SEISMIC INSTRUMENTATION OF FEDERAL BUILDINGS

A STRAWMAN DRAFT DOCUMENT FOR CONSIDERATION BY FEDERAL AGENCIES [PRESENTED AT THE NEP MEETING - JULY 8, 1997 FEMA BUILDING, WASHINGTON, D. C.]

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Open-File Report 97-452

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code). Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U. S. Government

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SYNOPSIS

The following is an expanded version of presentations "Instrumentation of Federal Buildings" made by the first author during the theme session "How to Comply: The Halfway Point" organized by Subcommittee on Buildings of the Interagency Committee on Seismic Safety in Construction (ICSSC) held at National Institute of Standards and Technology (NIST) on January 15, 1997 and during the Full Committee Meeting of ICSSC held in Dallas, Texas on January 28, 1997 .

It is redrafted herein as a strawman draft proposal to be considered by National Earthquake Hazards Reduction Program (NEP) agencies.

1.0 GENERAL BACKGROUND INFORMATION

There are two main approaches to evaluate seismic behavior and performance of structural systems. One requires a laboratory in which subsystems, components, or (if the facility is large enough) prototypes or large, scaled models of complete systems are tested under static, quasi-static, or dynamic loading. This approach does not necessarily demand a time-dependent testing scheme, such as a shaking table or hydraulically powered and electronically controlled loading systems; however, testing of structural systems under controlled simulated environments is desirable. Since the early 1950's such laboratory research has increased both in quantity and quality, with engineering colleges in the United States and private and governmental laboratories in Japan playing a key role. Laboratory testing has also contributed substantially to our understanding of dynamic soil properties and the interaction phenomenon between the soil and structure (Çelebi and others, 1987).

The second approach to evaluate behavior and performance of structural systems is to use the natural laboratory of the Earth, by recording structural motions on scale, and observing and studying the behavior and damage, if any, to structures from earthquakes. By determining why specific designs lack earthquake resistance, and then by using extensive laboratory testing of modified designs, significant progress in improved designs can be achieved.

For such design studies a natural laboratory would be a seismically prone area that offers a variety of structural systems; in optimum test areas, strong ground motions as well as moderate-level motions would be experienced frequently. Integral to the "natural laboratory" compared to "controlled laboratory " approach is the advance instrumentation of selected structures so that their responses can be recorded during future earthquakes. Thus, it is essential that integrated arrays of instrumentation be planned and installed to assess thoroughly the relation of ground motion that starts at a source and is transmitted through various soils to a substructure and finally to a superstructure. The direction for seismologists and engineers working together is clear: to develop integrated networks which measure the seismic source, the transmittal of ground motion, and the structural response processes.

1.1 General Objective

The main objective of the seismic instrumentation program for structural systems is to improve our understanding of the behavior and potential for damage of structures under the dynamic loads of earthquakes. This will be achieved through the development of integrated network that measures the earthquake source, transmitted ground motions, and structural response. These measurements will be correlated with observations of structural performance to evaluate current design and construction practices in order to minimize damage to buildings during future earthquakes. In accordance with Executive Orders 12941 [Seismic Safety of Existing Buildings] signed in December 1, 1994 and Executive Order 12699 [Seismic Safety of New Buildings] signed on January 5, 1990, this program will initially concentrate on instrumenting federally owned and leased buildings.

1.2 Prior Recommendations

Although not directly targeted to federal buildings, several workshops and meetings in the past referred to importance of seismic instrumentation. For example, the following quotes are from "Earthquake Prediction and Hazard Mitigation Options for USGS and NSF Programs" published in 1976 by NSF and USGS:

> Page 51: Under Activities for Subelement b: Acquisition of Strong-Motion Data: :
>
> 1. *Improve the national-strong-motion instrumentation network by:*
>   (a) *Replacing obsolete instruments,*
>   (b) *Installing adequate instrumentation arrays in all seismic regions,*
>   (c) *Developing arrays to measure the two and three dimensional distribution of ground motion.*
>   (d) *Instrumenting representative types of structures, particularly in the more active parts of the country.*

The following quotes are from "***Recommendations for the Strong-Motion Program in the United States***" published in 1987 by Committee on Earthquake Engineering of the National Research Council":

> Page 50: "***Plans for deployment of strong-motion instruments requires decisions as to whether they should be located in structures or in the free-field. Both kinds of data are needed by engineers, whereas seismologists prefer free-field data***."

> Page 49: "***An effective national strong-motion program must be concerned with all phases of activities, including strong-motion instrument development, deployment and operation of instruments, processing, archiving and dissemination of data, the uses of data, strong-motion research, strong-motion applications, integration of activities of various governmental agencies, universities and corporations taking part in strong-motion activities, and identification of the amount of funding required for such a national effort and the source of funding.***"

There are many other reports that are published between 1976-1997 that refer to the above "recommendations".

1.3 Requisites of an Instrumentation Program

The instrumentation of a structure should provide an optimal number of sensors to allow reconstruction of the response of the structure in sufficient detail to compare with the response predicted by mathematical models -- the goal being to improve the models. In addition, the data should make it possible to explain the reasons for any damage to the structure. ***The nearby free-field and ground-level time history should be known*** in order to quantify the interaction of soil and structure. More specifically, a well-instrumented structure for which a complete set of recordings has been obtained should provide useful information to:

(1) check the appropriateness of the dynamic model (both lumped-mass and finite element) in the elastic range,
(2) determine the importance of nonlinear behavior on the overall and local response of the structure,
(3) follow the spreading nonlinear behavior throughout the structure as the response increases, and determine the effect of this nonlinear behavior on the frequency and damping,
(4) correlate the damage with inelastic behavior models,
(5) determine the ground-motion parameters that correlate well with building response and/or damage, and
(6) make recommendations to improve seismic codes.

1.4 Code Recommendations for Instrumentation and Deficiencies

Various codes in effect in the United States recommend different types and schemes of instrumentation depending upon their purposes. For example, the Uniform Building Code (UBC) of 1976 (and those that followed, including the recent 1997 issue), recommended that, for seismic zones 3 and 4, a minimum of three accelerographs be placed in every building over six stories with an aggregate floor areas of 60,000 square feet or more, and in every building over ten stories regardless of the floor area. The purpose of this requirement by the UBC was to monitor rather than to analyze structural response. In 1976 the City of Los Angeles adopted the UBC's recommendation but in 1983 revised this requirement to require only one accelerograph (to be deployed at the roof of the building). Recently, there is a movement in Los Angeles to go back to the original UBC recommendation. The code instrumentation recommendation is illustrated in Figure 1a.

The recommendations for instrumentation according to the UBC provisions does not allow complete analyses of a building. For example, a single triaxial accelerograph deployed at a floor (Figure 1a) does not allow the evaluation of torsional behavior of a building. Furthermore, only one vertical component at the ground or basement level does not allow evaluation of rocking motions of a building, if any. This type of instrumentation was prevalent particularly prior to the 1971 San Fernando earthquake.

Since the 1971 San Fernando earthquake, extensive instrumentation of building structures has been used as demonstrated in Figure 1b. Such a scheme involves distribution of triaxial channels as uniaxial channels on different floors of a building such that both translational and torsional motions of the structural system can be recorded. Also, additional vertical sensors on the ground floor or basement facilitates the evaluation of rocking motions. Furthermore, whenever physically possible, a free-field triaxial accelerograph is deployed in the vicinity of the building to facilitate additional studies related to soil-structure interaction and correlation studies of possible damage with free-field ground motions. Figures 1c and d illustrate special cases of instrumentation for diaphragm effect and base-isolated buildings.

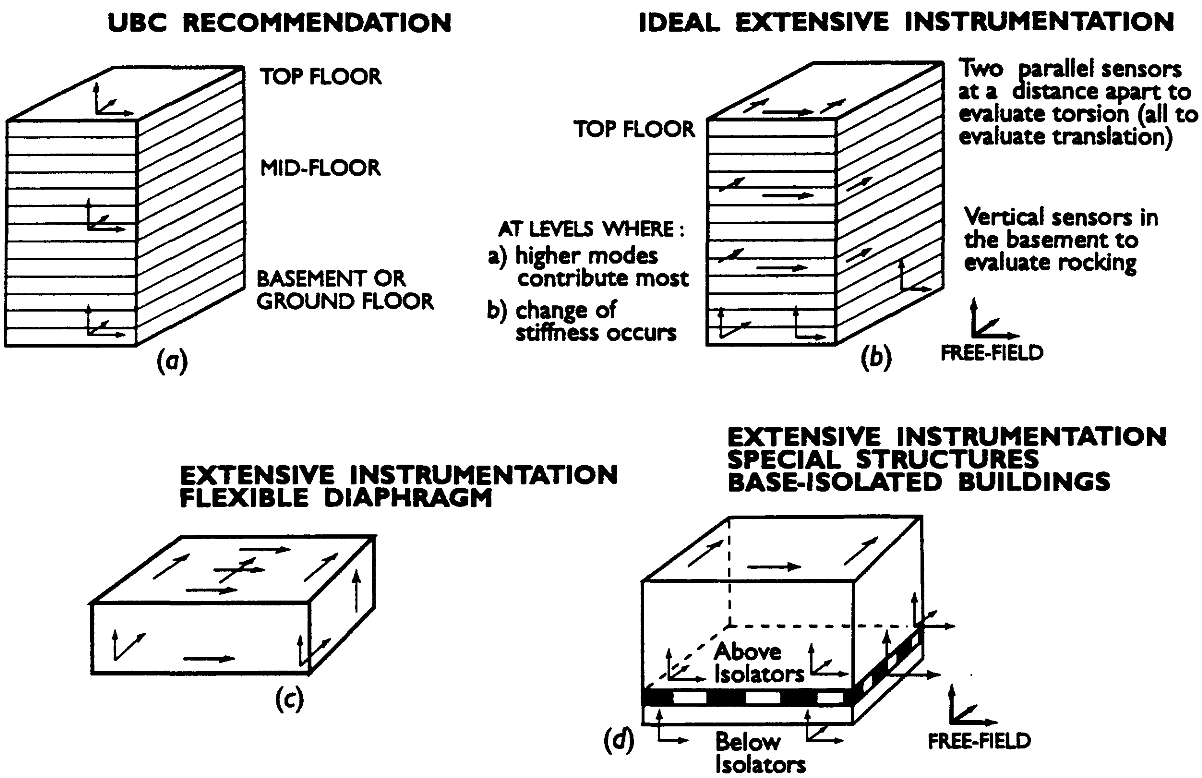

Figure 1. Instrumentation Schemes

1.5 Specific Issues Related to Seismic Instrumentation of Structures

- Instrumentation of structures requires multiple single-channels rather than a tri-axial unit used for free-field deployment. There are hardware costs involved as presented later in this document.

- Instrumentation of structures needs interconnection of cables between the accelerometers and recorders for common-time recording. Until such time when wireless/remote motion detection/recording is feasible, reliable, and readily available, cables will have to be used to achieve common-time recording. Furthermore, recent digital systems with GPS options require additional cable connection between the GPS unit (which has to be placed at the roof or appropriate location so that the GPS unit can see the sky) and the recording unit.

- There are installation costs. In some cases, this can be minimal and in other cases it can be substantial. The installation costs include conduits, pulling cables and electrical wiring.

- Finally, there is the maintenance, data retrieval, processing and dissemination issue. <u>In the past, with analog instruments, this was a major problem</u>. <u>However with recent advances and improvements on digital accelerograph systems</u>, <u>the cost to maintain, retrieve, process and disseminate data from such systems will be lower</u>.

2.0 WHY INSTRUMENT FEDERALLY OWNED BUILDINGS?

- In general, it is very difficult to pursuade private property owners to instrument their buildings. In most cases, it is not possible to get private property owners to allow federal or state (public) agencies to deploy seismic instruments or conduct comprehensive damage surveys. Part of the problem for building owners is the concern for possible future litigation. *This problem can be circumvented by instrumenting federally owned/leased structures.* **Federally owned/leased buildings will not require permits to deploy instruments by a federal agency** nor will they be closed to federal inspection teams following a damaging earthquake. *Making the connection between <u>recording</u> strong ground motions and <u>documenting</u> building performance is essential to a national earthquake engineering program.* [For example, very few (only 2) steel buildings that were damaged during the Northridge earthquake were instrumented (only minimally). Approximately 800 steel buildings that are being investigated for possible damage did not have any instruments in them. Currently, we are having trouble in obtaining permission from one of the owners of a (Northridge earthquake) damaged/retrofitted (SAC) steel buildings to deploy a seismic monitoring system (even at no cost to the owner)].

- Instrumentation of federally owned and leased buildings supports the aims of the 1977 National Earthquake Hazards Reduction Act which refers to priorities such as:

  - Assist in developing improved building codes
  - Assess earthquake hazards in federal facilities.

- Instrumentation of federally owned and leased buildings is compatible with the spirit of the Public Law 101-614 NEHRP Reauthorization Act. Section 8(a)(1) of this law states: " The president shall adopt, not later than December 1, 1994, standards for assessing and enhancing the seismic safety of existing buildings constructed for or leased by the Federal Government...."

- Instrumentation of new and existing federal buildings is particularly important in light of Executive Orders 12941 [Seismic Safety of Existing Buildings] signed in December 1, 1994 and Executive Order 12699 [Seismic Safety of New Buildings] signed on January 5, 1990. These two executive orders demonstrate both the concern and the need for safety of both the personnel that work within the buildings and the public that use the buildings. Public safety will be enhanced by seismic instrumentation because seismic instrumentation will provide important data to:

  - Assess the causes of damage, if any.
  - Develop the best methods to repair damaged structures.
  - Assess the vulnerability of the buildings
  - Evaluate the dynamic characteristics of the buildings for planning for and selection of the best methods to strengthen and retrofit structures, if necessary.

- ***There are approximately 84,000 federally owned and 5000 federally leased buildings in areas 3 and 4. The acquisition value of these buildings is $16 billion (does not include contents).*** Therefore, protection of property is also an issue. The distribution of federally owned/leased properties are illustrated in Table 1 and Figure 2 (both from GAO/GGD 92-62 Quake Threatened Buildings, 1992). Instrumentation of federal buildings therefore will lead to improvements in the seismic performance of the buildings, result in safety to employees, public, and protection of public property.

- Federal agencies should set an example by instrumenting federally owned/leased buildings.

- Evolution of new technologies in earthquake resistant design, construction and retrofit practices requires systematic and efficient verification of the performance of structures built with the new technologies or retrofitted with new methods. Such verification can only be accomplished in essence by strategically deploying seismic sensors in such structures to record their performances during future events. Several federal buildings in seismic areas are being retrofitted by such emerging technologies (e.g. VA Hospital in Long Beach, Court of Appeals Building in San Francisco [both buildings using base-isolation], a Navy Building in San Diego [using viscous elastic dampers]).

Table 1. Statistical Distribution of Federally Owned/Leased Buildings and Employees in Seismic Risk Zones Nationwide (from GAO/GGD -92-62: Quake Threatened Buildings)

Level of Seismic Risk	Level of Expected Damage	Number of Owned Buildings	Number of Leased Space Locations	Number of Employees
VERY HIGH	Most Buildings	32,000	2,000	215,000
HIGH	Many Buildings	52,000	3,000	224,000
MODERATE	Some Buildings	99,000	22,000	668,000
LOW	No Buildings	234,000	41,000	1,759,000

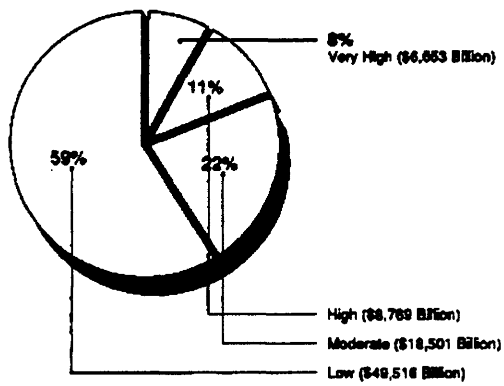

Figure 2. Distribution of Federally Owned Buildings and Acquisition Values (from GAO/GGD -92-62: Quake Threatened Buildings)

- The severity of damages to numerous steel structures during the January 17, 1994 Northridge earthquake (M_s=6.7) and Kobe (Japan) earthquake of January 17, 1995 (M_s=6.8) is a perfect example that points to the need for instrumentation of both the new generation design of mid-rise to high-rise steel buildings but also those that were repaired and/or retrofitted by methods developed for the particular damage problem. It is therefore essential to obtain data during future events for response studies to assess the effectiveness and revise and/or improve the new methods of design, construction and retrofitting.

- Federal building inventory should be compatible with at least the recommendations of Uniform Building Code.

- Within the United States, there are large inventories of buildings within 0-10 km of the major faults capable of generating M>7 earthquakes. This is particularly important now because, very recently, the Structural Engineers Association of California (SEAOC) issued the 1996 edition of the ***Recommended Lateral Force Requirements and Commentary*** which has provisions for increasing the design base shear by 0-100 % depending on the 0-10 km distance of the building from the fault. It is now also reflected into the 1997 issue of the Uniform Building Code. This implies that forecasting of the performance of buildings within 0-10 km of major faults, subjected to higher levels of motions, must be done more informatively. This requisite information can be achieved only through acquiring and studying response data from buildings during earthquakes.

- Recent developments on "Performance Based Design" necessitates response data from all types of structures. Such data will help improve future design procedures based on this concept.

3.0 SUGGESTED ACTION:

(a) Instrumentation of federally owned/leased buildings should be confined to Seismic Areas 3 and 4 only, federally owned and leased buildings on ***a selective basis*** that reflects the objectives of the strong-motion instrumentation of structures program. [Alternatively, the areas described by Leyendecker/Frankel maps as having the highest risk or highest PGA with 10 % probability of exceedance could be used]. (Refer to Figures 2 and 3).

(b) As an initial target, 0.1 % of the buildings can be feasibly instrumented. The number would reach approximately 90 (of the approximately 84,000 federally owned and 5000 federally leased buildings in areas 3 and 4) based on the current information and data base of inventory and geographical distribution of federally owned/leased structures within the seismic areas of the United States). ***This will create a visible program and set an example to other instutions, state agencies, private owners***.

(c) Funding for this effort should be provided by:
- Individual agencies,
- Federal Emergency Management Agency (FEMA),
- General Services Administration (GSA),
- Department of Defense
- Tie into EO 12941 and 12699
- A new Executive Order
- Other sources [*e.g.* special add-on to budget, NSF, etc.].

(d) USGS should provide expertise and guidance, monitoring on a reimbursable basis and management and dissemination of acquired data. **USGS should have umbrella agreements with FEMA, GSA and all other federal agencies.** [USGS currently cooperates with Veterans Administration and to a lesser extent with GSA to instrument, monitor, retrieve and disseminate data].

(e) Seismic instrumentation of federally owned/leased buildings should be included in the revisions of TR 4 & TR 5 prepared by ICSSC.

(f) Final selection of buildings to be instrumented should be made according to a protocol to be developed by an interagency committee drawn from members of the ICSSC. Some of the issues that would be addressed by this protocol include:

- **Selection Criteria**

  Building Types
  - Which of the 15 model building types [*e.g.* FEMA 178] do we instrument?
  - Additional priorities based on occupancy class, usage [re ICSSC TR-17]
  - Are there specific lessons or experiments that we need to conduct/learn for a specific building type?
  - Do we want to develop "Demonstration" Experiments? [*e.g.* similar structures in close proximity, with and without retrofit/rehabilitation or built to different codes [pre- and post- ICSSC benchmarks]

  Building Locations
  - Selection with respect to ground conditions (*e.g.* "hard rock" vs. "soft rock")

- Selection with respect to geologic considerations[*e.g.* distance from a specific earthquake source -- strike slip, normal, thrust faults)
- Selection with respect to geographic considerations[*e.g.* California, Seattle, Utah, Central US]
- "Demonstration" Experiments [*e.g.* Two similar structures in close proximity, built on different types of ground]

- Site Surveys for Geologic Conditions (all sites of instrumented buildings should be included in a separate or ongoing site characterization efforts). Some possible considerations for site surveys are:

    - Development of a standardized approach [adopt ATC-26-1 standards for all sites?]
    - Surface geology, Borehole logs [Lithology, Shear wave velocities, other geotechnical parameters]
    - Consideration of 3-D Sedimentary Basin structure, Wave Focusing and Defocusing Effects

- Instrumentation
    - **Hardware**
    - Deployment

        Within the building(s), development of standardized deployment for specific structure classes, and designs

        Outside the building(s), development of 'rule of thumb' for distance from structure to record true 'free field' measurements [re. soil-structure interaction].

(g) Schedule

- Develop funding base for initiative and/or partnership agreements
- Set up ICSSC Sub-Committee for Instrumentation Issues to deal with :
    (a) development of selection criteria of structures for instrumentation,
    (b) preliminary selection of specific structures,
    (c) strong motion experiments as necessary and feasible,
    (d) instrumentation,
    (e) data archiving & distribution,
    (f) organization of workshops as necessary
- Meeting to finalize building selection and strong motion experiments.
- Deployment

4.0 COST/BUDGET ISSUES:

- The cost of hardware and installation for each building can vary between $30-60 K based on the number of channels involved. It seems feasible to provide a standardized 12-18 channel instrumentation scheme that follows in general the illustration shown in Figure 1b. Therefore on the average $ 50 K per building is the current average expenditure for a building. This normally will include a triaxial free-field station in the immediate vicinity of the building, if physically possible. Therefore, notwithstanding special cases discussed below, hardware and installation costs for 90 federally/owned and leased buildings will be $4.5 M. This amount is for a duration of 5 years based on a calculation that approximately 18 buildings/per year can be instrumented. Instrumentation costs of $50 K for **a building and its contents** is a small investment when compared with the actual worth of a building (and its contents).

- In special cases, the geotechnical , geological and topographical environment of a building could provide opportunities to deploy additional hardware in the vicinity of the building to assess the performance of building structures in relation to those environs. I suggest consideration of $0.5 M for such special cases, again for the 5 year duration. For example,

  - One important aspect of structural response is the soil-structure interaction. In many cases, under specific geotechnical environment, certain structures will respond differently than if that structure was built as a fixed based structure on a very stiff (e.g rock) site condition. This alteration of vibrational characteristics of structures due to soil-structure interaction can be both beneficial and detrimental for their performances. To date, the engineering community is not clear about the pros and cons of SSI. In Mexico City, during the Michoacan earthquake of Sept. 19, 1985, many structures were negatively affected due to SSI because the lengthening of their fundamental periods placed them in a resonating environment close to the approximately 2-second resonant period of Mexico City lakebed. On the other hand, under different circumstances, SSI may be beneficial because it produces an environment whereby the structure escapes the severity of the response spectra due to shifting of its fundamental frequency. Certainly, in a basin such as that of Los Angeles area, SSI may cause both beneficial and detrimental effects in the response of structures. The identification of the circumstances under which SSI is beneficial or detrimental and the parameters is a necessity. **In some cases; therefore, we may wish to deploy additional hardware (e.g. free-field accelerographs on the surface and in boreholes [downhle accelerographs].**

  - There are many urban areas in the United States where structures are built on hills. There is now sufficient evidence to consider a phenomenon known as the topographical effect – amplification of ground motions due to the geological and geometrical characteristics of the topography of the site of a building. In some cases; therefore, we could deploy additional free-field accelerograph to assess whether the motions at the site of the building are amplified due to topographical effects.

- ***The total budget envisioned for the 5 year duration of this effort will be $5 M. or $1M /year.***

- **Other costs such as maintenance costs should be arranged by an umbrella agreement between USGS and the agencies involved.**

REFERENCES

Çelebi, M., Safak, E., Brady, G., Maley, R., and Sotoudeh, V., 1987, Integrated instrumentation plan for assessing the seismic response of structures--a review of the current USGS program, ***USGS Circular 947.***

Çelebi, M. (compiler) *et al.*, 1992, Recommendations for a Soil-Structure Inte[illegible] (Report Based on a Workshop Held at San Francisco, California on February 7, 1992), U.S. Geological Survey Open-File Report 92-295.

Çelebi, M., Safak, E., and Maley, R., 1989, Some Significant Records from Instrumented Structures in California—USGS Program, PROC., ASCE STRUCTURES CONGRESS, San Fransisco, CA, May 1989.

Çelebi, M., 1989, Seismic Monitoring of Buildings: Analyses of Seismic Data, USJN Panel on Wind and Seismic Effects, Tokyo, May 1989.

----------, 1992, Federal Buildings: Many are Threatened by Earthquakes, but Limited Action Has Been Taken, United States General Accounting Office, Report to Congressional Committees, GAO/GGD-92-62