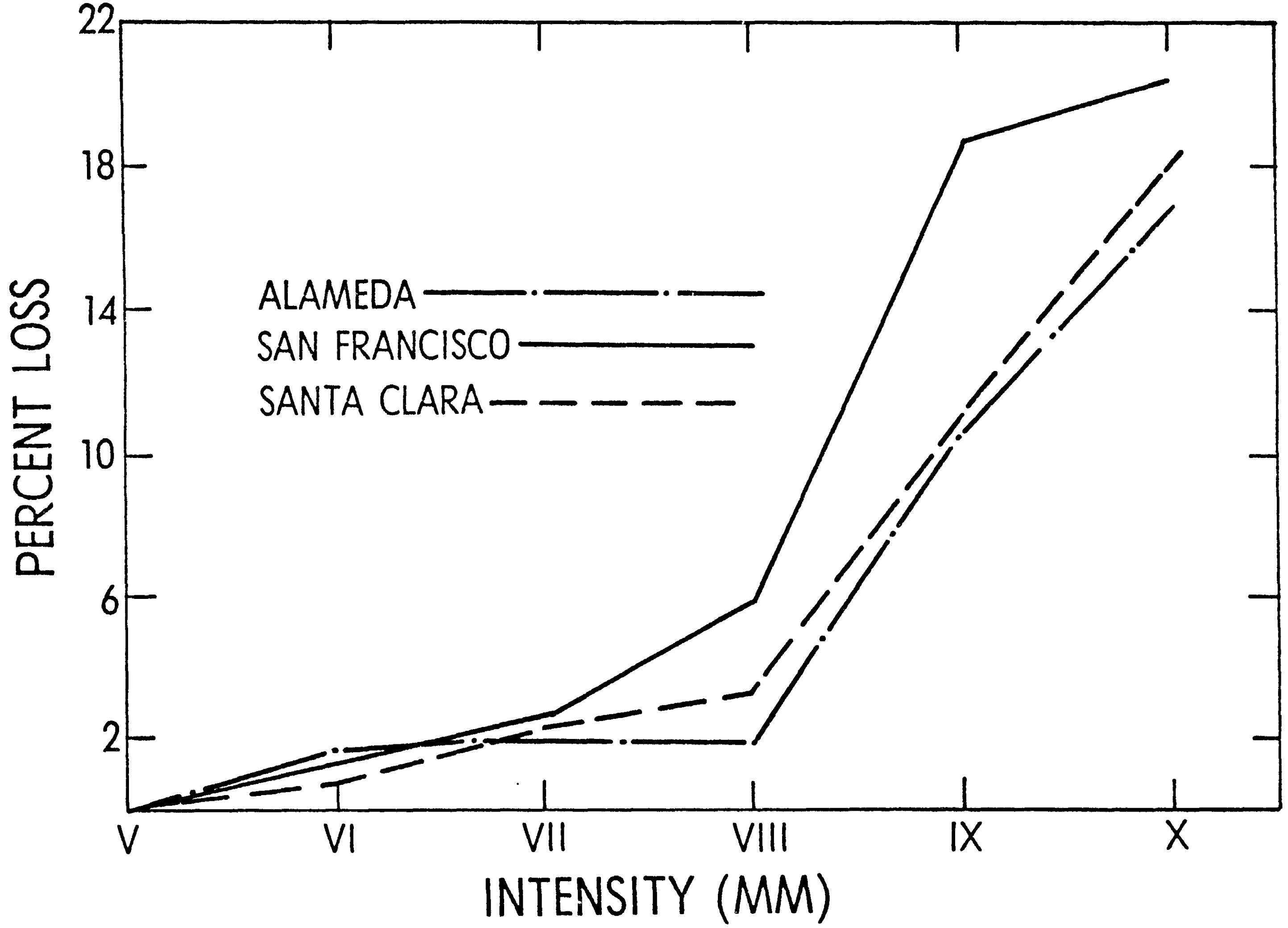

Figure 41.--Percent loss in selected counties for class 5D structures due to earthquakes on the San Andreas fault.

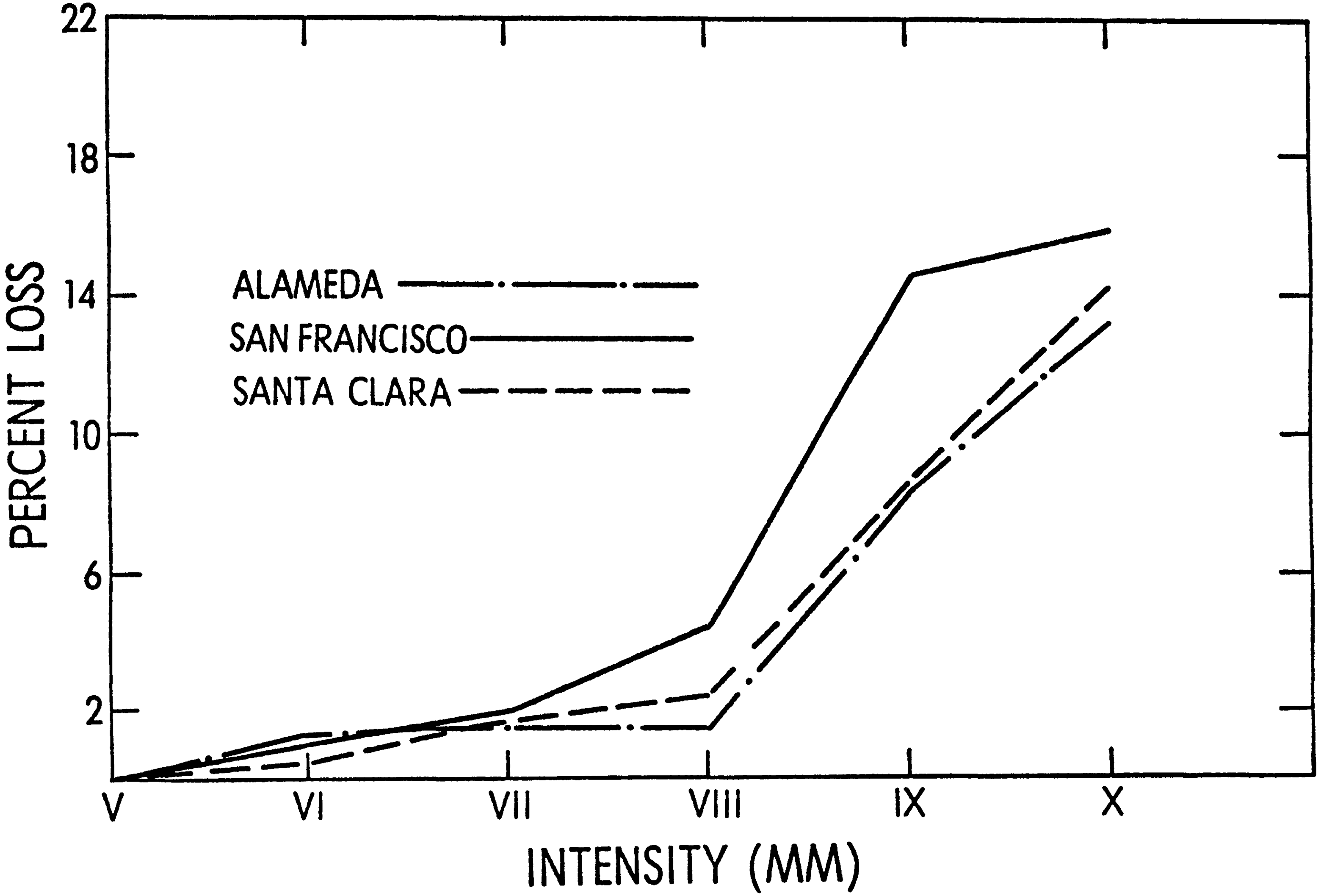

Figure 42.--Percent loss in selected counties for class 3B-low rise (steel) structures due to earthquakes on the San Andreas fault.

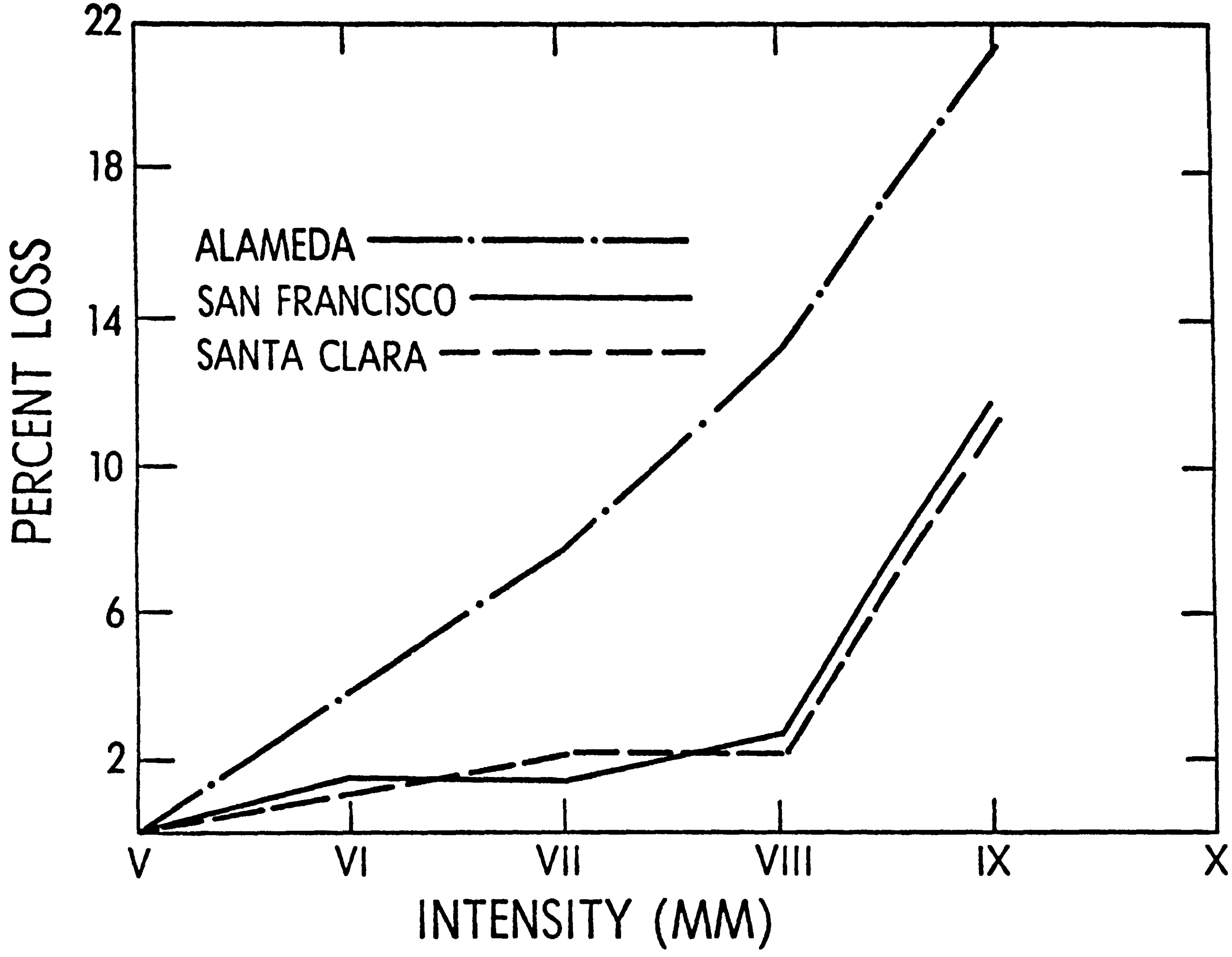

Figure 43.--Percent loss in selected counties for class 5D structures due to earthquakes on the Hayward fault.

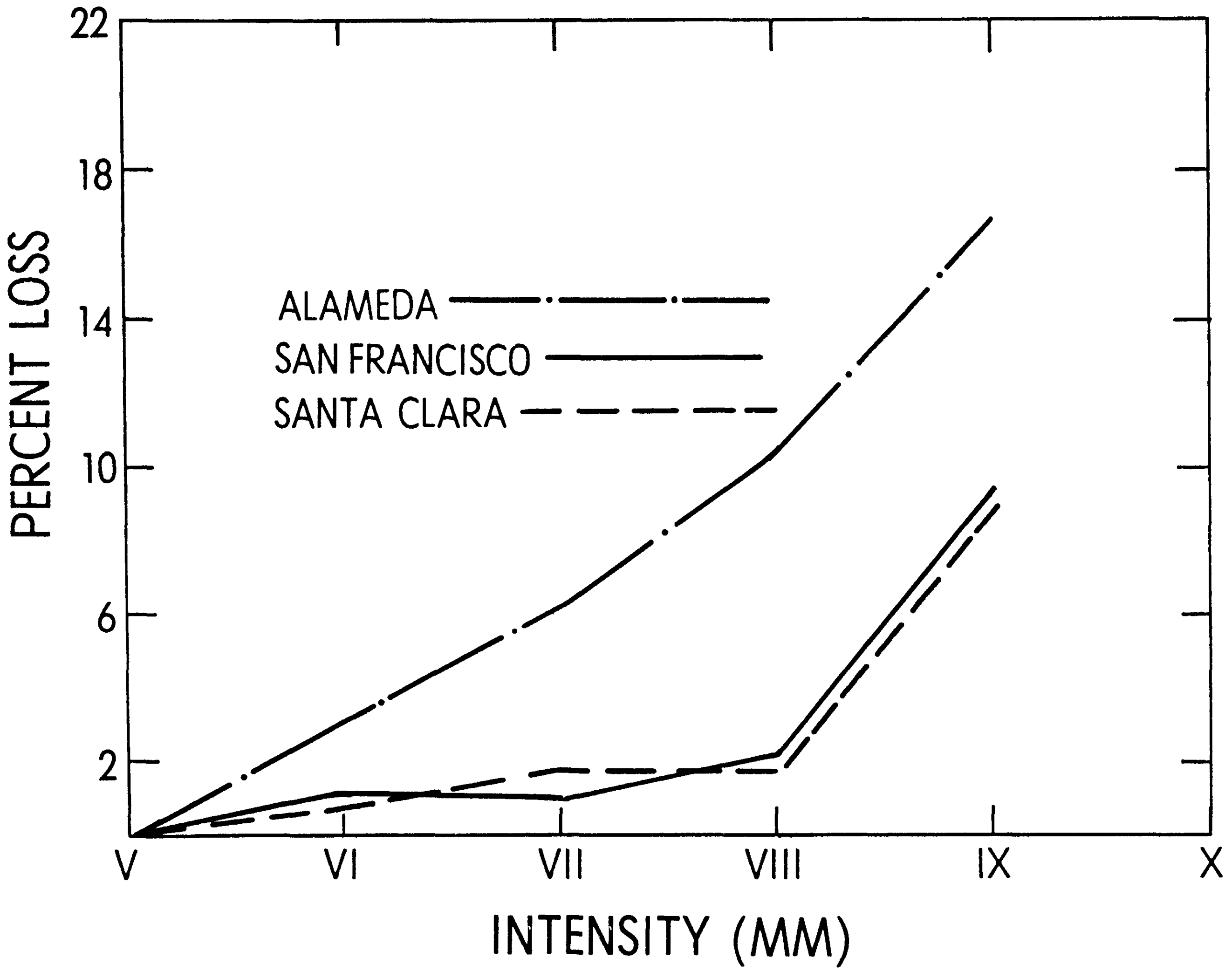

Figure 44.--Percent loss for class 3B-Low rise (steel) structures due to earthquakes on the Hayward fault.

Table 29.--Distribution of subclass 3HB buildings by county

County	Percent of structures in study area	Percent of value (such as floor area)
San Francisco	85.5	86.8
Alameda	12.5	12.0
Santa Clara	2.0	1.2

Figures 41-44 display the nature of the losses incurred in larger earthquakes on either the San Andreas or Hayward faults. In general, percent losses for all subclasses are larger than for single family dwellings investigated in earlier reports (Rinehart and others, 1976). Percent losses to certain subclasses appear to be larger in the East Bay area, Alameda County, than in San Francisco. This probably results from the proximity of the Hayward fault plus large areas of relatively unstable ground in the industrial areas of the East Bay area. It should also be noted that a fairly sharp break in percent losses occurs between the maximum intensity VIII and IX levels.

Average percent losses

Figure 14 shows percent losses in San Francisco County for selected subclasses computed using four different time spans of seismicity data. Note that for the most part the average losses are highest when the seismicity for the 100-year period 1800-1899 is used. This is a consequence of the three large earthquakes that occurred during this period (in 1838 on the San Andreas fault; in 1836 and 1868 on the Hayward fault). The average losses derived from the seismicity in the time span 1907-1974 (68 years) is the lowest of the averages shown. This low average occurs because no large earthquakes have occurred in northern California since 1906.

Figure 15 shows losses to selected subclasses for the entire nine-county study area. Note that certain subclasses show slightly decreased losses for the 100-year span while the balance of the structures show an increase. This is a consequence of the site geologic effect and the wider distribution (particularly in the East Bay area) of 4L and 5 subclasses.

Figure 16 shows average losses for subclass 2A computed by using losses averaged over 5, 10, and 15 years. The average is a moving average computed by summing losses for the year in question plus the preceding 4, 9, or 14 years and dividing by 5, 10, or 15 to obtain the required average. The predictive value of this type of average is low, as might be expected, and it has essentially no helpful insurance information. This may be seen by examining the averages just prior to the large earthquakes of 1836, 1838, 1868, and 1906.

A much more instructive and useful presentation of average percent losses may be found in figures 17-40 and table 19. These are average percent losses computed using seismicity data for from 1 to 1,000 years as previously described. Examination of these curves shows that as the time span of seismicity data increases the average losses converge to a relatively constant average loss. The averages are, of course, computed on the basis that the seismicity of the area repeats itself every 175 years. Even if this is a valid assumption, the averages are slightly low because of the incompleteness of the historical seismic record in the 19th century. The average losses converge to a more or less constant value for time intervals greater than about 300-500 years.

Averages based on 300 years or greater suggest reasonable long-term percent losses. The peak losses for each subclass of buildings, which are shown for short time base averaging,probably approach the maximum percent losses per class likely to be experienced in any 1- to 5-yr period. Comparison of the average annual percent losses in table 19 with the average annual percent losses based on four selected time samples of seismicity (1800-1974, 1800-1899, 1900-1974, and 1907-1974) found in table 18 show that the results of table 18 do not represent long term trends very well.

All of the averages computed, with the exception of the long term 1,000-yr averages, are erratic and not representatives of long losses. The 10-yr average losses are less erratic since 1906 simply because large earthquakes have not occurred in the San Francisco Bay area since 1906. There is considerable reason to believe that this condition will not continue in the future and that highly variable annual losses will again appear.

Losses associated with geologic effects

Losses associated with geologic effects such as landslides, liquefaction, surface faulting, and so forth, were not estimated in this study. They are, however, believed to be a small proportion of the total losses. An earlier study (Algermissen, Rinehart, Dewey, and others, 1972) showed that losses to single family dwellings from surface faulting in the San Francisco Bay area would be no more than 5 percent of the total losses. Since buildings larger than single family dwellings are normally more carefully engineered than single family dwellings (particularly with regard to site selection), one would expect that few large buildings would be sited on active fault traces. Losses associated with landsliding are difficult to estimate because of the effects of rainfall, evaluation of landslide potential, and so forth; but in the aggregate, losses associated with landslides are likely to be less than one fourth of the total losses. Losses associated with liquefaction are also difficult to estimate because of the problem of identifying those areas that may fail. Once again, the losses resulting from liquefaction are believed to be small compared to the total losses. There is little question that the major losses are associated with ground shaking (Algermissen, Rinehart, Dewey, and others, 1972).

Extension of the methodology to other areas

In general, the applicability of the methodology developed here to areas other than the nine-county San Francisco area will depend on the following:

> Inventory--The method used to obtain inventory in this report is transferable if (1) the building classification remains valid, and (2) if the area in question uses a land classification scheme similar to the one in the San Francisco area. Building design and construction practice in any area to which this methodology is to be transferred must be carefully evaluated.
>
> Loss-ground shaking relationships--Loss-ground shaking relationships (M.M. intensity) will remain approximately the same *if* the building classification used here remains valid in the new area where the methodology is to be applied. In the Eastern United

States, design and construction practice are, in some instances, different than in the present study area. Sound engineering judgment must be used to modify the loss-ground shaking relationships to take these differences in design and construction practice into account.

The Modified Mercalli scale as a measure of ground shaking--More quantitative measures of ground shaking derived from records of strong ground motion are still quite rare outside of California. Despite its flaws and limitations, the M.M. scale still provides a measure of ground shaking that is widely available for historical earthquakes that have occurred throughout the United States.

REFERENCES CITED

Algermissen, S. T., 1972, The seismic risk map of the United States, development, use, and plans for future refinement: Seismic Risk Assessment for Building Standards Conference, Department of Housing and Urban Development, Department of Commerce, Washington, D.C., p. 11-16.

Algermissen, S. T., Rinehart, W. A., Dewey, J., Steinbrugge, K. V. (principal consultant), Lagorio, H. J., Degenkolb, H. J., Cluff, L. S., McClure, F. E., Scott, Stanley, and Gordon, R. F., 1972, A study of earthquake losses in the San Francisco Bay area--A report prepared for the Office of Emergency Preparedness: U.S. Department of Commerce, NOAA, Environmental Research Laboratories, 220 p.

Algermissen, S. T., Rinehart, W. A., and Stepp, J. C., 1972, A technique for seismic zoning: Economic considerations: International Conference on Microzonation, Seattle, Proceedings, p. 943-956.

Algermissen, S. T., (principal investigator), Steinbrugge, K. V. (principal consultant), Hopper, Margaret, Campbell, Kenneth, Rinehart, W. A., Perkins, David, Lagorio, H. J., Moran, D. F., Cluff, L. S., Degenkolb, H. J., Duke, C. M., Gates, G. O., Jacobson, D. W., and Olson, R. A., 1973, A study of earthquake losses in the Los Angeles, California, area--A report prepared for the Federal Disaster Assistance Administration, Department of Housing and Urban Development: U.S. Department of Commerce, NOAA, Environmental Research Laboratories, 331 p.

Algermissen, S. T., Stepp, J. C., Rinehart, W. A., and Arnold, E. P., 1969, Appendix B, in Studies in seismicity and earthquake damage statistics: U.S. Coast and Geodetic Survey, 68 p.

Bannister, E. W., 1927, Rating buildings for liability to earthquake damage: Engineering News-Record, v. 98, no. 26, p. 1052-54.

Chick, Alton C., 1934, Discussion of fundamental factors involved in underwriting of earthquake insurance: Seismological Society of America Bulletin, v. 24, p. 385-397.

Freeman, John R., 1932, Earthquake damage and earthquake insurance: New York, McGraw-Hill.

Hopper, M. G., Langer, C. J., Spence, W. J., Rogers, A. M., Algermissen, S. T., Olsen, B. C., Lagorio, H. J., and Steinbrugge, K. V., 1975, Study of earthquake losses in the Puget Sound, Washington, area: U.S. Geological Survey Open-File Report 75-375, 298 p.

McClure, Frank, 1973, Performance of single family dwellings in the San Fernando earthquake of February 9, 1971: Department of Commerce, Department of Housing and Urban Development, 95 p.

Richter, C. F., 1958, Elementary seismology: San Francisco, California, W. H. Freeman and Company, 768 p.

Rinehart, W. A., Algermissen, S. T., and Gibbons, Mary, 1976, Estimation of earthquake losses to single family dwellings: U.S. Geological Survey Open-File Report 76-156, 57 p. plus appendices.

Rogers, A. M., Algermissen, S. T., Hays, W. W., Perkins, D. M., Van Strien, D. O., Hughes, H. C., Hughes, R. C., Lagorio, H. J., and Steinbrugge, K. V., 1976, A study of earthquake losses in the Salt Lake City, Utah, area: U.S. Geological Survey Open-File Report 76-89, 357 p.

Steinbrugge, K. V., and Lagorio, H., 1975, Building classifications and relationships among losses, intensities, and classes: Report to U.S. Geological Survey, v. 1, 88 p. and appendices.

Steinbrugge, K. V., Lagorio, H. J., and Algermissen, S. T., 1976, Methodologies for estimating life loss, property damage, and functional impairments: Proceedings of Chilean Association of Seismology and Earthquake Engineering (In press).

Steinbrugge, K. V., McClure, F. E., and Snow, A. J., 1969, Appendix A, in Studies in seismicity and earthquake damage statistics: U.S. Coast and Geodetic Survey, 142 p.

U.S. Coast and Geodetic Survey, 1969, Summary and recommendations, in Studies in seismicity and earthquake damage statistics: Department of Commerce, 142 p.

U.S. Department of Commerce, 1967, Studies in seismicity and earthquake damage statistics--part 1: ESSA, Coast and Geodetic Survey, 345 p.

U.S. Geological Survey, 1973, Atlas of urban and regional changes, San Francisco Bay area: U.S. Geological Survey Open-File Report, 44 maps, 1:62,500.

Voigt, D. S., and Byerly, Perry, 1949, The intensity of earthquakes as rated from questionnaires: Seismol. Soc. America Bull., v. 39, p. 21-26.

Wesson, R. L., Helley, E. J., Lajoie, K. R., and Wentworth, C. M., 1975, Faults and future earthquakes: U.S. Geological Survey Professional Paper 941-A, p. 5-30.

Western Economic Research Company, 1973, Census tract outline map of the Bay area and vicinity: Sherman Oaks, Calif., scale 1:125,000.

Wood, H. O., and Neumann, F., 1931, Modified Mercalli intensity scale of 1931: Seismological Society of America Bulletin, v. 21, no. 4, p. 227-283.

APPENDIX A

Average losses for various classes of construction are computed using the preceding 10 yr of historical earthquake history in the San Francisco Bay area are presented in this appendix. The losses are computed yearly. For example, the average losses for the period 1911-1920 are plotted for 1920.

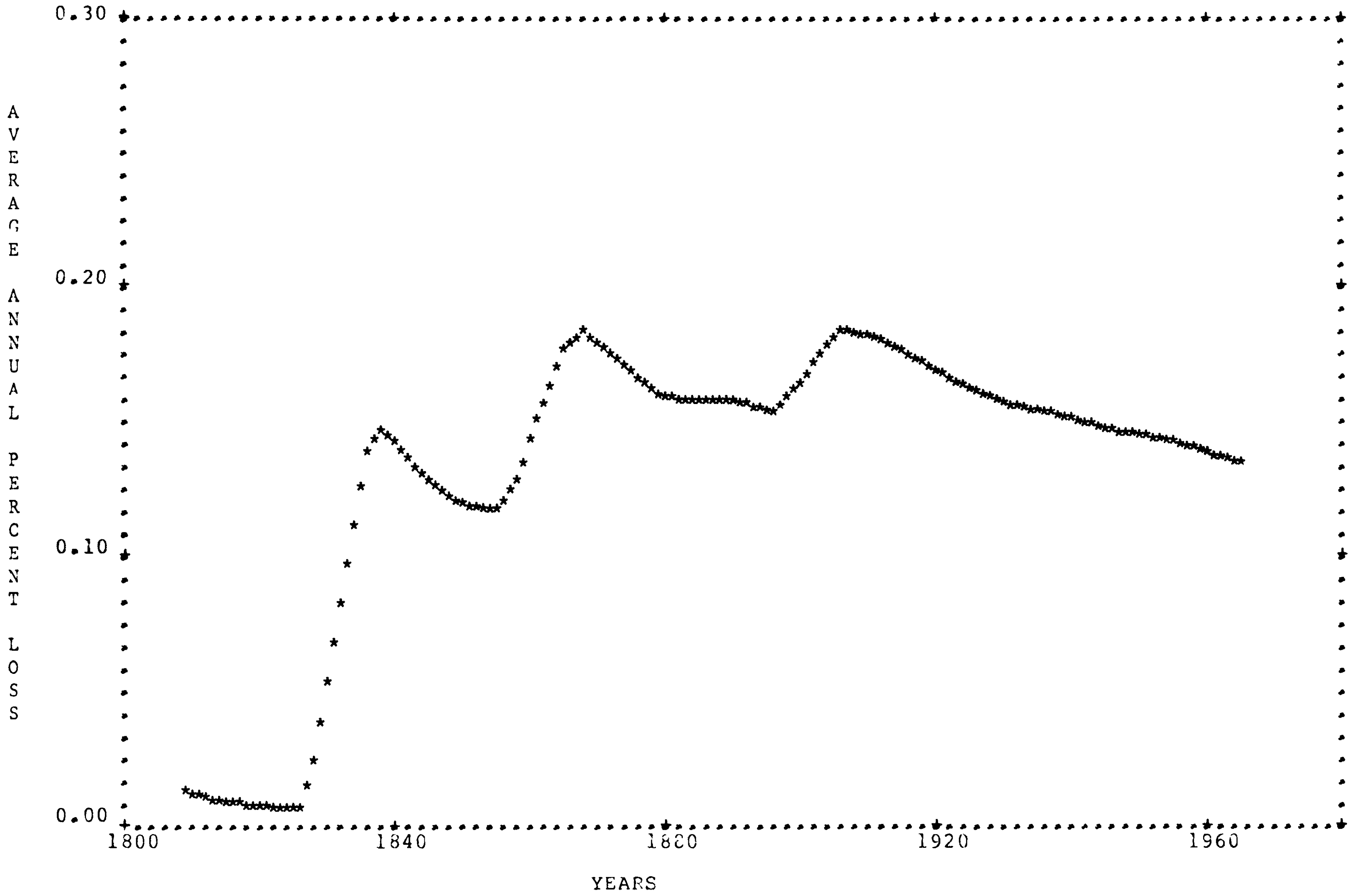

Figure A-1.--Average annual losses by class of construction (sublcass 2A) for the nine county area. The averages are computed using a 10 year moving time filter.

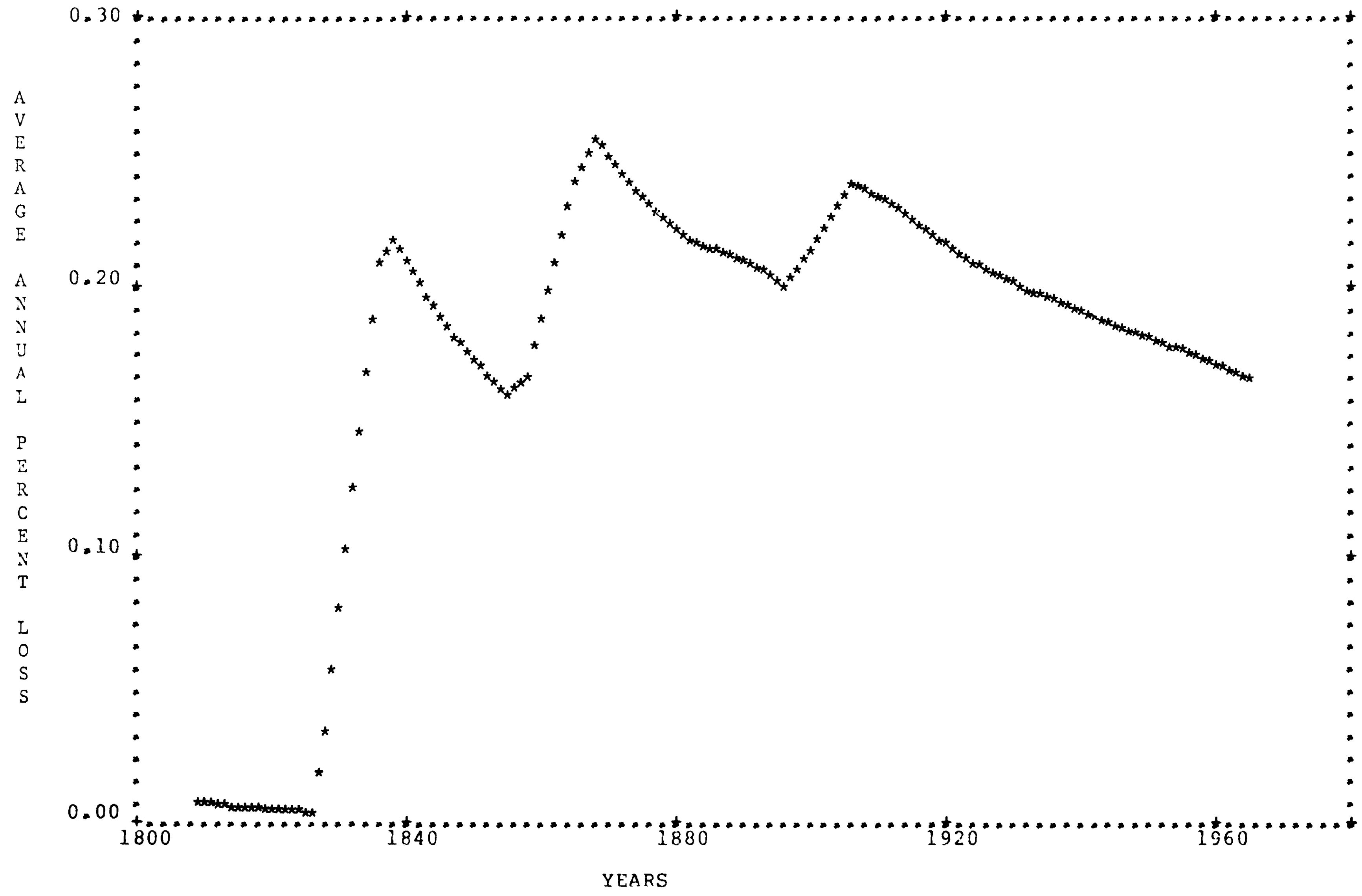

Figure A-2.--Average annual losses by class of construction (subclass 2B) for the nine county area. The averages are computed using a 10 year moving time filter.

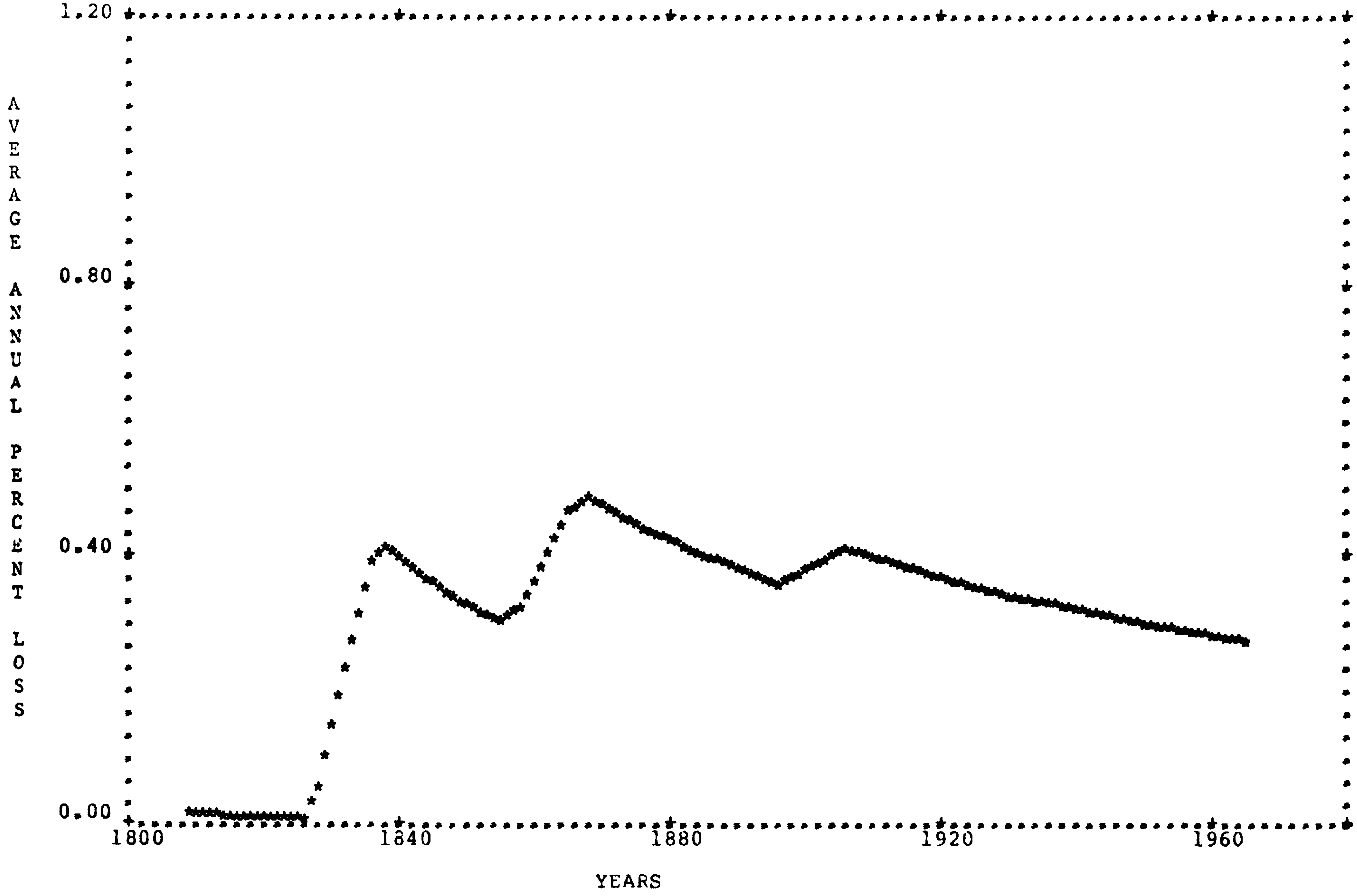

Figure A-3.--Average annual losses by class of construction (subclass 3HA) for the nine county area. The averages are computed using a 10 year moving time filter.

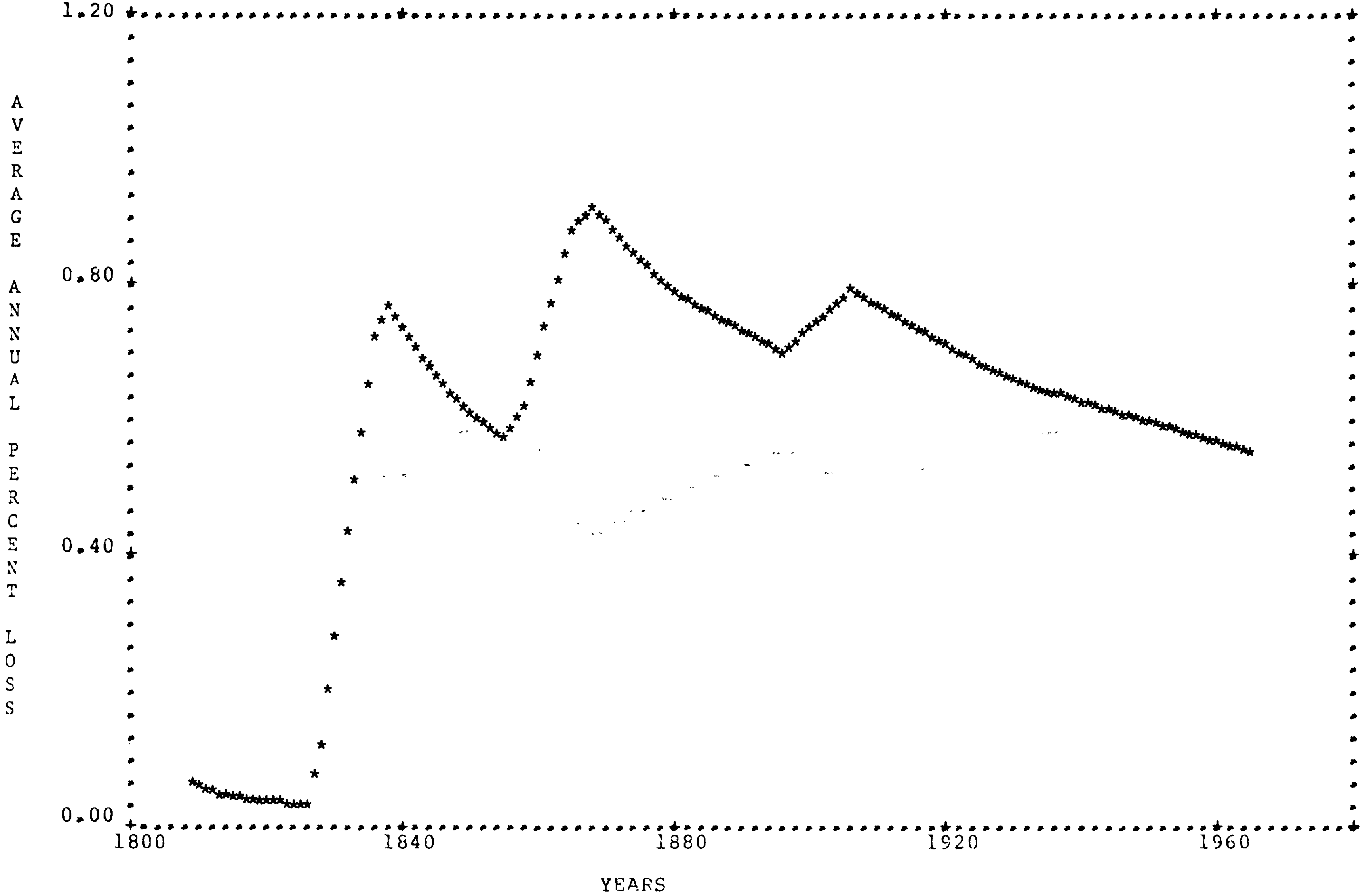

Figure A-4.--Average annual losses by class of construction (subclasses 3HB, 3HD, 4HC) for the nine county area. The averages are computed using a 10 year moving time filter.

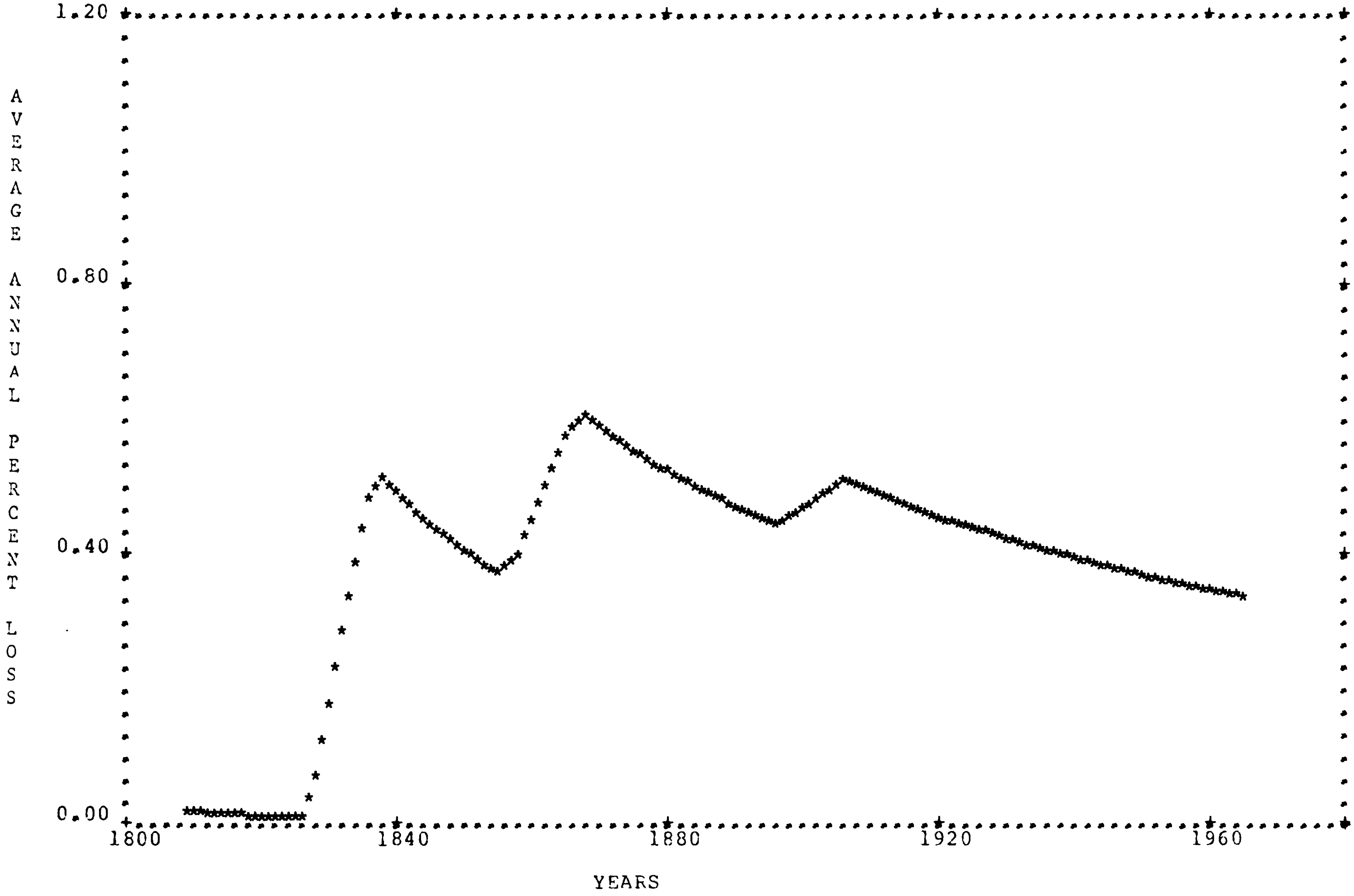

Figure A-5.--Average annual losses by class of construction (subclasses 3HC, 4HA) for the nine county area. The averages are computed using a 10 year moving time filter.

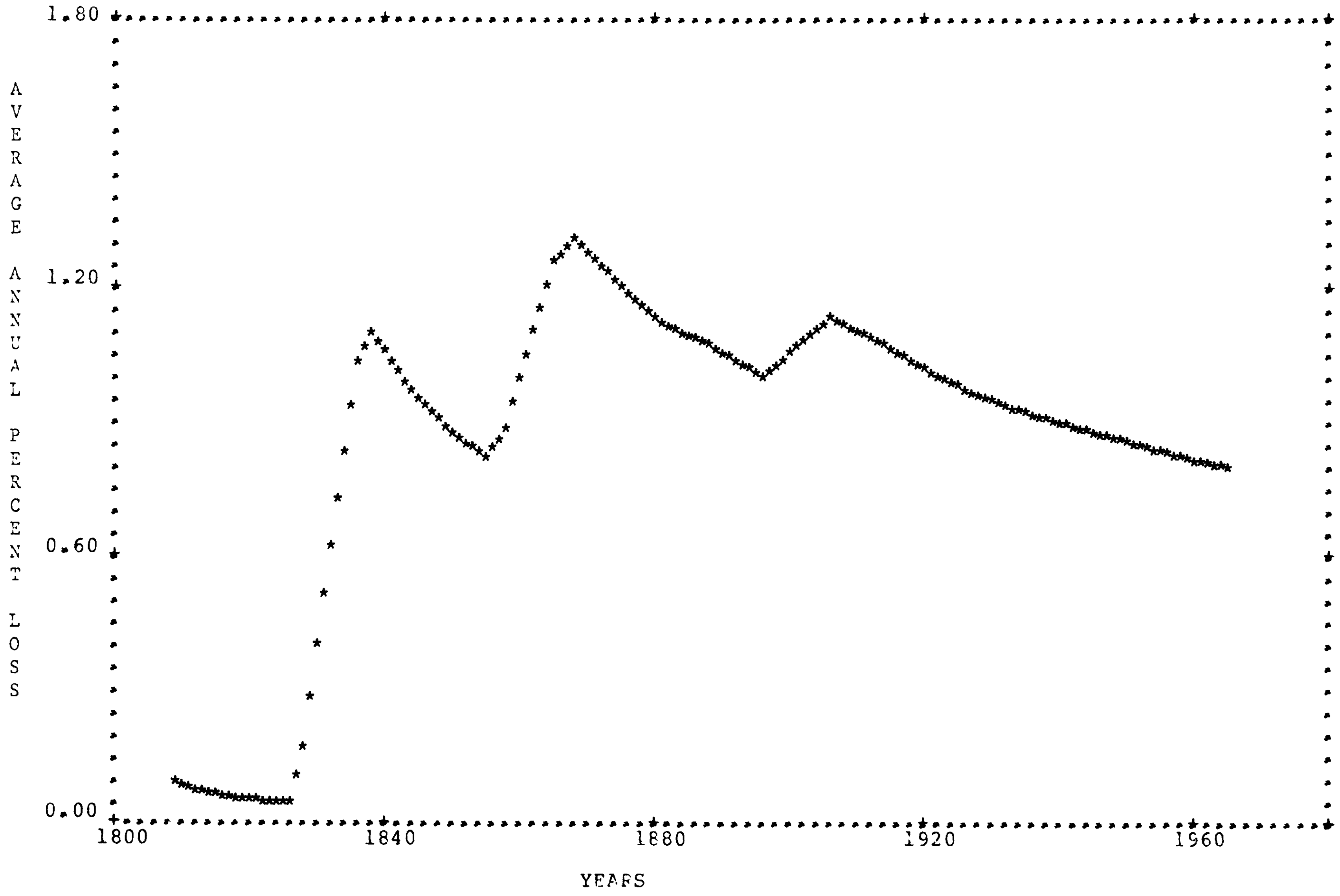

Figure A-6.--Average annual losses by class of construction (subclass 4HB) for the nine county area. The averages are computed using a 10 year moving time filter.

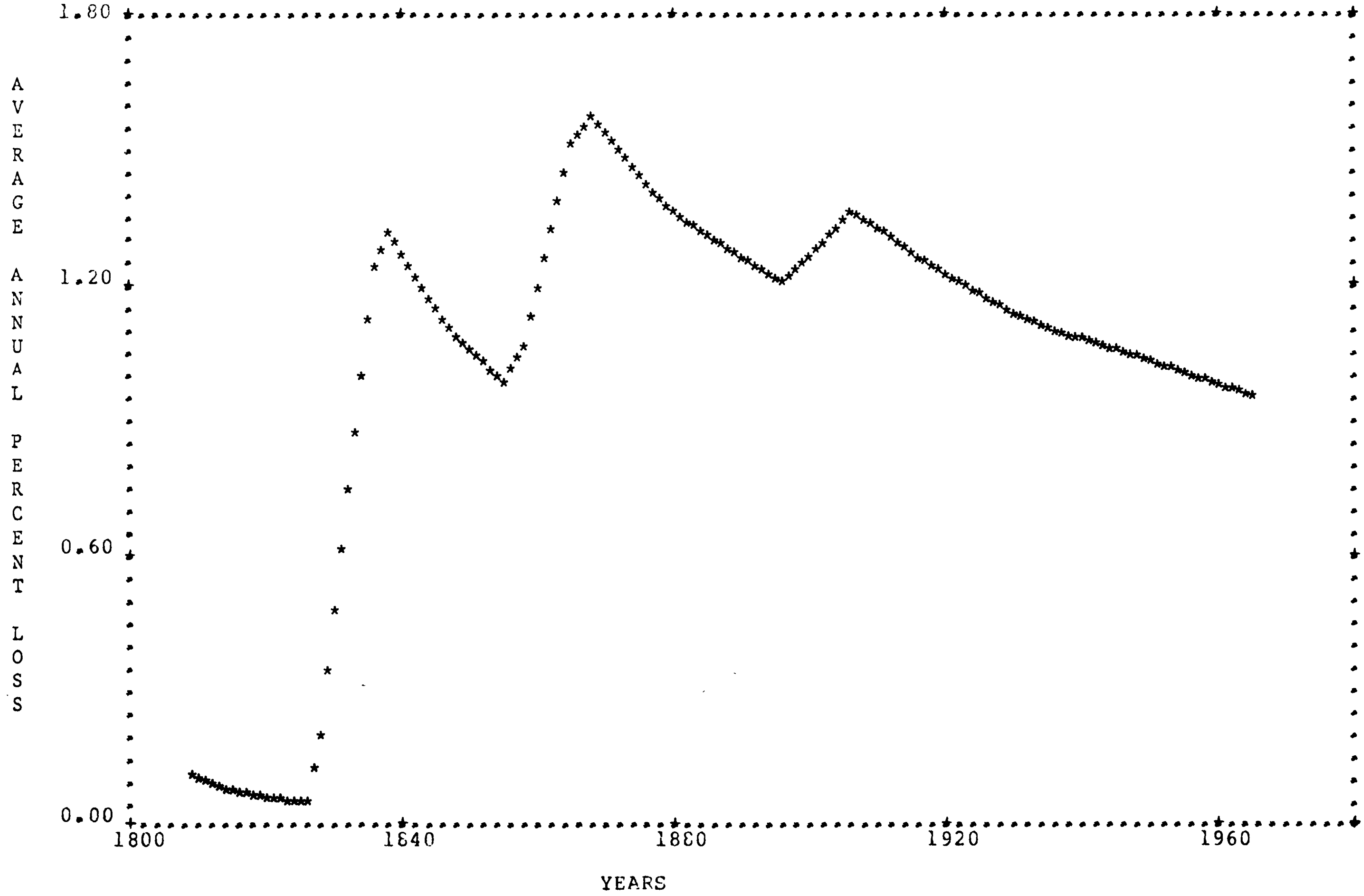

Figure A-7.--Average annual losses by class of construction (subclass 4HD) for the nine county area. The averages are computed using a 10 year moving time filter.

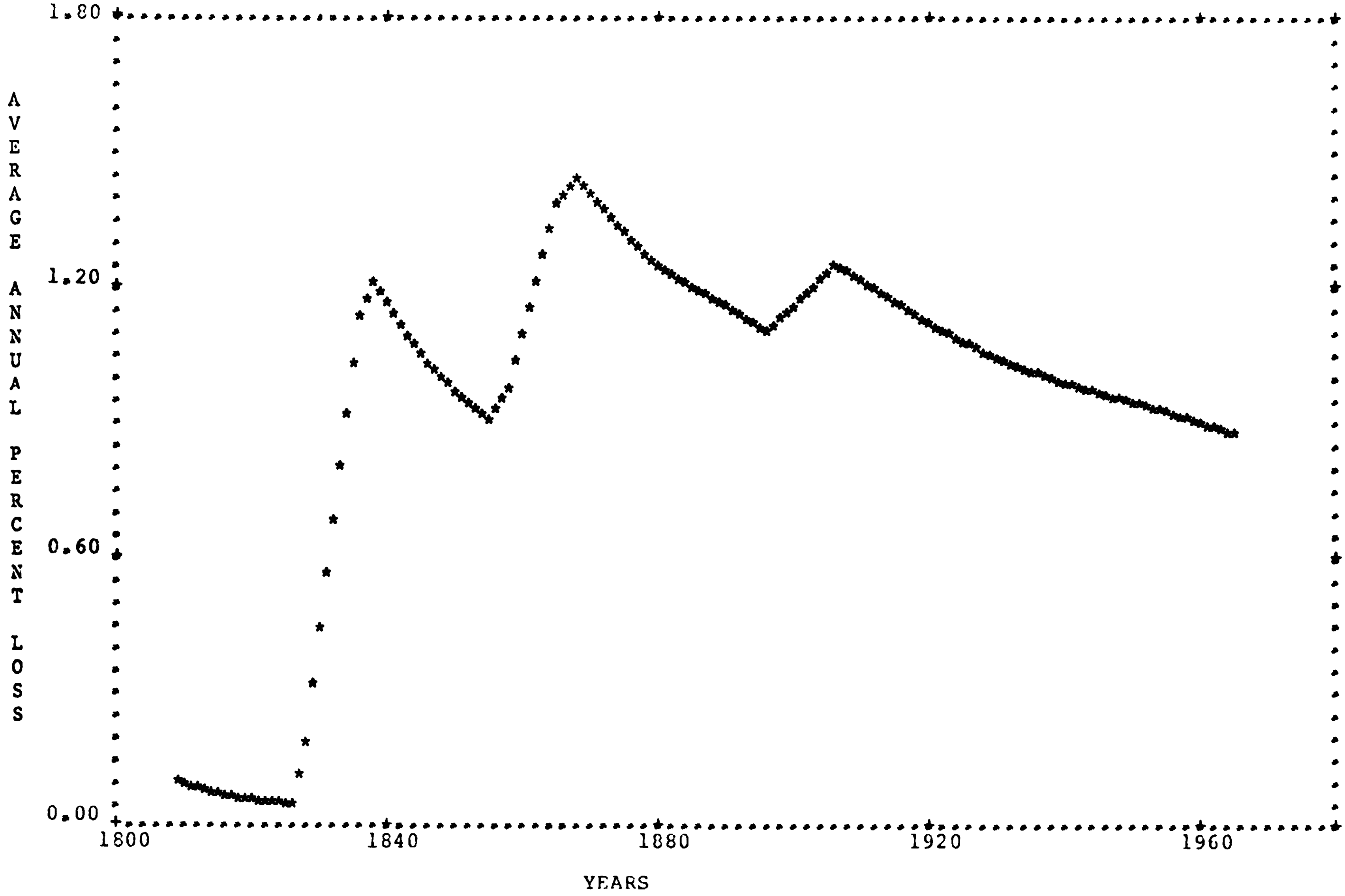

Figure A-8.--Average annual losses by class of construction (subclass 4HE) for the nine county area. The averages are computed using a 10 year moving time filter.

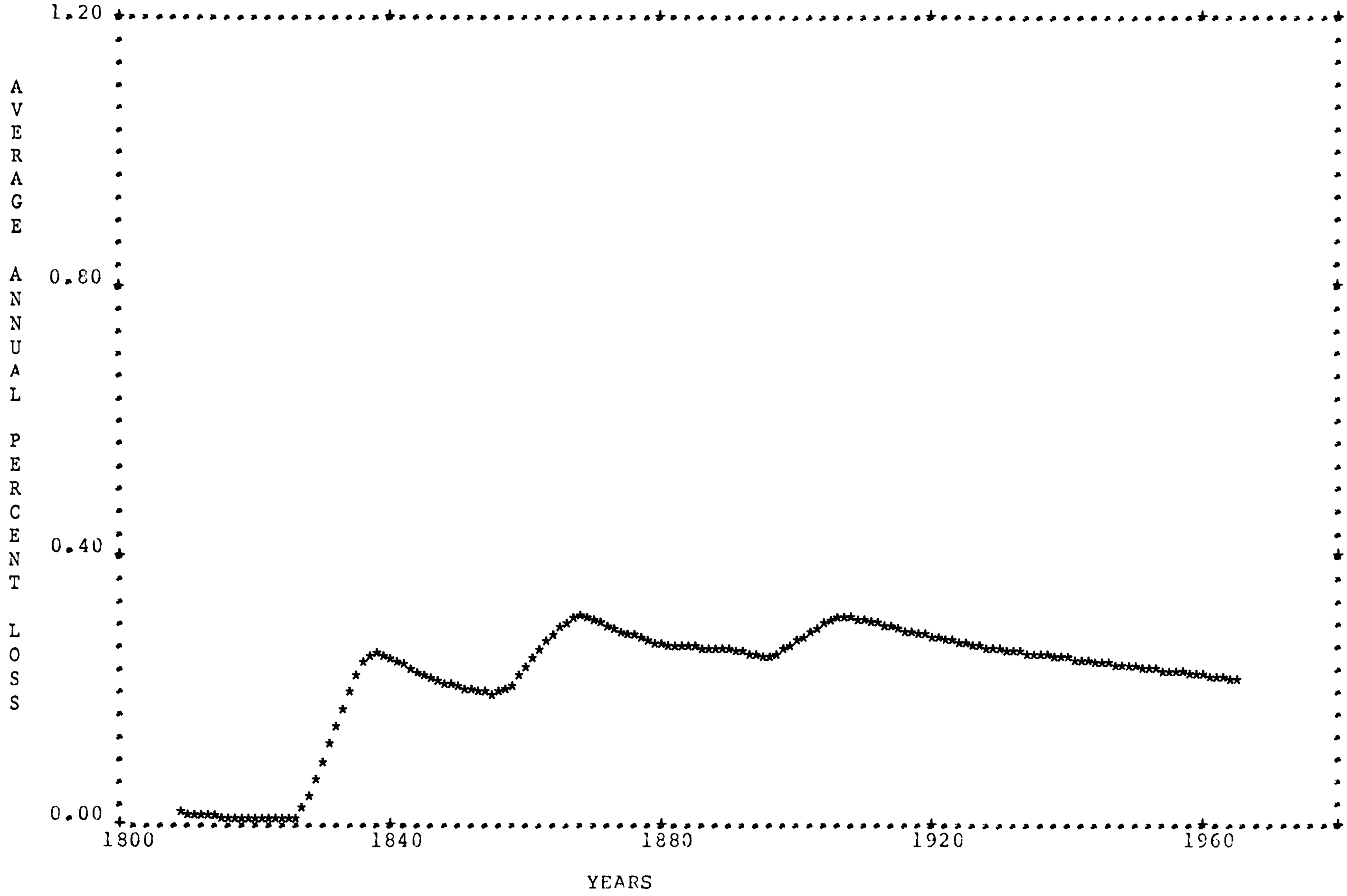

Figure A-9.--Average annual losses by class of construction (subclasses 5B, 3LC, 4LA) for the nine county area. The averages are computed using a 10 year moving time filter.

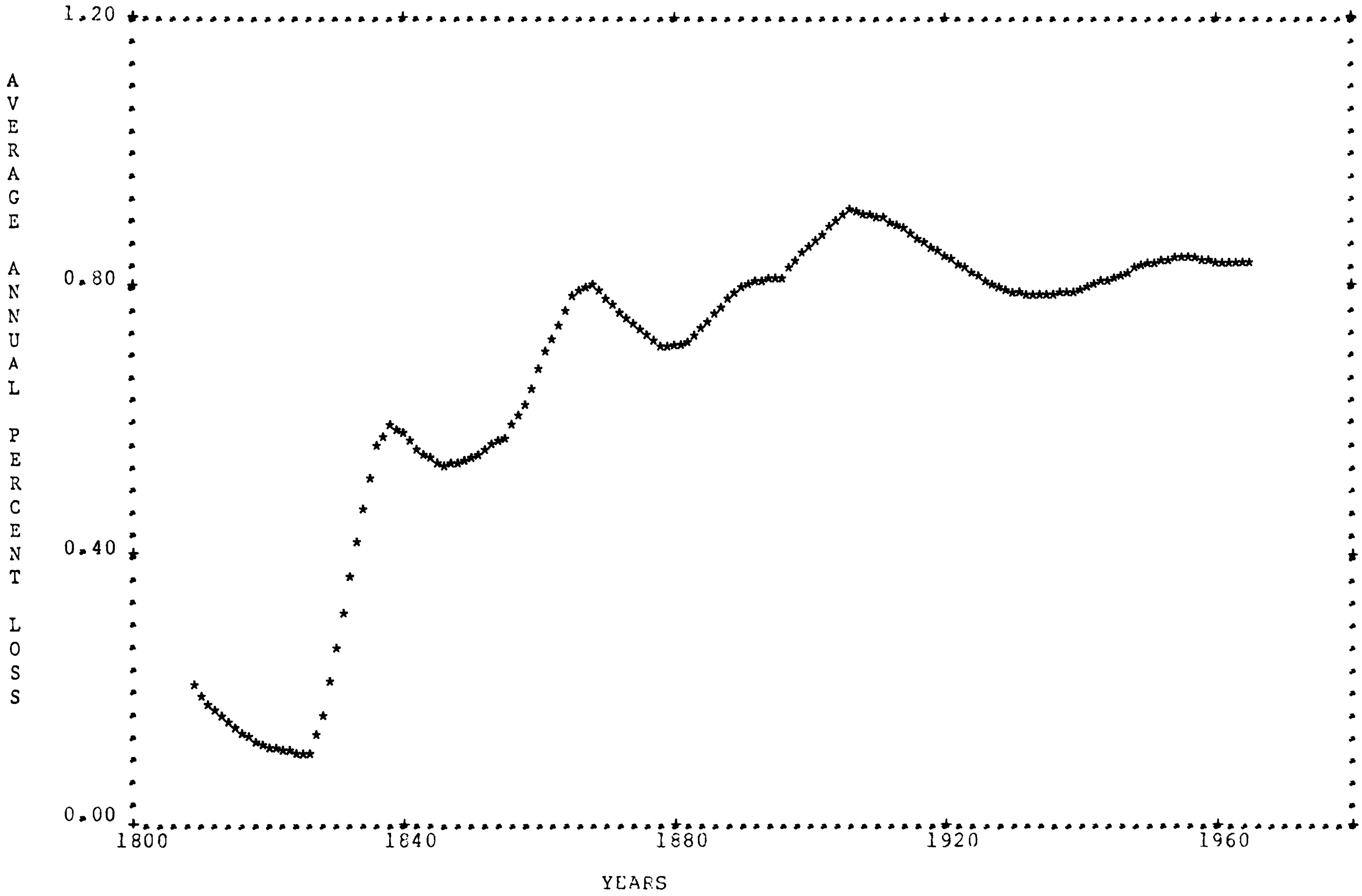

Figure A-10.--Average annual losses by class of construction (subclasses 5C, 3LB, 3LD, 4LC) for the nine county area. The averages are computed using a 10 year moving time filter.

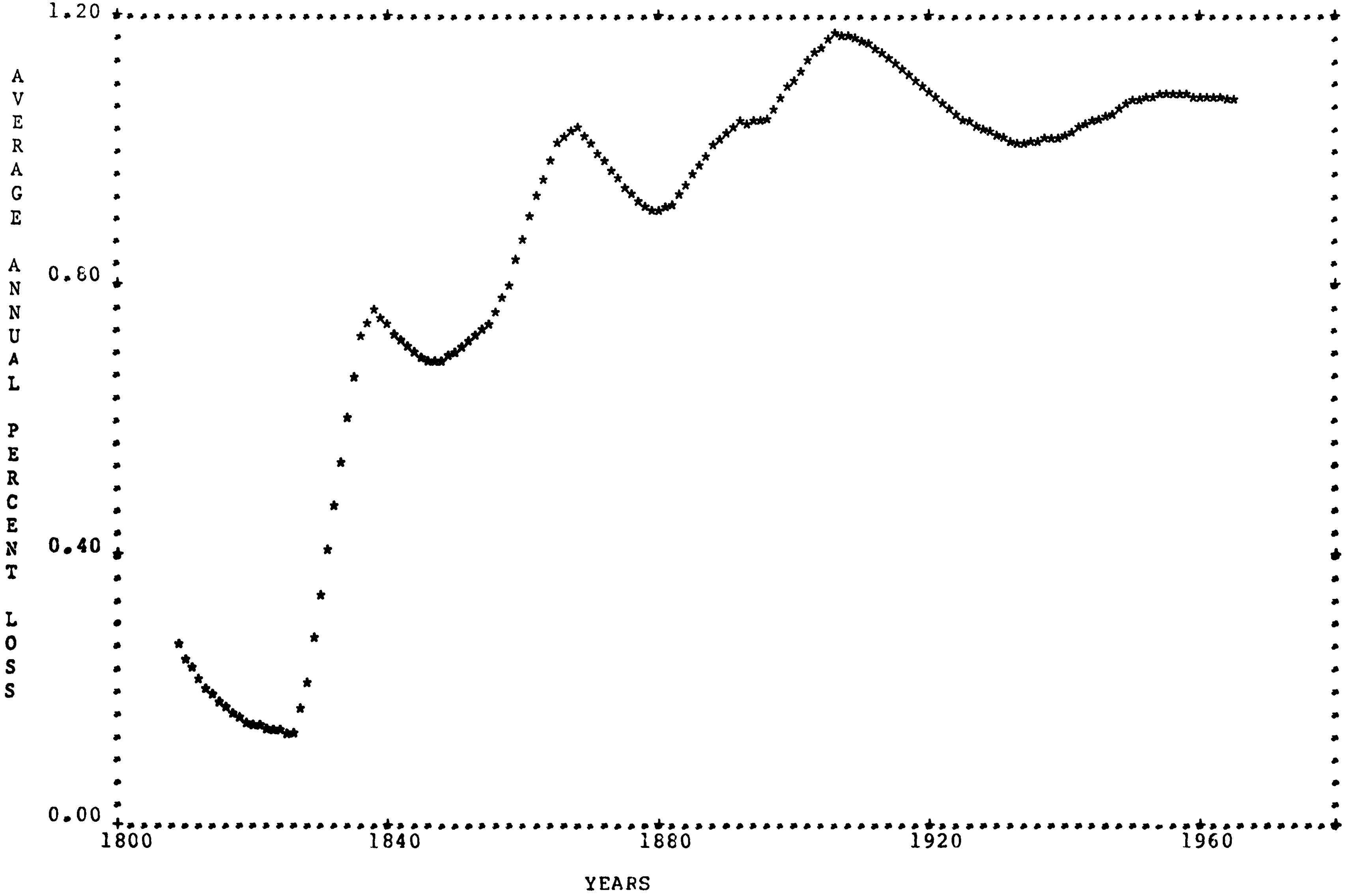

Figure A-11.--Average annual losses by class of construction (subclass 5D) for the nine county area. The averages are computed using a 10 year moving time filter.

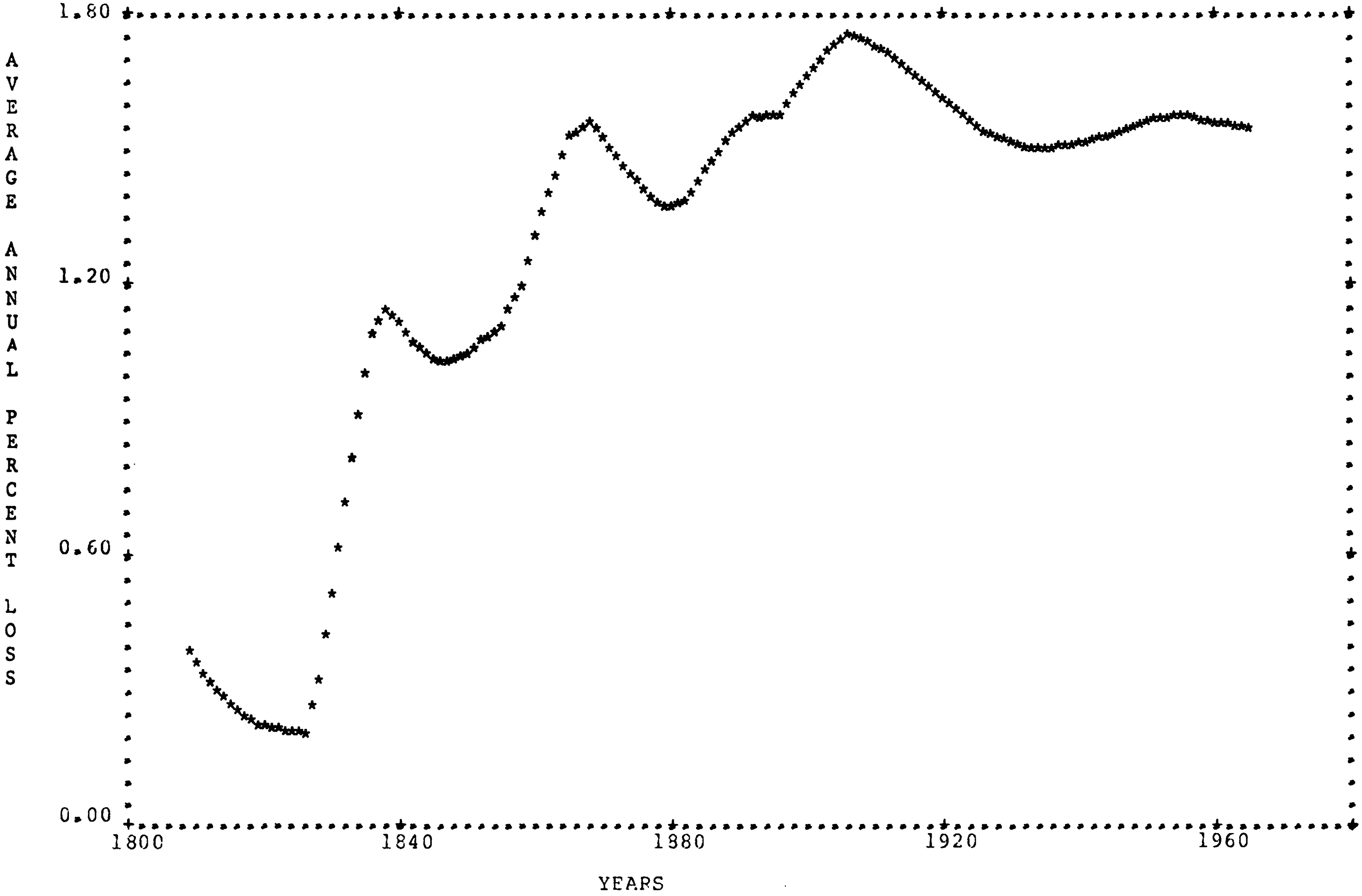

Figure A-12.--Average annual losses by class of construction (subclass 5E) for the nine county area. The averages are computed using a 10 year moving time filter.

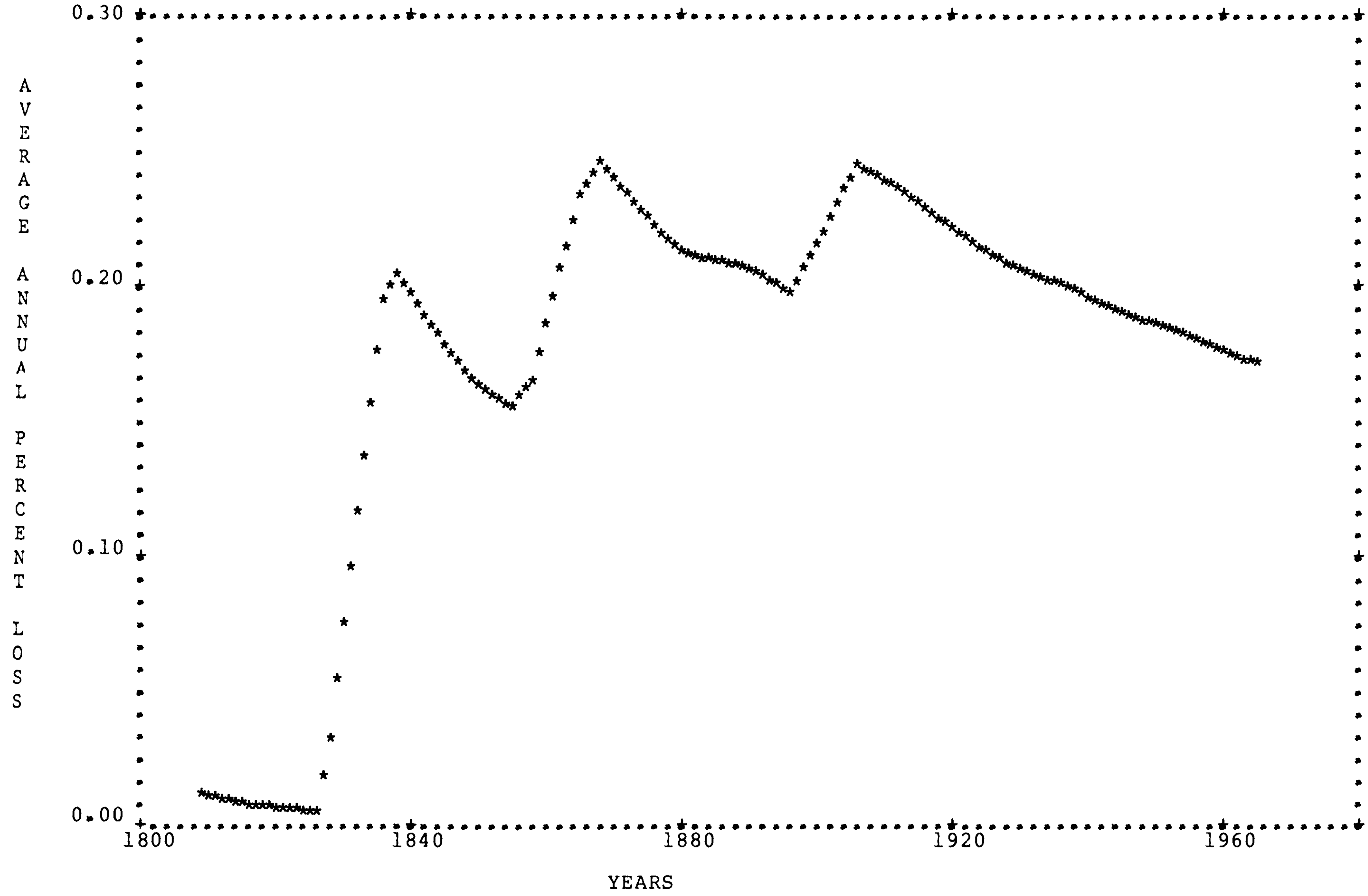

Figure A-13.--Average annual losses by class of construction (subclass 3LA) for the nine county area. The averages are computed using a 10 year moving time filter.

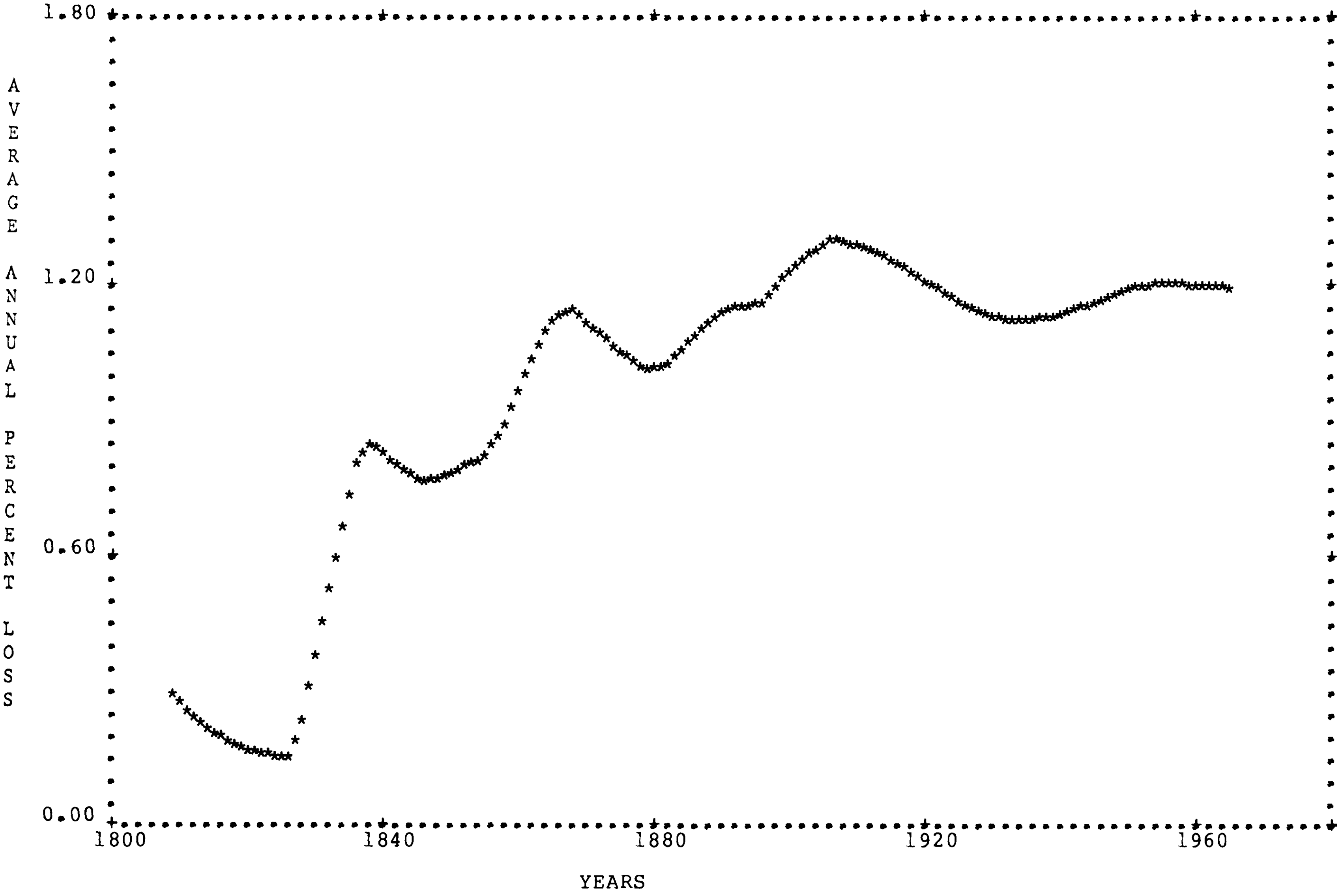

Figure A-14.--Average annual losses by class of construction (subclass 4LB) for the nine county area. The averages are computed using a 10 year moving time filter.

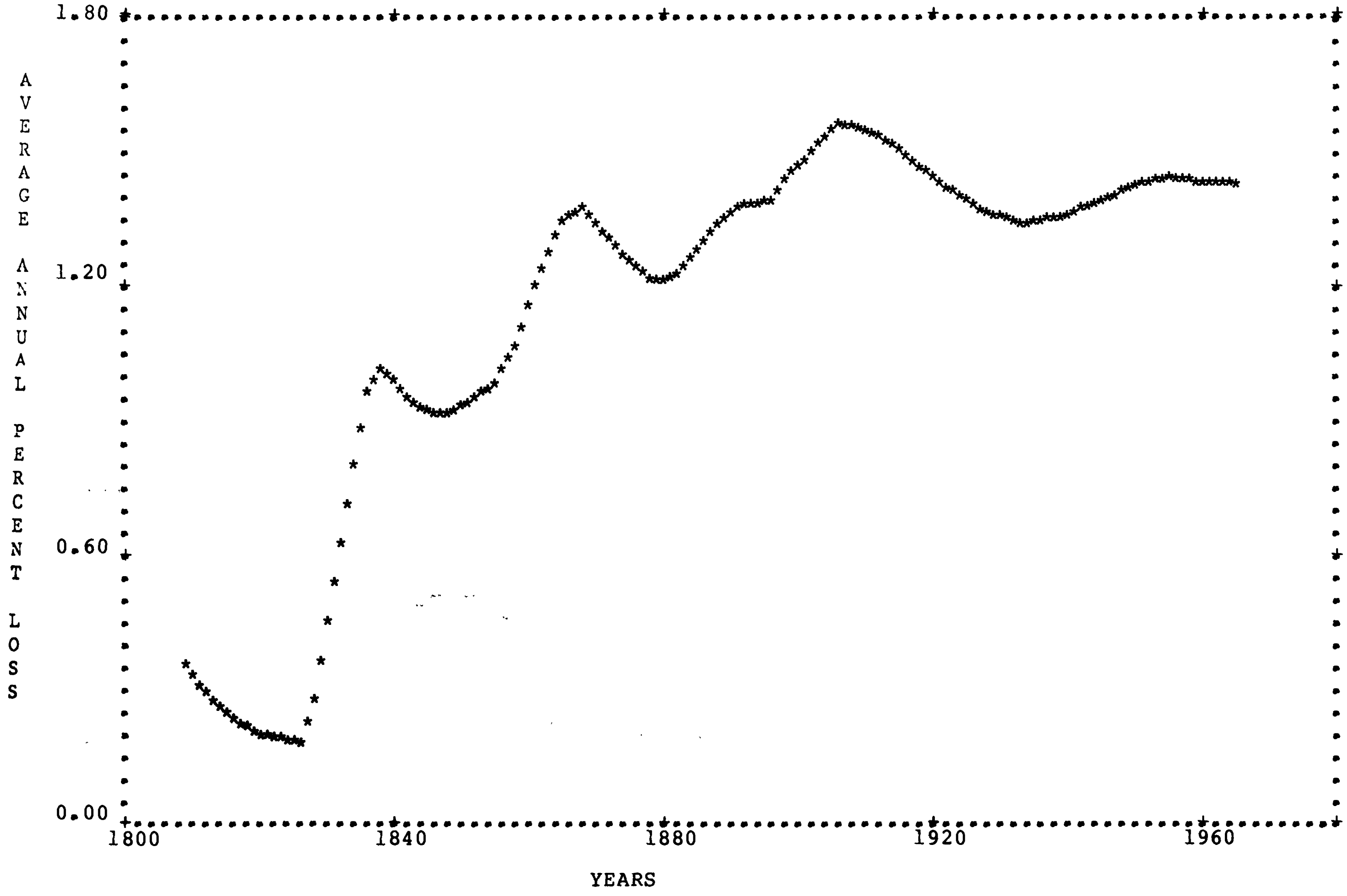

Figure A-15.--Average annual losses by class of construction (subclass 4LD) for the nine county area. The averages are computed using a 10 year moving time filter.

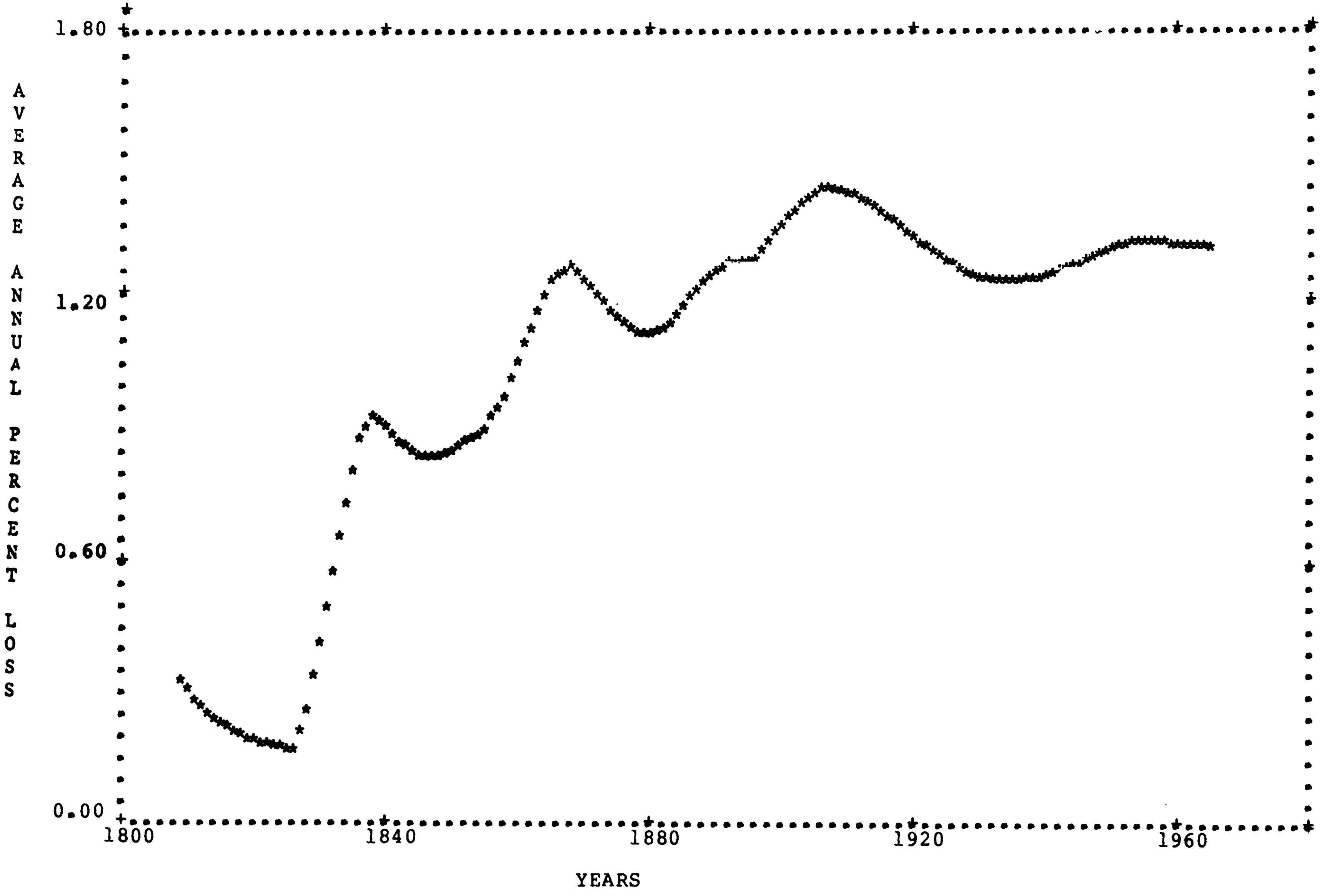

Figure A-16.--Average annual losses by class of construction (subclass 4LE) for the nine county area. The averages are computed using a 10 year moving time filter.

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