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The Development of Seismic Guidelines for the Stanford Linear Accelerator Center*

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This paper describes the development of Seismic Guidelines for the Stanford Linear Accelerator Center (SLAC). Although structures have always been built conservatively, SLAC management decided to review and update their seismic guidelines.

SLAC is about mid-way between the epicenters of the 8.3 Richter magnitude 1906 San Francisco and the 7.2 Loma Prieta Earthquakes. The west end of the two mile long electron/positron particle accelerator lies a half mile from the large San Andreas Fault.

Suggestions for seismic planning processes were solicited from local computer manufacturing firms, universities, and federal laboratories. A Committee of the various stakeholders in SLAC's seismic planning retained an internationally known Seismic Planning Consultant and reviewed relevant standards and drafted Guidelines.

A panel of seismic experts was convened to help define the hazard, site response spectra, probabilistic analysis of shaking, and near field effects.

The Facility's structures were assigned to seismic classes of importance, and an initial assessment of a sample of a dozen buildings conducted. This assessment resulted in emergency repairs to one structure, and provided a "reality basis" for establishing the final Guidelines and Administrative Procedures, and a program to evaluate remaining buildings, shielding walls, tunnels, and other special structures.

INTRODUCTION

In developing our *Seismic Guidelines*, we found that the standard ten point Seismic Resistance Value rating for facilities largely addresses only structural vulnerabilities, while ignoring most recovery issues. We are developing a system to characterize the problem in a manner that management can use to comprehensively analyze and prioritize seismic issues for the enterprise.

We had the misfortune of going through our planning process during the transition time when the field was slowly digesting Lessons Learned after the recent series of earthquakes: the 1989 Loma Prieta, 1994 Northridge, and 1995 Kobe. This became evident at this year's World Conference on Earthquake Engineering in Acapulco where there was more intense discussion of the shift to performance-based design (1). Although this became a relatively long and arduous project, we developed great empathy for the onerous responsibilities and liabilities of the structural engineers, and the difficulties in communicating adequately with the facility owner.

Although the site is very close to a high magnitude seismic source, we are very fortunate to also be in a expertise resource-rich environment, which greatly aided in developing this innovative program.

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Stanford Linear Accelerator Center

The Stanford Linear Accelerator Center (SLAC) site is utilized by over 2200 employees and visitors housed in more than 150 buildings with 160 thousand square meters of floor space situated on 172 hectares of land in Menlo Park, California.

SLAC conducts basic research into sub atomic particle physics. It is operated by Stanford University under contract with the United States Department of Energy (US DOE). The 3.2 kilometer long linear accelerator sends electrons and positrons into various experiments at nearly the speed of light. An international collaboration of high energy physicists conduct a year round program of experiments 24 hours a day. Three Nobel prizes have been awarded to SLAC physicists.

Design of the SLAC facilities started in the early 1960's and the site became operational in 1965. Designed and constructed by the consulting joint venture of Aettron, Blume, and Atkinson, the lead design firm was John Blume's. The seismic hazard was known to be high, so the design mitigated against seismic shaking. Blume (2) was one of the leaders in the development of seismic standards internationally, and many of seismic details they built into SLAC did not become part of the building code until many years later.

Roland Sharpe was the supervising engineer for all architectural, electrical, mechanical, and structural engineering for the project. Sharpe's summary report (3) states that the structures were designed to a horizontal acceleration from seismic shaking of 0.2g, which was higher than the 0.13g of the code of the time. Thirty years later, Sharpe became the Seismic Planning Consultant for this evaluation project.

Seismic Evaluation Project

There was concern over the seismic vulnerability of the thirty year old facilities and funding was requested from SLAC Management for a pilot project to characterize the problem. Project authorization and funding notification for the project came in November 1994. Shortly thereafter, President Clinton signed Presidential Executive Order 12941 (4), which adopted the *Standards of Seismic Safety for Federally Owned or Leased Buildings* prepared by the Federal Interagency Committee on Seismic Safety in Construction (ICSSC) (5). This Executive Order mandates an assessment of SLAC's buildings.

In order to frame the project workplan, I surveyed the literature and USDOE Standards and Guidance. Fortunately, our region has a lot of expertise in seismic planning and I consulted colleagues at Sillicon Valley industries and at other National Labs, as well as experts at the USGS, and on the Stanford Campus.

We formed a small committee of the major stakeholders in seismic issues at SLAC, i.e., the department heads for Environmental, Facilities, and Plant Engineering, as well as the chair of the Earthquake Safety Committee. We rediscovered Roland Sharpe, the structural engineer who had designed SLAC and has been on many of the national seismic standards committees. Sharpe became the technical guide to the Committee as our Seismic Planning Consultant.

As part of the pilot project, we developed draft *Seismic Guidelines* and contracted with three large seismic structural engineering firms to conduct phase one "Quick Look" assessments of a sample of a dozen of facilities of various ages, structural types, and sizes. The sample covered over half of the site's population and our emergency command facilities for disaster response.

The pilot project found relatively minor problems with the original structures at SLAC, but major problems with one of the newest structures. This resulted in emergency repairs and a major seismic upgrade to that structure, and provided a "reality basis" for establishing the final Guidelines and Administrative Procedures. SLAC management authorized a multi-year project to complete the *Guidelines* and the seismic assessment of the balance of the site's structures, and address the requirements of Executive Order 12941.

SEISMIC HAZARD

It was well known that the SLAC site is very close to the large San Andreas Fault (SAF), which was the source for the 1906 San Francisco Earthquake. The west end of the SLAC site is about one kilometer and the main Campus area is four to five kilometers east of the fault trace. The SAF forms the boundary between the Pacific and North American Plates.

U.S. Geological Survey personnel were contacted during the definition of the seismic hazard. The probability of occurrence of earthquakes on the SAF, probable attenuation of ground motion near the SAF were examined, and site specific response spectra developed.

Seismic Source

There are several large faults in the Bay Area which could be seismic sources affecting SLAC with high magnitude earthquakes which would shake the site as hard or harder than the 1989 Loma Prieta earthquake:

- 7.7 M - San Andreas Fault
- 7.3 M - Hayward Fault
- 7.5 M - Hayward/Rogers Creek Fault
- 7.1 M - San Gregorio
- 6.9 M - North Calaveras

These magnitudes are given on the Moment Magnitude $\mathbf{M_W}$ scale which is currently favored by the seismic community as providing a more consistent measure of energy release in an earthquake. The older Richter Magnitude $\mathbf{M_L}$ scale is still occasionally used, as are other magnitude scales, which provides for a great deal of confusion. The 1906 San Francisco earthquake on the San Andreas Fault was reported as 8.3 $\mathbf{M_L}$ Richter, which would be 7.7 $\mathbf{M_W}$ on the Moment Magnitude scale. Moment Magnitude will be used from this point on in this paper.

The USGS scientists agreed that the SAF is the controlling seismic hazard source for SLAC rather than that derived from a probabilistic analysis which would include the effects of the Hayward and Rogers Creek faults among others.

The largest hazard for SLAC is a 7.0 M to 7.7 M earthquake centered anywhere along the Peninsula Segment of the San Andreas Fault. The 1990 Stanford University Risk Management Commission (6) defined the design earthquake as a 7.0 M to 7.5 M earthquake centered at Crystal Springs, near San Mateo.

Shaking Intensity at SLAC

The Modified Mercalli Intensity (MMI) scale is used to provide a value for how hard an earthquake shook a particular location and the damage sustained. This scale is given in Roman numerals. The list below provides the shaking intensity at SLAC of the 1989 Loma Prieta earthquake and the forecast provided by the USGS and the Association of Bay Area Governments (ABAG) on the ABAG Web Site for other selected earthquakes:

	MMI
6.8 M - Loma Prieta	VI
6.9 M - N. Calaveras	VI
7.1 M - San Gregorio	VI - VII
7.3 M - Hayward	VI - VII
7.1 M - San Andreas	VIII - IX

Seismic Probability

The most recent consensus forecast from the USGS (7) is a 67% probability of a 7.0 M or greater earthquake in the Bay Area in the next 30 years and a 23% probability of a 7.0 M or greater earthquake on the nearby San Andreas Fault in the next 30 years. Table 1 below provides the probabilities of various earthquakes in the Bay Area.

Table 1a. Probabilities of One or More Large Earthquakes in the San Francisco Bay Region*

Segments	Probability for Intervals beginning 1/1/90				Level of Reliability A-E*
	5 yr	10 yr	20 yr	30 yr	
North Coast, San Francisco Peninsula, N. East Bay, S. East Bay, and Rogers Creek	0.15	0.33	0.50	0.67	B

Table 1 b. Probabilities of Earthquakes on Fault Segments in the San Francisco Bay Region*

Segment	Previous Event	Expected Magnitude	Probability 1990-2020	Level of Reliability A-E
San Andreas Fault				
S. Santa Cruz Mountains	1989	7	<0.01	B
San Francisco Peninsula	1906	7	.23	C
North Coast	1906	8	.02	B
Hayward Fault				
Southern East Bay	1868	7	.23	C
Northern East Bay	1836	7	.28	D
Rogers Creek Fault	1808	7	.22	D

Table 1c. Probabilities of Earthquakes along the San Andreas Fault*

Segment	Previous Event	Expected Magnitude	Probability[a] 1990-2020	Level of Reliability A-E
S. Santa Cruz Mountains	1989	7	~0.00	B
N. Santa Cruz Mountains[b]	1906	6.5	.18	C
San Francisco Peninsula[c]	1906	7	.23	C
San Francisco Peninsula[d]	1906	6.5 or 7	.37	C
North Coast	1906	8	.02	B

* Note: Magnitude is Moment Scale (M_W). Level of Reliability scaled A to E; A most reliable.
(a) Differences in probability of less that 0.10 are not considered meaningful.
(b) Subsegment of San Francisco peninsula Segment. Probability incorporates weight for this segmentation scenario.
(c) Weighted averageof San Francisco Peninsula Segment and mid- Peninsula segment probabilities.
(d) Aggregated probability of 6.5 M or 7 M on San Francisco Peninsula segment.

Ground Motion Criteria

The recommended site-specific spectra were developed following a logical deterministic approach. A M_W 7.7 earthquake occurring on the Peninsula Segment of the SAF is considered to be about the largest earthquake that could occur on this segment. The probability of occurrence of this size earthquake is estimated to be less than 10 percent in 30 years, or a return period of 300 plus years, which is less than the 1,000 year return period specified in DOE-STD-1020-94. However, as this earthquake is estimated to be the largest that can occur, it is essentially equivalent to the 1,000 year earthquake. Thus the seismic hazard requirement for the SLAC Site is being met.

The seismic ground motions to be used in the evaluation of structures, systems, and components, and for design and construction of 1996 and newer facilities are categorized according to which SLAC Zone the facility is in.

To accommodate the “near field effect”, in which the area within about five kilometers experiences dramatically y more violent shaking, the SLAC was divided into two zones: the areas west of and east of U.S. Highway 280. Response spectra for Class C facilities differ in the two zones.

CLASSIFICATION OF FACILITIES

For purposes of SLAC’s *Seismic Guidelines*, the buildings and structures were assigned to one of four classes as listed in the Table below. An updated list of the SLAC buildings and structures is maintained by the Facilities Department.

Table 2: Functional Classification of Buildings and Structures

Buildings and structures shall be assigned to one of the following four classes:

1. Class A - Emergency Command and Service Centers

1. Emergency command and service centers and associated support services.

2. **Class B - Mission Critical Buildings and Structures**

1. Linac and SPEAR buildings, structures, and associated supporting services.
2. Programmatic buildings and structures that directly support the research mission and associated supporting structures, e.g., PEP II, SSRL.
3. Buildings used to manufacture or produce items or store materials in support of the research mission.

3. Class C - General Occupancy Buildings

1. Occupied traditional office environments where personnel are primarily engaged in desk or workstation oriented tasks.
2. Traditional general service buildings where support to personnel and supply of goods and services for the basic site are performed.

4. Class N - Not Occupied

1. Buildings and structures that are not occupied or not otherwise classified as A, B, or C.

Definitions: Building. A roofed structure that is suitable for housing people, material, or equipment. Also included are sheds and other roofed improvements that provide partial protection from the weather.
Structures. Any improvement that is not a building or a utility constructed on or in the land. Examples of structures include bridges, retaining walls, antenna towers, tanks, fixed cranes, roads, and sidewalks.

SEISMIC PERFORMANCE LEVEL FACTORS

Once a facility is classified by function, then performance level standards for that class of facility can be applied and the facility seismically evaluated. SLAC has defined six factors that constitute a facility's performance level. These factors are rated on a ten point scale with 10 being the best and 1 the worst rating.

Table 3 below illustrates the spectrum of Performance Levels that SLAC's *Seismic Guidelines* address. We adopted the logic and framework of the *Vision 2000* Performance Standards (8) to base our factors on.

Table 3. Spectrum of Performance Levels*

Performance Level	Performance Damage	Functionality	Performance Level Thresholds
10 9	Negligible	Fully Operational	No damage, continuous service. Continuous service, facility operates and functions after earthquake. Negligible structural and nonstructural damage.
8.5			
8 7	Light	Operational	Most operations and functions can resume immediately. Repair is required to restore some non-essential services. Damage is light. Structure is safe for occupancy immediately after earthquake. Essential operations are protected. non- essential operations are disrupted.
6.5			
6 5	Moderate	Life Safe	Damage is moderate. Selected building systems, features or contents may be protected from damage. Life safety is generally protected. Structure is damaged but remains stable. Falling hazards remain secure.
4.5			
4 3	Severe	Near Collapse	Structural collapse prevented. Nonstructural elements may fail. Structural damage is severe, but collapse is prevented. Nonstructural elements fail.
2.5			
2 1	Complete	Collapse	Portions of primary structural system collapse. Complete structural collapse.

* Based on SEAOC *Vision 2000,* Figure 2-1.

Definition of Factors

The design of new facilities and the evaluation/upgrade of pre-1996 construction are to be in accordance with the seismic performance levels required for the functional classification of the specific facility. The performance levels are selected, as appropriate for each facility, for the following six separate components. See Table 4 for minimum required levels.

1. Structural Framing (SF)
2. Egress Systems (ES)
3. Nonstructural Building Systems (NBS)
4. Lifeline Utility Systems (LLS)
5. Programmatic Systems (PS)
6. Contents (CPF)

Structural Framing (SF)

The structural framing includes all elements of the structure required to support gravity loads and resist lateral forces induced by wind or seismic ground motions.

The assessment of the structural framing generally follows the system description elements listed in the *Guidelines* Appendix B. Note the ground motion seismic zone factor Z = 0.6g for the SLAC site (UBC lists Z = 0.4g for seismic zone 4).

A *Structural Framing (SF)* factor for the structural framing is assigned to each building or structure by the Reviewing Engineer (RE). An SF scale of 1 to 10 shall be used with 10 being the best and 1 the worst from a seismic capacity viewpoint, see the *Guidelines* Appendix B.

Egress Systems (ES)

Viability of egress from a building after an earthquake is vital, both for exiting of occupants and access by search and rescue personnel. Therefore, the evaluation of existing facilities and the design of new facilities would carefully consider avenues of egress.

Nonstructural Building Systems (NBS)

Nonstructural Building Systems include architectural elements such as interior partitions, ceilings, lighting fixtures, and exterior cladding of the structure; HVAC systems, elevators, electrical supply and control systems, and other systems such as fire sprinklers, toilets, and plumbing.

The assessment of building nonstructural elements, and systems including HVAC, electrical and plumbing systems generally follow the 1994 National Earthquake Hazards Reduction Program (NEHRP) provisions as modified by USDOE standards and other standards.

Lifeline Utility Systems (LLS)

The continued functioning or restart of a building or a programmatic system after an earthquake will be dependent on the availability of the lifeline utilities, i.e., potable water, cooling water, electric power, sanitary sewerage, and natural gas, and telecommunications.

Lifelines shall be assessed for seismic vulnerability. A rating is assigned which represents the best judgment of the RE of the seismic resistive capacities of the supporting lifelines.

A separate study of sitewide lifeline utility vulnerabilities is also being conducted to characterize the issues for utilities being delivered to the SLAC site interface and from that interface to site distribution systems.

Programmatic Systems (PS)

In order to recover to carry out SLAC’s research mission, continued functioning or at least nominal downtime/repairable damage after an earthquake is important for most programmatic facilities/systems (PS).

The RE assigns a PS rating after review of the PS in a facility. The evaluation of such facilities/systems shall follow the general guidelines given in the NEHRP provisions and/or Tri-Services Manual. PS include systems such as the Linac, power supplies, modulators, magnets, klystron assemblies, equipment/control instrumentation cabinets, cabling/cable trays, wave guide assemblies, and vacuum pumps/systems. Performance descriptions for the PSF are given in *Guidelines* Appendix B.

Contents (CPF)

The response to earthquake motions of building contents can impact life safety and recovery to normal operations. Bookshelves, computers other office machines, file cabinets, and hazardous materials can move abruptly or overturn and injure occupants, block doorways or corridors (thus preventing egress and slowing search and rescue), and contaminate work areas or the environment.

Seismic Performance Factor Ratings

Table 4 below shows the performance factors to be rated on a ten point scale for facilities in all functional classifications:

Table 4. Seismic Performance Factor Ratings

Functional Classifi-cation	Structural Framing	Egress Systems	Nonstructural Building System	Lifelines	Programmatic System	Contents
Class	SF	ES	NBS	LLS	PS	CPF
A B C N	1-10	1-10	1-10	1-10	1-10	1-10

ADMINISTRATIVE PROCEDURES

Various administrative procedures are being developed to implement these basic tools.

Seismic Assessment Form

A Seismic Assessment Form was developed to guide assessments by the Reviewing Engineer. The form provides space to record ratings and comments for each relevant parameter within a Factor as well as a summary rating for each factor. This information is transferred to a database for analysis.

Data Analysis

Seismic assessment information can then be analyzed via various database and spreadsheet analyses in various combinations to characterize seismic strengths and weakness:

- by the six factors
- by parameters within a factor
- by factor by organizational unit
- by factor by facility classification: A, B, C, N
- by geographic area
- by facility population

Management Reports

These analyses, and findings and recommendations for priority action provide a comprehensive overview for management of the seismic vulnerabilities of SLAC for both life safety and recovery issues.

These reports can then be provided to management for review and action.

Multiple Applications

This comprehensive approach to characterizing seismic vulnerabilities can be used for many purposes:

- Design of new facilities
- Evaluation of existing facilities
- Upgrade of existing facilities
- Post Earthquake assessments

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