GUIDELINES FOR UTILIZING STRONG-MOTION AND SHAKEMAP DATA IN POST-EARTHQUAKE RESPONSE: AN OVERVIEW

Christopher Rojahn
Applied Technology Council
Redwood City, California

Craig D. Comartin
Comartin-Reis
Sacramento, California

Stephanie A. King
Weidlinger Associates
Los Altos, California

Abstract

The ATC-54 Report, *Guidelines for Using Strong-Motion Data for Postearthquake Response and Postearthquake Structural Evaluation*, under preparation by the Applied Technology Council for the California Division of Mines and Geology, provides guidance on (1) the use of near-real-time computer-generated ground-motion maps in emergency response, and (2) the use and interpretation of strong-motion data to evaluate the earthquake response of buildings, bridges, and dams in the immediate postearthquake aftermath. Guidance is also provided on the collection of data describing the characteristics and performance of structures in which, or near which, strong-motion data have been recorded.

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, 1980), the number of strong-motion recording stations and 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 Division of Mines and Geology (CDMG), 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 (CDMG 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, CDMG 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. Under this project ATC will also 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

Now under development by ATC, the *Guidelines* are being 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*. Upon completion, the *Guidelines* will be presented in draft form at a Users' Workshop organized to solicit input on the draft. The final version of the *Guidelines* will be 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

This paper is one of three papers presented in the SMIP01 Seminar describing the contents of the resource document being prepared under this project, namely *Guidelines for Using Strong-Motion Data for Postearthquake Response and Postearthquake Structural Evaluation*, to be published as the ATC-54 Report (ATC, in preparation). The intent of this paper is to provide an overview of the ATC-54 *Guidelines* and pertinent background information, including a description of the format, content, and preparation of computer-generated ground-motion maps, a new technology that shows promise for emergency response planning and execution. We begin with a description of the purpose and scope of the *Guidelines*, followed by a brief description of computer-generated ground-motion maps. The remainder of the paper is devoted to a description of the *Guidelines* contents and to a set of preliminary recommendations for improving the use of strong-motion data and maps in postearthquake response planning and execution and postearthquake evaluation of structures. The companion papers, “Guidelines for Utilizing ShakeMaps for Emergency Response”, by S.A. King et al., and “Guidelines for Utilizing Strong-Motion Data for Evaluation of Structures”, by A. G. Brady and C. Rojahn, provide more in-depth information pertaining to the use of ShakeMaps and to the use of strong-motion data for structural evaluation, respectively.

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. This document is not intended to be a loss-estimation methodology; however, as discussed in the *Guidelines*, much emphasis is placed on the use of strong-motion data within existing loss-estimation tools for estimating the regional impacts of earthquakes.

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. The first concerns effective means for using computer-generated ground-motion maps in postearthquake response. The intended use of this part of the document is to provide guidance on the development and implementation of applications using such maps for emergency response. Specifically, the applications focus on assessing the following:

- 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
- insurance claims
- other postearthquake disaster and recovery ramifications

With respect to these applications, the *Guidelines* are intended to help users evaluate existing practices and policies, plan for future improvements, coordinate mutual aid, allocate resources, and design and budget for mitigation and planning exercises and programs.

The second topic concerns the rapid utilization of near-real-time instrumental recordings from ground and structure stations for postearthquake response and evaluation of structures. In this regard, the *Guidelines* are intended to help with damage determination, rapid estimation of structural distortions (e.g., inter-story displacements), and mathematical model identification and verification. Information is provided on (1) how to interpret data from strong-motion instruments to evaluate structural response rapidly, and (2) the form, type, and extent of data (in the immediate earthquake aftermath) to be collected from structures in the vicinity of strong-motion recordings.

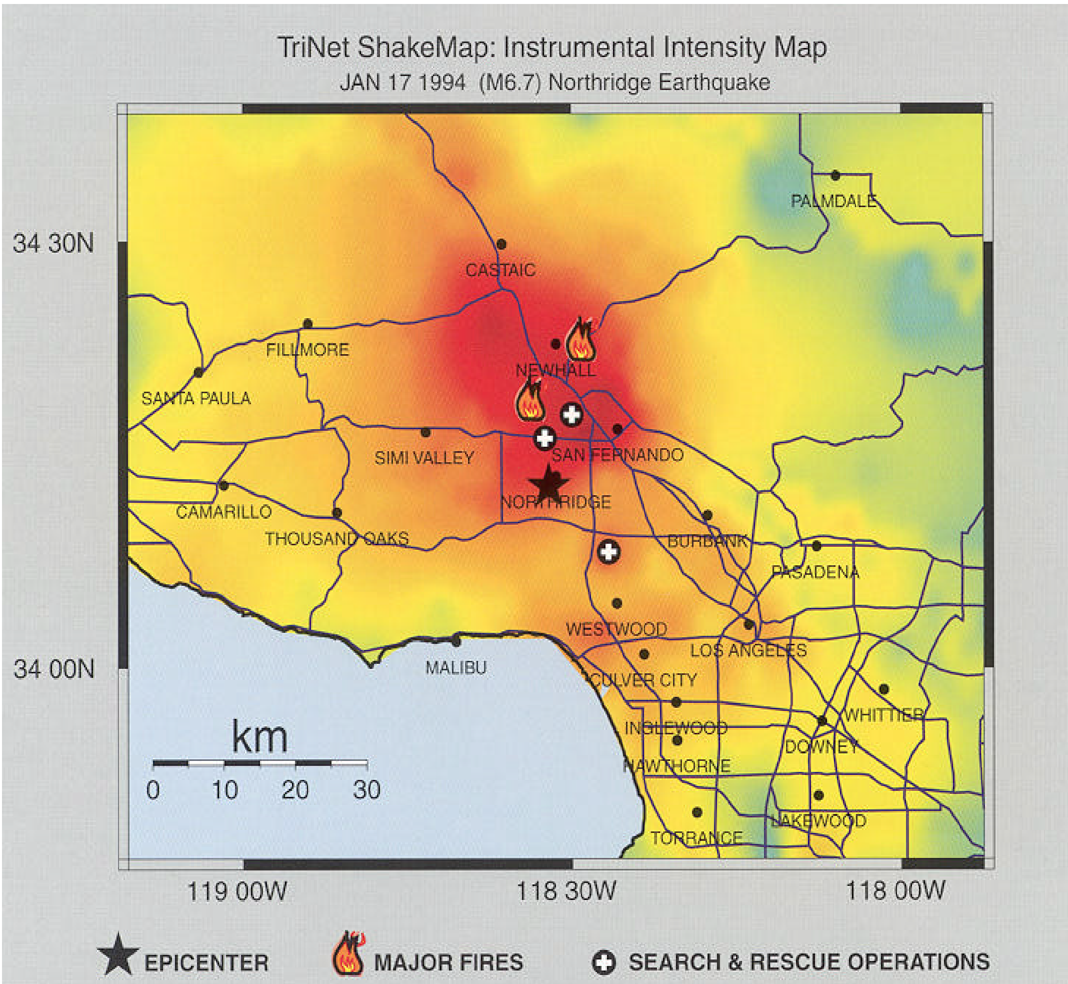
No new research, other than the determination of the state-of-the-art and state-of-the-practice, was undertaken under this project; rather the intent was to create one resource document containing broad guidance on the use of ShakeMaps and currently available resources and techniques for rapid evaluation of structures using strong-motion data.

Computer-Generated Ground-Motion Maps

One of the primary focuses of the *Guidelines* is on the computer-generated ground-motion maps produced by the TriNet program. TriNet is a five-year collaborative effort among the California Institute of Technology (Caltech), the U. S. Geological Survey, and the California Division of Mines and Geology to create an effective real-time earthquake information system for southern California and eventually northern California. A complete description of the history, background, and products of TriNet is available on the web site www.trinet.org.

TriNet ShakeMaps, an example of which is shown in Figure 1, are representations of the ground shaking produced by earthquakes. They are generated automatically following moderate and large earthquakes. These are preliminary ground shaking maps, normally posted within several minutes of the earthquake origin time. They show the distribution of peak ground acceleration and velocity, spectral acceleration at three periods, and an instrumentally-derived, estimated distribution of Modified Mercalli Intensity. The Instrumental Intensity Map is based on a combined regression of recorded peak acceleration and velocity amplitudes. In order to stabilize contouring and minimize the misrepresentation of the ground-motion pattern due to data gaps, the data are augmented with predicted values in areas without recorded data. Given the epicenter and magnitude, peak motion amplitudes in sparse regions are estimated from attenuation curves. As the real-time TriNet station density increases with the passage of time, the reliance on predicted values will decrease.

In addition to producing near-real-time ground-shaking maps, the TriNet ShakeMap program also produces earthquake scenario ground-shaking maps. The earthquake scenarios describe the expected ground motions and effects of specific hypothetical large earthquakes. The maps are used in planning and coordinating emergency response by utilities, emergency responders, and other agencies. The scenario earthquakes provide a more realistic example for training exercises and loss-estimation studies, and can be generated for any hypothetical or historic earthquake.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL. (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. TriNet ShakeMap for the 1994 Northridge, California earthquake (USGS, 2000).

The steps involve assuming that a particular fault or fault segment will (or did) rupture over a certain length, estimating the likely magnitude of the earthquake, and estimating the ground shaking at all locations in the chosen area around the fault. The ground motions are estimated using an empirical attenuation relationship, which is a predictive relationship that allows the estimation of the peak ground motions at a given distance and for an assumed magnitude.

The web address for the TriNet ShakeMaps is www.trinet.org/shake/. Users of the *Guidelines* are encouraged to visit this site often, not only for the near-real-time ground shaking maps, but also for the new or improved products that are periodically added to the web site.

Organization of the *Guidelines*

The *Guidelines* are intended to be used by a diverse audience, many of whom will only be interested in specific sections of the document. In addition, the document is written for the most basic level of user, so more advanced users will likely be able to skim certain sections within their areas of interest.

The *Guidelines* are organized into five chapters so that users will be able to target quickly their sections of interest (Figure 2). Chapter 1 contains introductory material and pertinent background information. Chapters 2 through 4 provide procedures for using strong ground-motion maps and recordings in emergency response, for evaluating the performance of individual buildings, bridges and dams, and for collecting and documenting postearthquake investigation data, respectively. The final chapter provides a summary of the *Guidelines* and highlights recommendations for more effectively utilizing strong ground-motion maps and data.

ATC-54: *Guidelines for Using Strong-Motion Data for Postearthquake Response and Postearthquake Structural Evaluation*

Contents

Figure 2. Guidelines Table of Contents

Chapter 1 provides a broad range of information designed to familiarize the reader with computer-generated ground motion maps, sources of strong-motion data and computer-generated ground-motion maps (including current web site addresses of principal providers). Chapter 1 also introduces current strategic planning for seismic monitoring statewide, including the goals for the next five years of the California Integrated Seismic Network[1] (CISN). The discussion notes that as efforts are undertaken over the next five years to meet these goals, as well as the

[1] The California Integrated Seismic Network is being proposed to provide the organizational framework to integrate the existing, separate monitoring networks in California into a single seismic monitoring system. The CISN Draft Strategic Plan for 2002-2006 includes the following goals: (1) operate a reliable and robust statewide system to record earthquake ground motions over the relevant range of frequencies and shaking levels; (2) distribute information about earthquakes rapidly after their occurrence for emergency response and public information; (3) create an easily accessible archive of California earthquake data for engineering and seismological research, including waveform data and derived products; (4) maintain CISN infrastructure as a reliable state-of-the-art data collection, processing, and information distribution system; (5) apply the latest research and technology to develop new algorithms for analyzing earthquake data and extracting more detailed information for new user products; and (6) maximize the use and benefit of real-time seismic information and other rapidly evolving tools and technologies through technology transfer to the user community.

goals of the proposed Advanced National Seismic System[2] (ANSS), the overview of strong-motion data resources in California provided in Chapter 1 is certain to be superceded by more current information. In general, it is noted that the efforts under the CISN and ANSS will provide additional resources and programs that will undoubtedly result in the more effective implementation of the *Guidelines*.

Chapter 2 covers procedures for using computer-generated maps for postearthquake response. The chapter begins with a section on the general framework for the use of real-time 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. The subsequent sections review the particular interests and needs of the ten emergency response areas listed above. Real and hypothetical examples are included to illustrate the use of ShakeMap products in emergency response.

Procedures for using and interpreting strong-motion records to evaluate the postearthquake response of structures, including structures in or on which strong-motion instruments have been installed as well as non-instrumented structures, are described in Chapter 3. The chapter covers buildings, bridges, and dams. For each of these three structure type, the most commonly used procedures are described, including assumptions about structural properties, applicable structure types, minimum instrumentation and data required, steps to be taken, outputs, and example applications. For buildings, the *Guidelines* address:

- damage indicators that are sometimes evident in strong-motion data from instrumented buildings;
- procedures for rapid visual and hand-calculator analysis of strong-motion data from instrumented buildings (using data collected both at the ground level and in the upper stories, including perhaps film records);
- rapid estimation of changes in building period during strong ground shaking, using visual inspection and Fourier analysis techniques;
- rapid estimation of inter-story drifts, including estimates based on response spectra calculated for ground motion records and estimates based on displacement time-history analysis involving differencing of displacement time histories calculated from acceleration time-histories recorded at different story levels; and
- procedures to verify and define mathematical models of building behavior.

Similar procedures are provided for bridges and dams, but not in such detail.

Chapter 4 focuses on procedures for documenting structural attributes and performance in the vicinity of ground motion recordings. Similar to Chapter 3, this chapter covers procedures for buildings, bridges, and dams and provides guidance for both instrumented and non-instrumented structures. For non-instrumented buildings, the procedures draw heavily on the approach used after the 1994 Northridge earthquake to collect data on the characteristics and performance of

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[2] The Advanced National Seismic System Network, as currently planned, will be a nationwide network of at least 7,000 shaking measurement systems, both on the ground and in buildings (USGS, 2000).

more than 500 buildings within 1000 feet of strong-motion recording sites (see Figure 3). For each structure type, the steps for data collection, data formatting and archiving, and data analysis and dissemination are included.

A summary of the *Guidelines* is given in Chapter 5, along with an emphasis on the key recommendations for how the strong-motion maps and data can be effectively utilized for postearthquake response and evaluation of structures. The recommendations highlighted in this chapter, as well as in other sections of the *Guidelines*, are based on input from current and potential users obtained from interviews and the Users' Workshop. Additional input was provided by the project Resource and Advisory Panel.

Three 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, and Appendix C includes a summary of the most commonly used linear and nonlinear structural analysis software programs.

References and a Glossary listing the acronyms and notation used in the document follow the appendices.

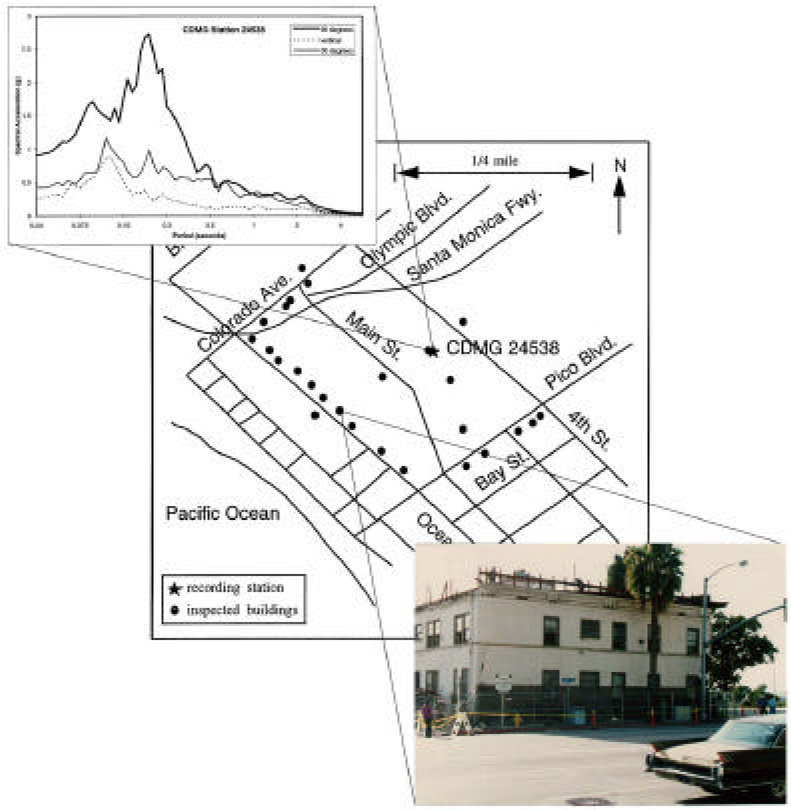
Preliminary Recommendations

Based on the efforts to date, the Project Team has developed the following preliminary recommendations for improving the use of strong-motion data and maps in postearthquake response planning and execution and postearthquake evaluation of structures:

1. For emergency response topics:
   - Develop or improve electronic databases containing facility information;
   - Convert information to GIS format and develop method for importing ShakeMap;
   - Automate simple damage and loss models based on specific post-event needs;
   - Consider use of maps that depict damage-potential ground-motion parameters (e.g., results from Bozorgnia's Year 2000 CSMIP Data Interpretation Project);
   - Automate the ranking of regions or facilities for response or inspection, respectively, if possible;
   - If already using loss-estimation software, improve databases for local regions;
   - Test system regularly;
   - Incorporate personal knowledge in all automated procedures to help convince personnel to start to trust computer output for first-order screening and ranking; and
   - Produce ShakeMaps at a larger scale, such as 1:15,000.
2. For evaluating data recorded in structures:
   - Develop pre-event computer models of the structure for the various types of analysis described;

ATC-38, Development of a Database on the Performance of Structures Near Strong-Motion Recordings

This project was formulated by ATC, the USGS, and several other northern California organizations immediately after the 1994 Northridge earthquake. The purpose was to document systematically the effects of the earthquake on structures adjacent to locations of strong ground motion recordings. Shortly after the earthquake, ATC dispatched teams of licensed civil and structural engineers to the areas of strong ground shaking to survey approximately 500 buildings in the vicinity of 30 strong-motion recording sites (within approximately 1000 feet) to document the characteristics and performance of buildings and other structures.



Prior to the site investigations, ATC provided training sessions to all inspectors instructing them on how to document their findings on the ATC-developed standardized survey forms, as well as in photographs. The data collected at each building site include information on the structure size, age, and location; the structural framing system and other important structural characteristics; nonstructural characteristics; geotechnical effects; performance characteristics; casualties; and estimated time to restore the facility to pre-earthquake usability. Damage is defined in both qualitative terms relating to repairability and in quantitative terms (estimated damage repair costs as a percentage of building replacement value). The survey data were archived in a relational database management system and mapped in a geographic information system. Digitized versions of the strong ground-motion recordings, as well as response spectra, for each site in the vicinity of which buildings were inspected, were also collected and archived with the survey data. The survey data and strong-motion information are documented in the ATC-38 Report and CD-ROM, *Database on the Performance of Structures Near Strong-Motion Recordings: 1994 Northridge, California, Earthquake*, which is available from the Applied Technology Council.

Figure 3. An Overview of the ATC-38 Database on the Performance of Structures Near Strong-Motion Recordings: 1994 Northridge, California, Earthquake (ATC, 2000).

- Develop means for quickly gathering and processing data; and
- Test system regularly.

3. For post-earthquake data collection:
   - Have procedures, personnel and funding ready before the event happens, including criteria for selecting facilities to inspect, and standardized data-collection forms;
   - Have computer database tables set up with trained personnel for data entry; and
   - Train inspectors in advance to collect the needed information using the standardized forms.
4. For strong-motion data and maps:
   - Increase density of instrumentation by:
     - Instrumenting additional buildings and other structures; and
     - Installing more free-field stations for improving ShakeMap interpolation between stations.

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