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ATC-54 GUIDELINES FOR USING STRONG MOTION DATA AND SHAKEMAPS IN POSTEARTHQUAKE RESPONSE

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SUMMARY

The ATC-54 report, *Guidelines for Using Strong Motion Data and ShakeMaps in Postearthquake Response*, addresses two distinct topics: (1) guidance on the use of computer generated ground motion maps ("ShakeMaps") in postearthquake response; and (2) rapid utilization of near-real-time instrumental recordings from ground and structure stations to evaluate the potential for damage. The procedures for using computer-generated ground motion maps enable emergency response personnel to assess: (1) extent of damaged buildings and need for related safety evaluation inspections; (2) condition of hospitals and other emergency response structures; (3) impact on utility systems and transportation networks; (4) extent of liquefaction, landslides, and inundation; (5) casualties and associated need for victim extrication from damaged structures; (6) extent of debris from collapsed structures; (7) sheltering needs; (8) extent of possible hazardous materials release; (9) insurance claims; and (10) other postearthquake disaster and recovery ramifications. The procedures for evaluating strong-motion data from ground sites and instrumented structures to evaluate structural damage potential apply to buildings, bridges, and dams. Nine procedures are provided for buildings, including three procedures for evaluation of strong ground motion data; two procedures for evaluation of strong-motion data from instrumented buildings using visual techniques; and four procedures for evaluation of data from instrumented buildings using digital data analysis techniques. For each procedure, information is provided on (1) expertise and time required to execute the procedure; (2) applicable structural framing systems and data required, (3) steps to be taken, and (4) example applications. The applicability of these procedures for the evaluation of bridges and dams is also discussed, as are other real-time processes for evaluating damage potential in bridges and dams. The *Guidelines* were prepared by the Applied Technology Council, with funding from Strong Motion Instrumentation Program (CSMIP) of the California Geological Survey.

INTRODUCTION

Background.
Since the installation of the initial network of nine strong-motion instruments at ground sites and in buildings in California in 1932 (Matthiesen [1]), the number of strong-motion recording stations and

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records has grown dramatically. Today there are more than 1000 instrumented sites and structures in California, including buildings, dams, bridges, and other lifeline structures. The instruments are operated by a wide variety of agencies and owners, including the California Geological Survey (CGS), California Division of Water Resources, California Department of Transportation, U. S. Geological Survey (USGS), U.S. Bureau of Reclamation, U.S. Army Corp of Engineers, several universities and university-affiliated centers, utility companies in northern and southern California, and owners of buildings where instruments have been mandated by building code requirements. Hundreds of strong-motion time histories have been recorded at these stations, resulting primarily from large damaging earthquakes, such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes. Such data are available in digital form from the principal network operators (CGS and the USGS) and other sources, including the world wide web virtual data center operated by the Consortium of Organizations for Strong-Motion Observation Systems (COSMOS).

Over the last 40 to 50 years, the technology for recording, analyzing, and representing strong-motion data has also advanced significantly. Major advances have included: the development of rapid scanning and processing techniques for converting photographic analog records to digital format; the development and deployment of digital accelerographs; the development of new computer analytical methods that use strong-motion records to verify and refine computer models of structural response and to compute estimated component forces and displacements; and, most recently, the introduction of computer-generated ground-motion maps that provide overviews of the regional distribution of ground shaking within minutes, and without human intervention, after damaging earthquakes.

Collectively the existing network of strong-motion instruments, the existing sets of strong-motion data, and the available techniques and technology for processing, analyzing, and displaying strong-motion data provide an ideal set of tools and information for postearthquake response planning and execution, as well as postearthquake evaluation of structures. In recognition of the enormous potential of these tools and information, and with the realization that practicing professionals do not have guidance readily available on how to take advantage of these current technical capabilities, CGS awarded a Year 2000 California Strong-Motion Instrumentation Program (CSMIP) Data Interpretation Project to the Applied Technology Council (ATC) to prepare the needed guidance. Specifically, the contract required that ATC develop *Guidelines* to: (1) facilitate improved emergency response with the use of near-real-time computer-generated ground-motion maps and (2) facilitate postearthquake evaluation of structures using strong-motion data from ground sites and instrumented buildings, bridges, and dams. The contract also required that ATC provide guidance on the collection of data describing the characteristics and performance of structures in which, or near which, strong-motion data have been recorded.

Guidelines Development Process

The ATC-54 *Guidelines* were developed through a multi-step approach by a multi-disciplinary team of experienced specialists in earthquake and geotechnical engineering, risk analysis, geographic information systems (GIS), and emergency response planning. Initially, the project team identified and described the state-of-the-art in available data resources, building and lifeline inventory data, GIS hazard maps, and loss estimation tools. The next step was to define the state-of-the-practice in emergency response planning at the state, regional, and local level, as well as in postearthquake structural surveys and evaluations. Based on this information, primarily developed through literature reviews and interviews with key individuals in various agencies and organizations throughout the state, an assessment was made of the existing capabilities in emergency response planning and postearthquake evaluation of structures. This assessment served as the basis for determining the level of information and extent of guidance to be provided in the *Guidelines*. The *Guidelines* development process also included a Users' Workshop organized to solicit input on the content and scope of the *Guidelines*. The finalized version of the *Guidelines* is based on input received at the Users' Workshop, as well as review comments from the

CSMIP staff and the California Seismic Safety Commission's Strong-Motion Instrumentation Advisory Committee (SMIAC).

Paper Focus and Contents

The intent of this paper is to provide an overview of the finalized version of the ATC-54 *Guidelines*. We begin with a brief discussion of the purpose and scope of the *Guidelines,* followed by a brief description of the contents of the *Guidelines,* including the appendices. The main body of the paper provides an in-depth description of guidance for using ShakeMaps in earthquake response, with an illustrative example application, and an overview of the procedures for using strong ground motion recordings to evaluate the potential for damage in buildings and other structures, including an in-depth description of one of the procedures.

PURPOSE AND SCOPE OF THE *GUIDELINES*

The *Guidelines* are intended to increase the utilization of strong ground motion data for improving postearthquake response and postearthquake evaluation of buildings, bridges, and dams. They are also intended, as is the goal of all CSMIP data utilization projects, to improve the understanding of strong ground shaking and the response of structures so as to improve seismic design codes and practices.

The audience for this document is diverse and includes local, regional, and state agencies with postearthquake responsibilities; design professionals; facility owners; policy makers; and researchers concerned with the various uses of strong ground-motion data. It is anticipated that most readers will not be interested in all sections of the *Guidelines*.

The *Guidelines* focus on two distinct topics: (1) guidance for using computer-generated ground-motion maps in postearthquake response; and (2) guidance for rapid utilization of near-real-time strong-motion data from ground sites and instrumented structures to evaluate the potential for structural damage.

ORGANIZATION OF THE *GUIDELINES*

The *Guidelines* are organized into four chapters so that users will be able to target quickly their sections of interest (Figure 1). Chapter 1 contains introductory material and pertinent background information. Chapters 2 and 3 (the main body of the report) provide procedures for using computer-generated strong ground-motion maps in emergency response, and for using strong-motion recordings to evaluate the performance of individual buildings, bridges and dams, respectively. Chapter 4 provides guidance for collecting and documenting postearthquake investigation data. For non-instrumented buildings, the procedures of Chapter 4 draw heavily on the approach used after the 1994 Northridge earthquake to collect data on the characteristics and performance of more than 500 buildings within 1000 feet of strong-motion recording sites (ATC, [2]).

ATC-54: *Guidelines for Using Strong-Motion Data and ShakeMaps in Postearthquake Response*

Contents

1. Introduction and Background
2. Guidance on Use of Computer-Generated Ground-Motion Maps in Postearthquake Response
3. Guidance on Use of Strong-Motion Data for Damage Evaluation of Structures
4. Guidance on Collection of Data for Correlating Ground Motion and Structural Performance
5. Appendices

Figure 1. Guidelines Table of Contents

Seven appendices are included that contain supplemental information. Appendix A describes the process that was used to develop this document. Appendix B includes a summary of the most commonly used regional earthquake loss-estimation methods, which are referenced in Chapter 2. Appendix C provides guidance on strong-motion instrumentation of buildings, and Appendix D contains a summary of the most commonly used linear and nonlinear structural analysis software programs. Appendix E provides guidance on strong-motion instrumentation of bridges (with examples instrumented by the California Department of Transportation), and Appendix F provides resources and guidance for strong-motion instrumentation of dams. Postearthquake survey forms are provided in Appendix G.

GUIDANCE ON USE OF SHAKEMAPS IN POSTEARTHQUAKE RESPONSE

Chapter 2 of the ATC-54 *Guidelines* covers procedures for using computer-generated maps for postearthquake response (see example in Figure 2). Such maps, known as ShakeMaps, are generated automatically following moderate and large earthquakes and are normally posted within several minutes of the earthquake origin time, without the aid of human-kind. These maps show the distribution of peak ground acceleration and velocity, spectral acceleration at three periods, and an instrumentally-derived, estimated distribution of Instrumental Intensity, which is akin to Modified Mercalli Intensity. Instrumental Intensity maps are based on a combined regression of recorded peak acceleration and velocity amplitudes.

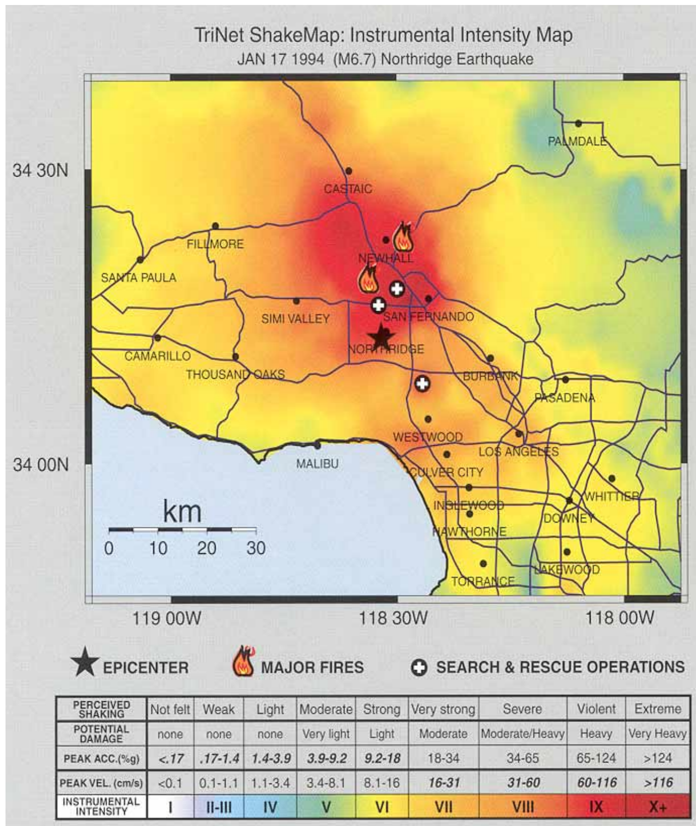

Figure 2. TriNet ShakeMap for the 1994 Northridge, California earthquake (USGS, [3]).

Chapter 2 begins with a section on the general framework for the use of real-time ShakeMap data for emergency response, including the data resources and procedures that are commonly related to the utilization of strong ground motion data for the various areas of emergency response (see below). The subsequent sections provide guidance (with illustrative examples) on the development and implementation of applications using ShakeMaps for emergency response. The following applications are addressed:

- extent of damaged buildings and planning related safety evaluation inspections;
- condition of hospitals and other emergency response structures;
- impact on utility systems and transportation networks;
- extent of liquefaction, landslide, and inundation;
- casualties and associated need for victim extraction from damaged structures;
- extent of debris from collapsed structures;

- sheltering needs;
- extent of possible hazardous materials release;
- estimates of economic losses; and
- insurance claims.

General Principles and Guidelines
There are several basic concepts related to the use of strong ground motion maps and data for postearthquake response. The focus here is on emergency response – the decisions that are made immediately after an earthquake has occurred. Time and effective communication are critical, as the needs for quick and reliable decisions and information dissemination are typically the most important issues facing emergency managers. Given an earthquake occurrence, questions such as the following need to be immediately addressed:

- What has happened and where?
- How bad is it?
- How can I allocate my resources most effectively?

As discussed briefly in this paper and more thoroughly in the *Guidelines*, the use of near real-time ground-motion maps can provide information that helps answer these questions.

Essential Information
Near real-time ground-motion maps (i.e., ShakeMaps) provide excellent information on the distribution of shaking in the region affected by the earthquake. Postearthquake response decisions can be made based only on the ground shaking information, however; these decisions require various levels of inference and are not making the most effective use of the ground shaking data. Combining the ground shaking information with other types of data for the region will allow for more reliable and meaningful emergency response decisions.

The basic information that is essential for making quick and reliable postearthquake response decisions includes:

- Ground Shaking Data – information about the distribution of ground shaking in the region
- Facility Inventory Data – information about structures in the region
- Demographic Data – information about people who live or work in the region
- Vulnerability Data – information about how structures and people are typically affected by various levels of ground shaking

The most efficient procedure for storing, combining, and displaying these various types of data is through the use of a GIS. A GIS is similar to a regular database management system, except that in addition to dealing with tables of data, it has the added capability of storing and processing data on maps. Information on individual maps can be overlaid (or combined to form new maps) to show relationships and help with decision making, especially those that involve locations in a region.

A GIS with complete databases for a region is the ideal, but not often the reality, of those involved with postearthquake response. The time and financial resources involved with setting up the system with required maps and data can be quite substantial, even for a small region. The procedures described in the *Guidelines* assume the most basic level of user in terms of experience and know-how, but not in terms of access to computer and data resources, as well as GIS or relational database management software. The purpose of the *Guidelines* is to outline the procedures for the most effective use of strong-motion data and maps, which in almost all cases involves combining the strong-motion maps and data with other types of data for the region.

Basic Steps

The basic steps for effectively using computer-generated ground-motion maps in postearthquake response are outlined in this section. They are general, as the more specific information is described in the sections of the *Guidelines* that deal with the individual postearthquake response topics. Ideally, some of these steps would be done before an earthquake occurs, or the entire process could be done as a training/planning exercise. The steps include:

1. Download the relevant ShakeMaps that illustrate the distribution of ground shaking parameters in the region.
2. Assemble the relevant inventory data, such as building portfolio information, Census data, street maps, and utility system maps, that can be overlaid or combined with the ShakeMaps to identify areas or facilities subjected to high levels of shaking.
3. Estimate damage or loss to regions or facilities based on the combination of ground shaking levels and inventory information. Some users will rely on a specific loss estimation methodology or software for this step. The three most commonly used ones, HAZUS (NIBS, [4]), ATC-13 (ATC, [5]), and EPEDAT (Eguchi, et al, [6]), are described in Appendix B of the *Guidelines*.
4. Combine or overlay additional inventory data, such as emergency vehicle locations, shelters, and hospitals, as needed to provide information for decision making.

Limitations

There are several general limitations that should be kept in mind when using the computer-generated ground-motion maps for postearthquake response. The most important issues include the following; more specific ones are discussed in the sections of the *Guidelines* that deal with the individual emergency response topics:

- ShakeMaps are generated automatically after moderate and large earthquakes and are not initially checked by humans. They are based on recorded data and augmented with predicted values in areas without a sufficient number of recording instruments. It is possible that the distribution of shaking will be biased towards a high anomalous recording, such as the Tarzana record in the 1994 Northridge earthquake.
- Following an earthquake, users need to be able to rapidly update data and mapped information based on reports from the field and revised ShakeMaps.
- Inventory data needs to be kept up to date in terms of accuracy and completeness, especially with respect to locations and facility information.

Application to Damaged Buildings and Safety Inspections

For each of the ten areas of postearthquake response listed previously, the *Guidelines* describe the procedures for effectively utilizing ShakeMaps for postearthquake response by discussing the typical users and needs, the potential data resources, and the potential models or data analysis procedures. Examples, real and hypothetical, are included to illustrate the concepts. Following is a summary of the information contained in the *Guidelines* for one of the ten areas of postearthquake response – damaged buildings and safety inspections.

Typical users and needs
Near real-time ground-motion data will be most useful in aiding engineers or officials in local jurisdictions with prioritizing building inspections within the first day or two following an event. In this application, the focus is on the use of ShakeMaps for help with making quick and reliable decisions, typically for a large group of buildings or for all buildings within a specific region.

Following a moderate to large earthquake, a building owner or manager is under pressure from the occupants to have a trained professional inspect the building and determine whether or not it is safe to occupy. Owners and managers of multiple buildings, as well as the consulting engineers they hire for building investigation services, typically need some sort of priority ranking to effectively deal with occupancy decisions within a reasonable amount of time. Computer-generated ground-motion maps, such as ShakeMap, can be used to quickly determine the level of ground shaking experienced at each building and, when combined with structural and occupancy information, help illustrate which buildings should be inspected first.

Local emergency response managers and building officials would use near real-time ground-motion maps to help prioritize the inspection of public and essential services buildings, as well as allocate staff or consultants for responding to citizen requests for assistance with building safety issues. In addition, this information could be used to notify residents or businesses about the potential loss of city services in specific areas, assign police and fire response to neighborhoods most likely to be damaged, establish the most critical locations to set up emergency shelters, and several other uses (as described in the sections of the *Guidelines* focusing on these other applications).

Potential data resources
In order to effectively use computer-generated ground-shaking maps for prioritizing building inspections and determining regions of most severe damage, building information needs to be stored electronically and geographically referenced. Most building owners or managers have electronic databases of their facilities; however, few have this information in a geographic information system (GIS). As described previously, one of the basic analysis steps involves being able to overlay a map of facilities on the map of ground shaking distribution in the region. Converting existing electronic or paper building inventory databases to GIS format is not as difficult or time consuming as it would seem, given the user-friendly and reasonably-priced GIS software that is now available. In addition, the ability to store and manipulate building inventory data in a GIS has many benefits beyond responding to an earthquake.

Overlaying a map of buildings on a map of ground shaking distribution in the region will identify which buildings were subjected to the various levels of ground shaking. To make the most effective use of the GIS data and capabilities, the building data should include structural information, attributes that are often not part of typical building inventories. The exact structural information to be collected and stored depends on the resources available for database development (some information may require a structural engineer), as well as how the data are going to be used in the future, for postearthquake response and other building management decisions. A relatively complete record in a building inventory database would include the following information:

- Location: address, ZIP code, Census tract, longitude and latitude
- Size: square footage, height, number of stories
- Construction data: year built, lateral load system, gravity load system,
- Occupancy data: use type, daytime occupancy, nighttime occupancy
- Other: existing condition, retrofits, irregularities, importance factor

The information listed above is sufficient in most cases to make first order estimates of earthquake damage and loss to buildings when combined with a map of ground shaking distribution. More detailed information on building attributes, such as that collected during rapid visual screening using ATC-21 procedures (ATC, [8,9]), results from detailed building evaluations using ASCE 31 (ASCE, [7]) or push-over analysis investigations to develop capacity curves, would provide an improved capability for estimating building vulnerability.

For regional use of computer-generated ground-shaking maps, building information is typically stored by summary statistics for the area. For example, Census tract or ZIP code maps can have the number or square footage of each building type as an attribute in the GIS database. The information is typically not very detailed because it is aggregated by geographic region and any building-specific information will be lost in the aggregation. Additionally, the use of the data for first-order prioritization of damaged areas, does not warrant more detailed building-specific information. Regional databases of building inventory can be found in existing loss estimation software or can be developed using techniques described in the loss estimation methodology reports. Information on loss estimation methods and software is described in Appendix B of the *Guidelines*.

Potential models or data analysis procedures
Building owners and managers typically rank life safety as the top priority and business operation as the next most important for prioritizing postearthquake building inspections. In order to use near real-time ground motion information they must develop at least four important pieces of information before the earthquake occurs. These are similar to the four basic steps outlined previously, and include:

- A database of their facilities with information on occupancy and the importance to overall business operations.
- A list of engineers who are contracted to provide postearthquake inspections. In lieu of this, companies will rely on building officials from the local jurisdiction, and volunteer structural engineers, to make inspections.
- A software program (typically a GIS) that can be used to access and store the near real-time ground motion maps and combine them with the facility database.
- Models that: (1) relate the level of ground shaking to damage and loss of function for each building (such as those found in the loss estimation methods described in Appendix B of the *Guidelines*), and (2) assign an inspection priority to each building (this is user-dependent). The level of sophistication of the models depends on the financial resources of the building owner or manager, the in-house technical capabilities, the level of detail in the facility databases, and the desired results. These models can include:
    1. Simple visual inspection of map overlays to make qualitative decisions
    2. Programs within the software that will do the analyses automatically
    3. Programs external to the software, run as a post-processor on the output of the map overlays

The information described above also applies to regional use by local emergency response managers and building officials. The main differences are in the facility databases as discussed above. In this case, the building information is stored in an aggregated format. Local officials are likely to be estimating building damage in conjunction with other effects of the earthquake, such as casualties, need for shelter, and preliminary economic loss – many of which are conditional on building damage. Although several of them still rely on manual methods as discussed in the *Guidelines*, the most efficient methods for making first-order estimates of emergency response needs in a region require the investment to develop accurate regional databases of facility information, and to acquire and learn an automated GIS-based loss estimation methodology.

Example

In this example, the FEMA-352 Report, *Recommended Postearthquake Evaluation and Repair Criteria for Welded Steel Moment Frame Buildings* (SAC, [10]), are used to illustrate the screening of steel moment-frame buildings for possible earthquake damage. FEMA-352 recommends, "Prior to performing preliminary or detailed postearthquake evaluations, it is recommended that screening be performed to determine if a building has likely experienced ground shaking of sufficient intensity to cause significant damage." Ground motion indicators of potential damage are given for considerable and slight damage to steel moment-frame buildings. The indicators include short-period spectral acceleration, peak ground acceleration (PGA), and Modified Mercalli Intensity (MMI) – all ground motion parameters currently available on ShakeMaps. The potential damage indicators, in terms of PGA, given in FEMA-352, are 0.25g for considerable damage and 0.15g for slight damage. Figure 3 illustrates a map overlay of a hypothetical steel moment-frame building database on the Magnitude 6.9 Newport-Inglewood Scenario PGA ShakeMap. From this overlay, those building with potential for slight and considerable damage can be identified and postearthquake survey resources can be allocated accordingly.

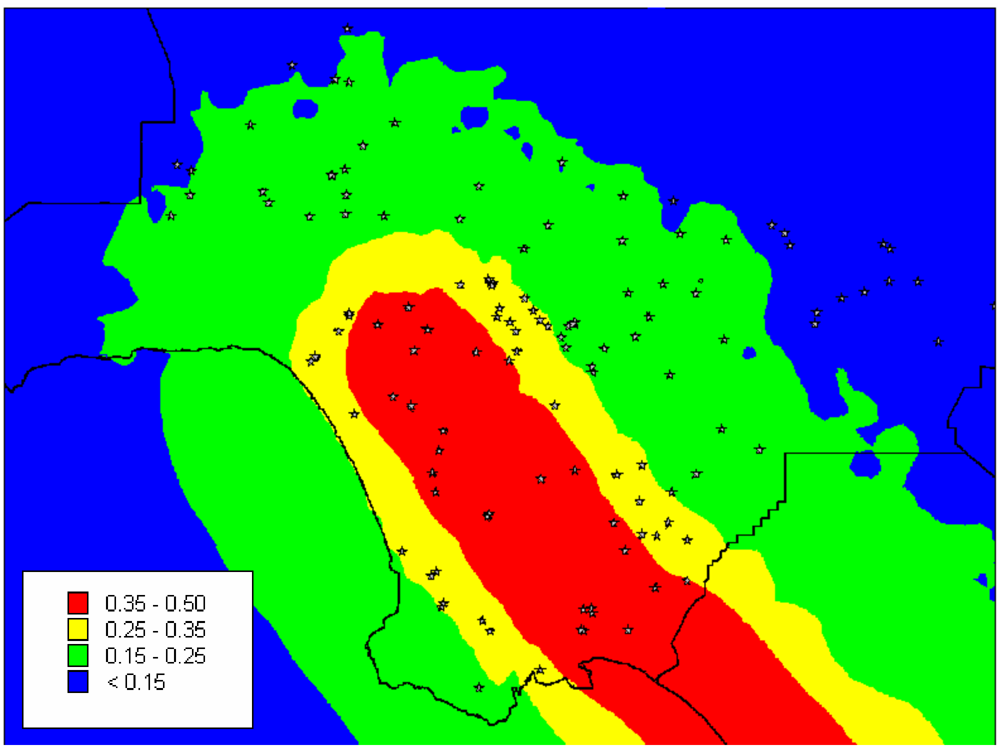

Figure 3. Illustration of SAC FEMA-352 screening criteria (in terms of peak ground acceleration) with hypothetical inventory.

GUIDANCE ON USE OF STRONG-MOTION DATA FOR DAMAGE EVALUATION OF STRUCTURES

Chapter 3 of the ATC-54 *Guidelines* provides guidance for interpretation of strong-motion data in the immediate earthquake aftermath (within minutes to days after the earthquake) to evaluate structural performance. Specific procedures are provided for evaluation of strong-motion data in or near buildings and more general guidance on instrumentation and performance assessment is provided for bridges and dams. In general the procedures apply to records of acceleration recorded as a function of time, otherwise known as acceleration time histories, or accelerograms. Extensive background information is also provided, including discussions of (1) prior efforts to evaluate strong-motion to assess structural performance; (2) the limitations of data from instrumented structures; (3) existing strong-motion networks; and (4) data sources and processing. The main focus of the chapter is a set of procedures for the evaluation of strong-motion data recorded in or near buildings. One set of procedures pertain to the evaluation of ground motion data to determine the likelihood of potential damage in nearby structures. These procedures enable:

- comparisons of ground motions estimated from ShakeMaps with design ground motions (PROCEDURE 1);
- comparisons of recorded ground motions with design ground motions (PROCEDURE 2); and
- estimation of building drift ratios and their significance in terms of damage potential (PROCEDURE 3).

A second set of procedures pertain to the evaluation of strong-motion from instrumented buildings. These procedures include:

- visual examination techniques to (1) identify changes in modal periods of response and estimate mode shapes, story forces, story shears, and overturning moments (PROCEDURE 4); and (2) evaluate high-frequency bursts of acceleration (PROCEDURE 5);
- Fast Fourier Transform moving-window analysis to evaluate changes in building period (PROCEDURE 6);
- displacement time history analysis to estimate building periods, inter-story drift, in-plane bending response, and torsional response (PROCEDURE 7);
- an approach to develop push-over curves using data from more than one earthquake (PROCEDURE 8); and
- system identification techniques to define and verify mathematical computer models of building behavior (PROCEDURE 9).

The description of each procedure includes (1) expertise and time required to execute the procedure; (2) applicable structural framing systems, (3) instrumentation and data required, (4) steps to be taken, and (5) example applications. In certain instances, the procedures applicable to buildings are also applicable to the evaluation of strong-motion data from instrumented bridge and dam sites. The applicability of these procedures is described in those sections of Chapter 3 pertaining to bridges and dams.

Following is a description of Procedure 3.

Procedure 3, Estimation of Building Drift Ratio Using Recorded Ground-Motion Displacement Response Spectra

This procedure uses displacement response spectra computed for horizontal components of basement, ground level, or nearby free-field strong-motion records, and a modification factor that relates spectral displacement response to the roof displacement of the building (displacement modification factor), taken from the recently published FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (ASCE, [11]), to estimate building drift ratio, which is defined as the horizontal drift at the roof level divided by the height of the building.

Expertise and Time Required.
This procedure requires the ability to (1) obtain or compute displacement response spectra using digital strong-motion data, and (2) select an appropriate value of the displacement modification factor and determine the roof drift ratio using a straightforward equation. This requires a level of expertise normally attributable to an engineering analyst (Professional Engineer).

The procedure can be executed in hours, if the person executing the procedure has the necessary expertise.

Applicability and Required Data.
This procedure for the estimation of building drift ratio from recorded-motion displacement response spectra applies to frame buildings up to twelve stories, including wood-frame, concrete moment-frame and steel moment-frame buildings. The procedure requires the use of horizontal components of strong-motion data, in digital format, recorded at a ground-level site, either in the lowest level of the building, or at a nearby free-field site. If free-field data are used, the building being evaluated should be not more than 1000 feet from the free-field site.

The procedure also requires use of the following formula for estimating roof drift ratio, δ_R:

$$\delta_R = \frac{S_d(T)C_o}{H}$$

where $S_d(T)$ is the spectral displacement demand obtained from the 5% damped response spectrum of the earthquake ground motion recorded at or near the building site, C_o is a modification factor that translates the spectral displacement demand to the roof displacement of the building, and H is the building height above the base. Both $S_d(T)$ and H must be in the same units, e.g., inches. The value of C_o, which depends on the number of stories of the building, is taken from Table 3-2 of the FEMA 356 report, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (ASCE, [11]); a triangular load pattern is assumed. C_o values are provided in Table 1

Table 1. Values of C_o for Estimating Roof Drift Ratio (Frame Buildings)

Number of Stories	*Value of* C_o
1	1.0
2	1.2
3	1.2
4	1.25
5-12	1.3

Steps.
The procedure consists of the following *steps*:

1. Obtain or develop the displacement response spectra for 5% damping using ground motions recorded at or near (within 1000 feet of) the site. If two orthogonal components of horizontal motion have been recorded, determine or develop response spectra for both components. (Information on sources for already-computed displacement response spectra, and for methods of computation and related resources, are provided in Step 1 of Procedure 2 of the *Guidelines*).

2. Estimate the fundamental period, T (seconds), of the building under consideration, using one of the following equations, depending on the lateral-force-resisting system: $T = 0.075h^{0.75}$ for wood-frame buildings, $T = 0.043h^{0.8}$ for steel moment-resisting frames, and $T = 0.022h^{0.9}$ for concrete moment-resisting frames, where h (ft) is the height of the building. The equations are based on the period equations given in FEMA-356 (ASCE, [11]). To account for the fact that the FEMA 356 equations underestimate periods during strong ground shaking (see FEMA 356 commentary); the multipliers have been increased to yield periods that are 25% longer than would be obtained using the FEMA 356 equations directly.
3. Determine the displacement response for the period, T, determined in *Step 2*. for both components of ground motion. Use the larger value, expressing the result in inches or centimeters.
4. Determine C_o for the building using values from Table 1 and compute the roof drift ratio, δ_R, using the above equation (be sure to use the same units for H and S_d).
5. Use the information provided in Table 2 to evaluate the potential damage inferred by the roof drift ratio computed in *Step 4*. Based on this evaluation, and if the building is not obviously damaged, determine if the building should be evaluated for hidden damage by a structural engineer experienced in seismic design.

Table 2. Descriptions of Expected Damage for Various Building Types as a Function of Roof Drift Ratio*

	Roof Drift Ratio at Which Damage May Occur		
Expected Damage	*Concrete Moment-Frame Buildings*	*Steel Moment-Frame Buildings*	*Wood-Frame Buildings*
Very Light Damage: Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All systems important to normal operation are functional.	0.5%	0.5%	0.5%
Light Damage: Structure substantially retains original strength and stiffness. Minor crack of facades, partitions, and ceilings as well as structural elements. Elevators can be started. Fire protection operable.	1.0%	0.7%	1.0%
Moderate Damage: Some residual strength and stiffness left in all stories. Gravity-load-bearing elements function. No out-of-plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions.	2.5%	2.5%	2.0%
Severe Damage: Little residual stiffness and strength, but load bearing columns function. Some exits blocked. Infills and unbraced parapets failed or at incipient failure. Building is near collapse	4.0%	5.0%	3.0%

*Damage descriptions and associated roof drifts are based on information provided in Tables C1-2 and C1-3 of FEMA 356. All damage descriptions and estimated drift ratios are based on engineering judgment.

Example.
The building in this example, with building ID number CDMG231-GZ-17, was taken from the ATC-38 report, *Database on the Performance of Structures Near Strong-Motion Recordings: 1994 Northridge, California, Earthquake* (ATC, [2]).

The building is a concrete moment frame building having 8 stories (see Figure 4), designed in 1967, presumably in accordance with the 1967 *Uniform Building Code*. Ground level motions were recorded at a nearby site at station CDMG 24231.

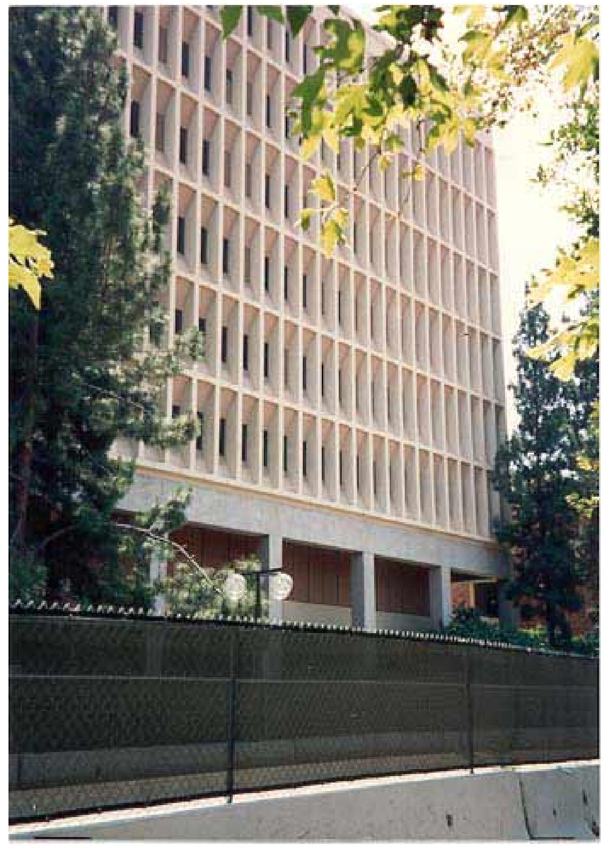

Figure 4. Building CDMG231-GZ-1709 (from ATC [2])

In *Step 1*, acceleration time histories and displacement response spectra were taken from the ATC-38 report (ATC, [2]). The displacement response spectrum for the east-west component, which has the highest displacement response, is provided in Figure 10.

In *Step 2*, the fundamental period is estimated using the equation for concrete moment frames (specified for this procedure) and assuming a story height of 13 feet, as follows,

$$T = 0.022\ h^{0.9} = 0.022 \times (8\times13)^{0.9} = 1.44 \text{ sec.}$$

The amplitude of displacement response was determined in *Step 3* by interpolation of the digitized displacement response values (taken from the ATC-38 CD) in the period range, 1.2 to 1.7 seconds. The amplitude of displacement response for the more significant component (Figure 10) is 3.7 cm.

In *Step 4*, based on the information provided in Table 1, C_o is determined to be 1.3, and δ_R is calculated to be $3.7 \times 1.3 / (8\times13\times12\times2.54)$, which equals 0.0015 (0.15%).

In *Step 5*, the roof drift ratio estimated for the example building (0.15%) was concluded to be an unlikely indicator of damage, because this value was less than the estimated roof drift ratio associated with very light damage (Table 2). The ATC-38 survey of the building revealed that the building suffered Insignificant Damage during the 1994 Northridge earthquake. Both structural and nonstructural damage were estimated to be between 1% and 10% of replacement value.

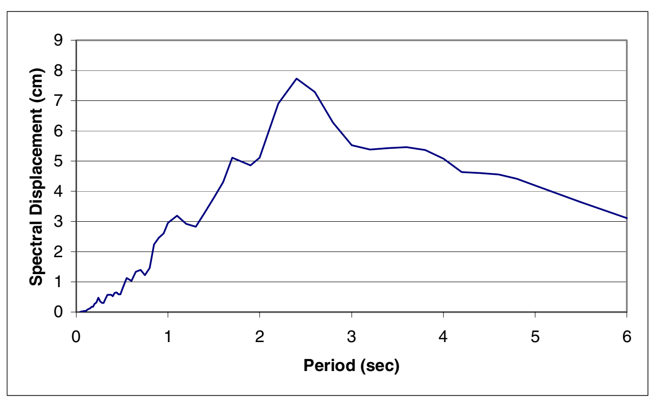

Figure 5. Plot showing displacement response spectrum for east-west components of motion recorded at Station CDMG 24231, 1994 Northridge, California, earthquake (from ATC [2]).

CONCLUDING REMARKS

The ATC-54 Report, *Guidelines for Using Strong Motion Data and ShakeMaps in Postearthquake Response* document, published in early 2004, is envisioned as a living document, with periodic updates and revisions planed as new knowledge, information, and technologies become available. The Applied Technology Council and the Strong-Motion Instrumentation Program of the California Geological Survey intend that the document remain as a primary resource for guidance on the use of computer-generated ShakeMaps in emergency response and for guidance on practical, state-of-the-art procedures for rapid evaluation of structures using strong-motion data. Suggestions for improvement are encouraged.

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