Title
The Economic Benefits of a Disaster Resistant University: Earthquake Loss Estimation for UC Berkeley

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THE ECONOMIC BENEFITS OF A DISASTER RESISTANT UNIVERSITY:

Earthquake Loss Estimation for UC Berkeley

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I. EXECUTIVE SUMMARY

Disasters affect universities across the country. In the past decade, Stanford University and California State University, Northridge were severely damaged by earthquakes; the University of Miami, Tulane University and East Carolina University were closed by hurricanes; the University of North Dakota, Colorado State University, Syracuse University, and many others have faced damage and business interruption from flooding. Not only are universities unique organizations that serve their communities and states, but the federal government also has a significant economic and social investment in them. Annually, federal agencies fund about $15 billion in university research. Much of the research is multi-year, and the value of ongoing research is obviously higher. Much American progress is fueled by academic research results.

The Federal Emergency Management Agency (FEMA), together with the University of California, Berkeley, has funded the research and development component of the Disaster Resistant Universities Initiative as the pilot for a national program. The Disaster Resistant Universities Initiative is intended to motivate and enable the nation's universities to manage their vulnerability to local hazards and reduce their losses in foreseeable disasters. Beyond the primary need to protect students, staff, and faculty, the Disaster Resistant Universities Initiative is designed to help universities safeguard their research capacity as well as the human capital associated with the academic environment.

The Disaster Resistant Universities research and development project generates a national model that can be adapted and used by other institutions. The project has five major components: 1) hazard assessment and loss estimation; 2) evaluation of economic impacts; 3) development and implementation of a strategic risk management plan; 4) development of a model program for university disaster resistance; and 5) progress on national funding for hazards mitigation in research universities. This report documents the research work undertaken at the University of California, Berkeley on the first two components: a prototype for the development of loss estimation procedures, and evaluation of the potential economic consequences of the most severe local disaster—a major earthquake on the Hayward fault. Separate documents include a strategic risk management plan for the University of California, Berkeley and guidelines that other universities can use in their own loss reduction efforts. In Washington DC, FEMA staff are working with Congressional staff and a coalition of other universities to establish new funding for the DRU initiative over the next ten years.

This report and three technical appendices were prepared by Mary Comerio, Professor of Architecture at the University of California, Berkeley, with assistance from the project team consisting of faculty in engineering and economics, graduate student researchers, and professional consultants. The report is intended for the Chancellor and senior administrators at University of California, Berkeley who demonstrated their commitment to seismic safety through the establishment in 1997 of the SAFER (Seismic Action Plan for Facilities Enhancement and Renewal) Program. In addition, the report is for James

Lee Witt, Director of the Federal Emergency Management Agency, who saw the potential for a national university-focused hazard mitigation initiative evolving from UC Berkeley's SAFER Program. More broadly, this report is for all major universities and their surrounding communities, to assist in estimating the impacts of natural disasters, and to focus attention on the importance of loss reduction programs and business resumption planning.

This study of earthquake hazards and the economic consequences of potential losses at the University of California, Berkeley grows out of a long-term commitment to understanding and addressing seismic safety issues on the part of the campus and the systemwide administration. The campus conducted its first seismic review of campus buildings in 1978. Based on that survey, a number of buildings were strengthened, including South Hall, University Hall, Doe Library, and the Valley Life Sciences Building. In the late 1990s, the campus renewed its commitment to improving structural conditions in campus buildings with the launching of the SAFER Program. This bold seismic safety initiative established a twenty-year time line and a $1 billion dollar budget to improve the seismic resistance of campus buildings, making them safer for students, faculty, and staff.

This research advances our understanding of potential earthquake losses by assembling data on soil conditions, infrastructure, nonstructural building conditions, contents, numbers of occupants, and the location of critical functions. Taken together, the data are used to assess the potential financial loss, and the University’s capacity to recover after a damaging earthquake. The findings of this study, in combination with the ongoing SAFER program, serve as the basis for an effective seismic risk-management program.

Although no other campus in the United States has done more than the University of California, Berkeley in addressing its natural hazards risks, the university needs to minimize the impact of potential losses through wide-ranging hazard mitigation programs and post-disaster business resumption planning.

The Loss Model

Estimating the toll is the first step toward reducing losses. To assess the hazards and estimate the potential losses resulting from an earthquake, the project team relied on multiple engineering evaluations of various conditions. To develop a loss-estimating model appropriate to a campus setting, we prepared a microzonation soil map of the campus, estimates of ground shaking, and maps of the location and condition of campus infrastructure. We studied the structural and nonstructural conditions of campus buildings, and we described each building in terms of how it is used (e.g., classrooms, labs, offices, libraries, event spaces), and in terms of the annual average number (as well as peak hour number) of occupants. The campus data were then used to estimate the cost of repairs and downtime in three earthquake scenarios, defined as Occasional, Rare, and Very Rare.

Conservative cost estimates for replacements and repairs suggest that damage could reach $600 million to $2.6 billion, assuming that buildings with 60 percent or more structural damage would be replaced. If 50 percent of structural damage were to be used as a measure of replacement, the upper limit of replacement and repair costs would rise to $3.5 billion. Equally significant, in a Rare earthquake (M7.0), approximately 40 to 60 percent of all campus space could need more than twenty months for repairs. This does not literally mean that 40 to 60 percent of campus buildings would be closed for up to two years, but gives a good indication that significant amounts of space will not be useable for long periods of time. In an earthquake, building damage and the time needed for repair will vary, depending on the location of the epicenter, the duration and directivity of the ground motions, and the availability of money and materials for repair.

Under the circumstances of the Rare earthquake scenario, the research team believes that present building conditions could force the campus into a short-term closure. Although a limited schedule of classes could be resumed using temporary trailers, we estimate that it could take up to two years before a normal schedule could be offered. In a Very Rare earthquake (M7.25), 50 to 75 percent of all campus space could need more than twenty months for repair, which could close the campus for up to one year. It is likely that it could take four years for a return to pre-earthquake standards of operation.

These estimates are based on conditions current in 1999. Obviously, as buildings are renovated, their conditions are improved and downtimes are reduced. By 2006, ten major central campus buildings will have completed seismic retrofits. Another fifteen buildings are slated for seismic repairs by 2011, reducing the potential for long-term building closure substantially.

Economic Impacts

The evaluation of the economic impact a severely damaged university would have on the surrounding community takes into consideration the estimates of potential loss and the capital flow of the university (operating expenditures, salaries, income). In the event of a Very Rare earthquake—the only economic scenario in which a year-long campus closure was considered possible—the first year losses in three counties include approximately 8,900 jobs, $680 million in personal income, and $861 million in sales. While these losses would be offset in the larger economy by the increase in construction jobs generated, it is important to note that the losses and gains are in very different sectors of the economy.

The research team conducted two additional economic studies to evaluate the impact of the various earthquake scenarios on research at the University of California, Berkeley and on human capital in the region. In a survey of organized research units, we found that 72 percent of all research income went to twenty-five research units, primarily in science and engineering. Moreover, 50 percent of the research dollars which come to the campus are concentrated in just seven buildings, or 12 percent of campus space. Seventy-five percent of research funds are expended in a total of seventeen buildings, one third of campus space. The seismic ratings of eleven of these buildings are such that, in a Rare earthquake scenario, they would be closed for repairs for an extensive period. Although four of the eleven buildings are scheduled for seismic repairs by 2006, the potential for loss in the research sector suggests that the viability of the ongoing research endeavor at UC Berkeley would be threatened.

Using data for recent graduates of the University of California, Berkeley's College of Engineering and Haas School of Business, we estimated the number of out-of-state students who continue to reside in California after graduation. The University exercises considerable influence in attracting and retaining post-graduate workers. Each additional graduate that remains in California results in almost a million dollars in increased state output (gross domestic product), and $100,000 in state tax revenue, over a lifetime, in present value terms.

This economic analysis suggests that when a university is located in a large metropolitan area with a complex and dynamic economy, the impact from an institutional closure is not entirely represented by the immediate loss of jobs and local sales. Much more important is the university's contribution of highly trained professional workers to the regional economy. If the supply of professionals from the University of California, Berkeley were ever seriously interrupted, that would have a dramatic impact on the region.

Findings

The University of California, Berkeley remains vulnerable to earthquake losses, despite the extraordinary commitment to improve the life safety of hazardous buildings. This vulnerability can be attributed to three key factors. First, even buildings considered "fair" in the 1997 structural evaluation may be subject to considerable nonstructural (contents) damage. Under current conditions, structural and nonstructural damage could close 50 to 75 percent of campus space for up to one year after a magnitude 7.0[1] or larger earthquake on the Hayward fault. Secondly, among the seventeen buildings in which 75 percent of the research is concentrated, the same proportion of space—that is, 50 to 75 percent—is likely to be significantly damaged and closed after a major seismic event. [2] This will seriously disrupt existing research and limit the capacity to take on new research for a long period. Finally, one third of the replacement value of the campus is in its contents—books, technical instruments and research equipment, art, specimens—all highly susceptible to damage and essential to the teaching and research mission of the University.

Although the loss to buildings and contents represents 30 to 40 percent of the replacement value of the campus, the greatest potential losses, in academic and economic terms, would result from a substantial quake that forces even a partial campus closure. This study adds a business-oriented perspective to the traditional development of natural

[1] Based on ground shaking estimates used in the Rare scenario earthquake, that is, with a 10 percent probability of exceedance in a fifty-year period, also known as an earthquake with a 475-year return period.
[2] As buildings are repaired, the percentage of vulnerable space will be reduced over time. However, structural improvements reduce, but do not eliminate, earthquake damage.

disaster loss-reduction measures for universities. It suggests a comprehensive approach that includes educating the campus community about the many aspects of, and possibilities for loss reduction.

Specific to the University of California, Berkeley, the SAFER Program's goal to improve life safety in campus buildings should expand to seek above-code performance for some new buildings, and to include policies and assistance for campus-wide business resumption and disaster recovery planning, comprehensive nonstructural hazard mitigation, and campus community education and training—all of which are necessary to the maintenance of its tradition of academic and research excellence. The ongoing success of the SAFER Program can be enhanced by implementing the following recommendations:

1. A policy to look beyond the life-safety criteria for seismic retrofits to the concomitant importance of limited damage in teaching, research, and library space, and limited damage to critical infrastructure in order to insure continued operations after a large earthquake. Such an approach would include a priority system for all campus construction (retrofits, demolitions, and new construction) that considers life safety and loss reduction, as well as ongoing operational needs.
2. A campus-wide nonstructural mitigation program aimed at loss reduction in laboratories, libraries, classrooms and offices.
3. A strategic campus plan, encompassing academic and physical planning, as well as business resumption planning, that uses the seismic retrofit program to improve the quality of teaching and research activities for the future. The current master planning effort, the New Century Plan, must maintain its focus on seismic safety as the driver for many of the changes on campus in the foreseeable future.

In order to have a campus that remains one of the nation’s most prestigious academic institutions, the University of California, Berkeley should continue the program of structural retrofits for existing buildings and consider, for each retrofit or new project, constructing above code to ensure post-earthquake functionality in the structure. In addition, the seismic improvements to structures should be one part of a comprehensive risk management program. For any major teaching and research institution where operations are threatened by natural disasters, hazards mitigation and post-disaster recovery strategies must be a regular part of the ongoing planning in every academic department and management unit.

II. INTRODUCTION

Disasters in the last decade have captured national and international attention. Although casualties in recent American disasters remain low, the unprecedented economic losses that have resulted from urban disasters have created increased awareness of the need to both improve methods of estimating disaster losses and make plans to reduce them. The science of loss estimation is in an exciting stage of development. As the authors of a recently published journal (*Earthquake SPECTRA*, 1997) note in the preface to an issue devoted to loss estimation, advances in software technology, particularly geographic information systems (GIS), combined with improved data bases from recent disasters have allowed researchers to better assess the performance of structures and the potential economic, social, and human losses.

One of the most significant developments in earthquake loss estimation is the comprehensive HAZUS[3] software package, which was funded by the Federal Emergency Management Agency (FEMA), and has been tested in numerous cities and regions. HAZUS combines state of the art approaches for characterizing earth science hazards, estimating damage to buildings and lifelines, and estimating casualties, shelter requirements, and economic losses. HAZUS is one of the best tools available for estimating losses at the regional level, but, like all standardized tools, it does not meet the needs of many specific applications.

Universities, for example, are unique and specialized in terms of their physical facilities, which serve both research and teaching, and in terms of their economic function within a community. Universities are also self-contained communities with housing facilities, food services, small businesses (from retail stores to printing presses), and hospitals. Universities frequently have too many buildings to conduct complete building by building assessments of hazards and potential losses. Yet a campus is small enough to take into account how the loss of specific portions of individual buildings will affect the ability of the University to operate, a loss modeling approach that HAZUS does not yet contain. Similarly, universities have concentrated value, not only in terms of their facilities and specialized contents, but also as long-term public investments, with multi-year and inter-institutional research projects, and with critical pedagogic roles. Furthermore, research universities have a unique economic function in that they provide a combination of traditional employment/wage, goods and services benefits locally and they are a source of growth and development for key economic sectors, locally and nationally.

In twenty-four hours after the 1989 Loma Prieta earthquake, Stanford University had to decide if the university could remain open as a result of the damage sustained in 242 buildings. Two dozen buildings were closed. The University decided on quick repairs to

[3] HAZUS stands for Hazards US. It is a GIS-based software developed by the National Institute of Building Science for FEMA. The software is designed for regional earthquake loss estimation.

three academic buildings and four dormitories, using unrestricted gifts and general funds, because the buildings were essential for continued operations. The remainder of the closed buildings stayed closed for years. For example, repair to the two corner buildings of the main quadrangle, Geology and Language, did not begin until 1994, and was not completed until 1996.

The construction delays occurred primarily because university and FEMA officials could not come to agreement on the value of the repairs. Subsequently, Stanford officials decided to narrow the negotiating focus to buildings that were essential to academic functions. Ten years later, a number of buildings remain closed for a variety of reasons, including the fact that no funding agreements with FEMA were realized. Overall, the estimated value of the damage to the Stanford campus was over $200 million dollars, of which FEMA contributed a net amount of $50 million for repairs. The university used its own unrestricted funds, and had to make up the difference by reprogramming other funding streams not intended for repairs. In the decade since the Loma Prieta earthquake, Stanford University has expended about $750 million for various capital projects, including seismic retrofits and new construction.

As a result of the Loma Prieta earthquake, Stanford University developed a building policy aimed at avoiding closure in future events. The Stanford policy, drafted in November of 1990 by the Earthquake Risk Policy Commission, provided funding priority to retrofit buildings identified as "necessary for survival," recognizing that a core of campus buildings must be operational after a disaster so that teaching and research can be continued. The policy added "the preservation of the academic program" to the goals of maintaining life safety, reducing risk, and rendering life safety aid to the community residents. To accomplish the goal of preserving the academic program, the report set building repair standards that are intended to limit damage to the buildings used for teaching, research, administration, library, and housing to no more than 5 to 20 percent of the total square footage in each sub-area.

After the 1994 Northridge earthquake, all the buildings at California State University, Northridge were closed. It is a tribute to the administration that the campus reopened for classes one month later—using 450 trailers and other temporary buildings spread around on available campus space. Unfortunately, five years later, the campus still does not have a chemistry laboratory or any wet laboratory open and available to faculty and students. Across the country, hurricanes, floods, power outages, and fires have interrupted operations at universities in Florida, North Carolina, North Dakota, Colorado, New York, and Louisiana. All institutions are vulnerable to extensive damage from a variety of hazards, and all face dire economic and human capital losses from campus closures.

The University of California, Berkeley is a worldwide leader among universities in research, education, and public service. The central campus houses over 40,000 students, faculty, and staff in more than 100 academic departments and organized research units. The central campus has 114 buildings on 177 acres, with about 5 million net square feet of classrooms, libraries, offices, research laboratories and other specialized facilities. In the 1998 fiscal year, the campus operating budget was approximately $998 million and sponsored research awards totaled $362 million (of which, more than two thirds comes from federal agencies). Overall, the University's Risk Management Office has estimated the insured value of the campus at $4.7 billion (compared with a total replacement value for buildings of approximately $8.8 billion).

The Disaster Resistant Universities report represents eighteen months of research undertaken at UC Berkeley on a prototype loss estimation methodology and on an evaluation of the economic impact of three disaster scenarios. The work was funded by the Federal Emergency Management Agency (FEMA) and the Chancellor's Office at the University of California, Berkeley as the pilot study for a national initiative to recognize the importance of Disaster Resistant Universities. This report and the three technical appendices document two of the five components of the study—a loss estimation model and an economic impact model. Two additional components of the project, a strategic risk management plan for UC Berkeley and model guidelines for other universities, will be prepared as separate documents. The final component of the initiative, the attempt to fund a long-range program to assist universities in identifying risks and responding to risks, is being managed by FEMA staff and a steering committee of universities from around the country.

III. ESTIMATING LOSSES IN THREE EARTHQUAKE SCENARIOS

The University of California, Berkeley and other universities, as well as the public and private investors in them, need a more specialized method of evaluating the extent of their potential disaster losses and the subsequent impact of those losses on the region and on the nation. Our research builds on the significant work already undertaken to identify and retrofit buildings on the Berkeley campus. The campus has had a seismic corrections program in place since 1978 and has spent about $250 million on structural improvements. In 1997, the campus hired three structural engineering consultants, Degenkolb, Forell-Elsesser, and Rutherford and Chekene, to undertake a structural survey of all university buildings. In this survey, structural conditions were evaluated in terms of the ten-point performance index in the Structural Engineers Association of California, Vision 2000 methodology for performance based design (Hamburger et al. 1995; SEAOC, 1996). In the 1997 Preliminary Seismic Evaluation (PSE), the engineers found that 27 percent of the useable space on campus was in "poor" or "very poor" structural condition (equivalent to a 1-3 Vision 2000 rating). See Table 1.

Each building was evaluated in terms of its performance in three earthquake scenarios: an Occasional, Rare, and Very Rare event. The scenarios are defined as follows:

> A Level 1 Occasional Earthquake was defined as one with ground motion of moderate severity that is likely to occur as a result of an earthquake on any of the active faults in the Bay area. This ground motion is characterized in probabilistic terms as having a 50 percent probability of being exceeded in 50 years (known as a 72-year return period). It is not associated with a particular event or fault.
>
> A Level 2 Rare Earthquake was defined as a severe event expected to occur on the nearby northern segment of the Hayward Fault. A magnitude 7.0 is postulated for this segment, and ground motions were estimated using deterministic methods at expected median values. These estimates yield ground motion levels similar to those derived probabilistically, using uniform risk methods with a 10 percent probability of being exceeded in a 50-year period (known as a 475 year return period).
>
> A Level 3 Very Rare Earthquake was defined as one with extremely severe ground motion, with an expected magnitude of 7.25 on the Hayward Fault, and a 5 percent probability of being exceeded in a 50-year period (a 975-year return period).[4]

[4] The Level 3 event was originally defined in the 1993 Hearst Memorial Mining Building study (HMMB) as a Maximum Credible Earthquake (MCE) with ground motions having a 10 percent chance of exceedance in a 250-year period (known as a 2450-year return period). In both the 1997 Preliminary Seismic Evaluation and in this study, consulting engineers believed the 975-year return period was more appropriate.

These earthquake scenarios were based on a study of seismicity and ground motion for the Hearst Memorial Mining Building by Rutherford and Chekene in 1993, on a campus policy statement regarding seismic design procedures from January 1995, and the 1997 Preliminary Seismic Evaluation. As described in the 1997 PSE, the actual spectral value used was derived from the 1997 Uniform Building Code near fault rules which compare closely with the ground motions used for the HMMB study.

In this research project, we worked with the same team of structural engineers (Degenkolb, Forell-Elsesser, and Rutherford and Chekene), coordinating with Professor Vitelmo Bertero, to evaluate the non-structural building conditions and to enhance the previous structural assessments of campus buildings with additional analysis. We also worked with Geomatrix Consultants, geotechnical engineers, to identify the site soil classifications, and to evaluate previously developed earthquake ground motion response spectra. In addition, Geomatrix evaluated the potential for seismic-geologic (earthquake-induced) hazards that could result in an interruption of the operation of a facility or could pose a substantial life safety risk to the occupants of buildings within the central campus.

Geotechnical Inputs

Appendix One contains full details of the Geomatrix report. The key findings are described briefly below.

Site Classifications
According to the 1997 Uniform Building Code (UBC) and the 1997 National Earthquake Hazards Reduction Program (NEHRP) Provisions of the Building Seismic Safety Commission [BSSC], site classifications are required as an input to the selection and development of response spectra. The soils underlying the central campus can be characterized as rock and shallow soils overlying rock. Thus, these soils classify as soil profile types S_B and S_C, respectively. The older alluvial soils overlying bedrock at the central campus are classified as soil profile type S_C, whereas for areas of the central campus where there is less than 10 feet (3 meters) of soil overlying bedrock, the appropriate soil profile type would be S_B. Additional site-specific studies may indicate additional areas where the appropriate soil profile type is S_B. See Figure 1.

Evaluation of Earthquake Ground Motions
Geomatrix conducted a preliminary site-specific analysis of earthquake horizontal ground motions at a rock site on the campus located close to the Hayward fault. The purpose of this analysis was to evaluate the suitability of existing campus response spectra for use in the campus loss estimation study, and not to develop new response spectra for designing new campus buildings or retrofitting of existing structures. The evaluations of these three spectra—Level 1 Occasional, Level 2 Rare, and Level 3 Very Rare—were conducted using both deterministic (maximum magnitude earthquake) and probabilistic ground motion analyses. Consistent with the characterization of the Level 3 as a “very rare event” producing “extremely severe” ground motion, Geomatrix incorporated estimated maximum directivity effects (i.e., effects of fault rupture propagation toward the site that increases long-period—greater than 0.5 second—ground motion). Consistent with the

fact that both Level 2 and Level 3 events are near-fault events for which it has been found that long-period ground motions exhibit directionality, the preliminary ground motion analyses developed fault-normal (i.e., perpendicular to fault strike) ground motions as well as average horizontal ground motion. The fault-normal ground motions are higher than the average horizontal component in the long-period range (periods greater than 0.5 second).

The comparisons made in the ground motion study indicate that the following rock response spectra are appropriate for use in the campus loss estimation study. As such, the Geomatrix study states:

> For the Level 3 earthquake, the Hearst Memorial Mining Building (HMMB) Maximum Credible Earthquake (MCE) spectrum is appropriate for periods of vibration equal to or less than 1.5 seconds.
>
> For the Level 2 earthquake, the HMMB Level 2 spectrum is appropriate for periods of vibration equal to or less than 2 seconds.
>
> For the Level 1 earthquake, it is recommended that the campus loss estimation study consider a revision to the HMMB Level 1 spectrum, with some increases in the low period range.

Subsurface conditions in the central campus range from rock—or very thin soil overlying rock—to more than 70 feet (21 m) of soil above rock. For most of the central campus, it appears that the depth to rock is less than 50 feet (15 m). For this predominant condition, the effects of soil response on the rock response spectra will be minimal and likely limited to the period range of 0.5 to 1 second.

Because of the new knowledge that has been acquired in recent years regarding the Hayward Fault and the characteristics of near-source ground motions, Geomatrix has recommended that the university consider conducting a detailed ground motion evaluation to update the existing campus spectrum for design applications. This ground motion reexamination should incorporate the latest knowledge and include both probabilistic and deterministic analyses. At the time of this writing, this evaluation is already underway.

Seismic-Geologic Hazards

The seismic-geologic evaluations conducted by Geomatrix include the following earthquake-induced hazards: surface fault rupture, soil liquefaction, differential soil compaction, landsliding, and flooding. The seismic-geologic study delineates areas where significant seismic-geologic hazards do not appear to exist; significant hazards may exist, but further studies are required to evaluate them; and/or significant hazards exist and hazard mitigation should be considered. The evaluations of these earthquake-induced hazards are based on currently available information. Summaries of the findings for the individual hazards are given below.

***Surface-Fault Rupture Hazard* -** Active traces of the Hayward Fault pass through California Memorial Stadium and close to Bowles Hall. Thus, it is judged that a potentially significant surface-fault rupture hazard exists for these buildings. A potentially significant surface-fault rupture hazard also exists for utility lines that cross the mapped active traces of the Hayward Fault. These include the Pacific Gas and Electric (PG&E) 12kv power feed, the U.S. Sprint fiber optic cable for internet connections, and the East Bay Municipal Utilities District (EBMUD) water distribution lines. For the remainder of the central campus west of Gayley Road and Piedmont Avenue, it is judged that there is not a significant surface-fault rupture hazard, except as would result from loss of utility services that cross the Hayward Fault.

***Liquefaction Hazard* -** Review of geotechnical borings drilled across the campus shows that the earth materials are bedrock, stiff clays, or dense clayey soils that are not susceptible to liquefaction. Therefore, no significant hazard due to liquefaction has been identified at the central campus.

***Soil Differential Compaction Hazard* -** The earth materials at the central campus are bedrock or stiff clays or dense clayey soils that are unlikely to settle differentially during an earthquake. Thus, no significant hazard due to differential compaction has been identified for the central campus.

***Landsliding* -** Site reconnaissance and a review of both available landslide hazard mapping and of geologic evaluations show that landslides have occurred on several slopes along the eastern part of the central campus. Further, steep cut slopes occur along Stadium Rim Way and near several buildings along Gayley Road in the eastern part of the central campus. Site reconnaissance of these cut slopes shows that the hill slopes are underlain by Great Valley Sequence or Franciscan bedrock and that there are no landslides or other signs of slope instability. Because these cut slopes appear to be stable, it is judged that there is not a significant landslide hazard for any of these cut slopes.

A large landslide complex was mapped along the hillslope that lies east of Bowles Hall and Stadium Rim Way (HLA, 1986, 1988a, c). Although part of this landslide complex apparently was remediated during construction of the parking lot east of Bowles Hall, the southern portion of this landslide complex still remains upslope and to the east of Bowles Hall and Stadium Rim Way. Thus, a potential landslide hazard exists for the area upslope and east from Bowles Hall and Stadium Rim Way. It is judged that there is not a significant landslide hazard for the central campus because no facilities are located within the area of potential landsliding. A potentially significant hazard due to landsliding may exist for the PG&E 12kv power feeds; these power cables apparently pass through the area of potential landsliding within the central campus study area and through other areas east of the central campus where landsliding may occur. A potentially significant risk also may exist to any other utility services that pass through the area of potential landsliding or other areas susceptible to landsliding east of the central campus study area.

Based on review of detailed topographic maps and on field reconnaissance of hill slopes, Geomatrix concluded that the slopes in the central campus are stable and are not prone to significant slope failures, except for the hillslope southeast of Bowles Hall. Because potential landslides on this hillslope are unlikely to extend near to Bowles Hall or other facilities, a significant hazard has not been identified for any facilities near this zone of potential landsliding. Thus, no significant landslide hazard has been identified for any existing facilities or structures at the central campus. Small soil slumps or slides may occur along slopes near some structures; however, these failures are expected to be limited in size and extent such that they would not impact or significantly damage any structures.

Flooding - Based on site reconnaissance and a review of topographic maps, there are no dams, bodies of water, or other conditions that could result in post-earthquake flooding in the central campus. Thus, no significant earthquake-induced flooding hazard exists for the central campus.

Building Conditions

The building by building data collected in the 1997 structural survey of buildings became the basis for the expanded loss estimation model. We improved our basic understanding of the structural performance of ninety larger campus buildings, using a preliminary pushover analysis of each building (or building sub-area if multiple systems were present). The structural pushover analysis was developed to provide additional insight into the performance of buildings and to provide preliminary data for future use in automated loss models such as HAZUS. The research team did not change the structural ratings from the PSE for use in the methodology we developed for evaluating other building conditions or in the loss analysis. See Figure 2.

To describe the performance of the non-structural components in the major use areas of campus buildings, our approach was to evaluate six major building components. These included the cladding and glazing on the building exterior; the architectural finishes; the Mechanical, Electrical, and Plumbing (MEP) systems; the contents; and the potential for water damage to the building interior. These components were evaluated in each of the major use areas within each campus building: classrooms, laboratories, offices, libraries, and special/other (e.g. recreation and/or performance spaces), as well as residential buildings, and parking structures.

For each building, a list of occupancy classifications was made from a campus Facilities Management space-use database, and this list was used to create an evaluation form listing the building components. The consulting engineers then rated the replacement value of each component as High, Medium, or Low and rated the non-structural performance of the component using the one to ten Vision 2000 performance index. For example, the cladding and glazing in each building were rated as High, Medium, or Low as a measure of their replacement cost value and given a numerical performance index for each of the three earthquake scenarios. Similarly, architectural finishes, MEP, contents, and potential water damage were rated for classrooms, laboratories, and other sub-areas in each building.

For example, in Cory Hall, a five-story concrete shear wall building built in 1950, 57 percent of the assignable space is in laboratories, 32 percent in offices, 4 percent in classrooms, and the remainder is in special/other uses, in this case primarily storage. In the structural analysis, it is rated 5, 4, 3 in the Level 1, 2, and 3 earthquakes, respectively. By the UC rating system, used in the 1997 PSE, this building is considered "fair." As such, Cory Hall is not one of the buildings that would have warranted further analysis.

Adding performance ratings for the non-structural components allowed us to make a more refined estimate of damage and losses. In the non-structural evaluation of Cory Hall, for example, cladding was rated as Low (not costly to replace), with performance ratings of 7, 5, 4. Glazing was rated as Medium, with performance ratings also at 7, 5, 4. Each of the occupancies was reviewed in terms of architectural finishes, MEP, contents, and potential water damage. In the main space, all the laboratory components were rated Medium, except for contents that were rated High, because of the presence of highly specialized and expensive equipment. In Cory Hall's laboratory space, the non-structural ratings were as follows in the three scenarios:

System	Level 1	Level 2	Level 3
Architectural Finishes	7	5	4
MEP	6	4	3
Contents	7	5	4
Potential Water Damage	6	4	2

The numerical ratings were based on standardized definitions for each component, from Complete Damage at 1, to No Damage at 10, with descriptive examples for each rating value. Definitions and application rules were developed for each category. For example, MEP at 8, 6, 4 was used as a standard rating for modern buildings with well-braced pipes and lights. A rating of 7, 5, 3 was used for modern buildings with poorly braced pipes and lights, and 6, 4, 3 was used for older buildings with poorly braced pipes and lights. A rating of 2 was used only if a particular vulnerability was observed. From these ratings, it is clear that the greatest vulnerability in the laboratories is damage to the mechanical, electrical, and plumbing systems, as well as the potential for water damage and loss of contents. This is, in fact, a typical condition in most spaces in most buildings.

To insure comparability across buildings, the engineering team met regularly to compare their assessments and to refine their definitions. The engineering team also estimated the time needed for repairs in each building in each scenario. Cory Hall was estimated to need six months for repairs in the occasional scenario, and twenty-four months in either the rare or very rare scenario. This "downtime" estimate took into account that certain kinds of repairs could be done with campus staff, in a few weeks or months, with some areas of the building open for use. However, with more severe damage, in which the building's structural condition would require an engineering evaluation and repairs would require drawings, peer reviews, etc., repair times might take months or longer. Under such conditions, it is likely that all or part of a building would be completely unusable until work was complete. The downtime estimates and the building component performance evaluations were the key data sets to be used in the loss estimation model.

Translating Building Performance Ratings to Loss Curves

As the building data was assembled, the engineering team translated the structural and non-structural ratings into loss curves. A great deal of research already completed (ATC-13, HAZUS) equates the damage observed in previous earthquakes with a percentage of structural loss. In the HAZUS methodology, slight damage is set as 2 percent of complete, moderate damage is 10 percent of complete, and extensive damage is 50 percent of complete, but the damage cost for each building type is ultimately calculated using a probabilistic distribution of damage within that building type. Similarly, in this research, we assigned a percent structural damage to each of the ten point ratings, and then used a probabilistic method for distribution within each rating. Thus, a building assigned a structural rating of 5 (with 30 percent damage) in a particular earthquake scenario has a 21 percent probability of actually sustaining 30 percent structural damage, a 16 percent probability of 50 percent damage (rating 4), an 18 percent probability of 10 percent damage (rating 6).

Separate loss curves were developed for the non-structural building components (Architectural Finish, MEP, Contents, Cladding, and Glazing), based on data available from recent earthquakes and on the judgment of the engineering team. In cases where the team assigned percentage losses to only even rating numbers, regressions were run on ratings against percentage using several different functional forms. The best fitted equation was used to estimate the values for the "in between" ratings. No probabilistic distributions were used for the non-structural building components because there was not sufficient data to justify that level of mathematical sophistication.

The percent losses for Potential Water Damage were created as an addition to losses in Contents and Architectural Finishes. However, this is more complex than a simple add-on. The degree to which water damage adds to the cost of losses depends on the amount of other damage. If losses to structure, architectural finishes, or contents in a particular building in a particular occupancy were severe, then the damage percentages and associated costs would be at or near 100 percent of replacement. In this case, water damage rated at 2 (severe) should not take losses over 100%. In contrast, if structural, architectural finishes, and contents damage were moderate (> 4), and the water damage was rated 2 (severe), the percent loss added to architectural finishes and contents would be higher to reflect the added increment in repair costs.

Replacement Cost Estimates

We conducted a detailed review of new construction and seismic retrofit expenditures on projects at UC Berkeley during the last ten years, and of construction costs for numerous comparable university buildings around California. The replacement cost spreadsheets were developed for the seven main building types in the study—classroom, laboratory, office, library, special use, residential, or parking. The replacement costs were based on Type I and II mid-rise campus buildings, with costs expressed for low, medium and high quality of construction in current dollars in California, reflecting the cost of construction at any campus in California. From the base costs, a group of multipliers were developed to reflect adjustments needed for locally specific work. These included:

- The cost of work on the Berkeley campus.
- The anticipated cost of work under the 1997 UBC for near-field seismic construction.
- The additional cost for repairing components over the cost of the same components in new construction.
- The university related soft costs for design and management.

In addition, multipliers were added to accommodate unique structural or building components that might be present, such as high rise buildings, historic buildings, super complex buildings, or hospitals. A deduction multiplier was used for small wood frame buildings.

For each building type, the building costs were organized into the same categories as the building sub-components so that each cost component could be multiplied by the percent loss of the component in each sub-area. In general, the loss estimate is characterized as a percentage loss of each building component, based on replacement cost values for the building type. It is assumed that even a building predominantly used as a library will have some offices or classrooms in it. The cost sheet for libraries reflects that typical condition, and the library costs are divided among structure, cladding, glazing, architectural finishes, MEP, and fixed contents. Values for non-fixed contents, such as furniture, equipment, computers, library books, art, etc., were added to each building estimate, based on annual university reports on the value of equipment and building contents. The formulas for calculating exterior building components, structure, and interior building components vary slightly because of the use of the distribution function in the structural calculation and the need to compute the interior components based on different ratings for different uses.

Structural Loss sample formula:
Structural % Loss x distribution function x OGSF x Cost of Component by Building Type

Exterior Component Loss sample formula (cladding and glazing):
Component % Loss x OGSF x Cost of Component by Building Type

Interior Component Loss sample formula (architectural finish, MEP, fixed contents):
Component % Loss + (Potential Water Damage % Loss) x ASF x (ASF/OGSF) x Cost

Where OGSF is Overall Gross Square Footage, and ASF is Assignable Square Footage.

The sum of all these components plus the special feature factors and the non-fixed contents gives the values of the losses as repair costs. Before proceeding to a final estimate, it was necessary to account for the fact that all the damage percentages associated with an event and a building may go to 100 percent if the damage to the structure went over a certain threshold. We examined the results of three potential thresholds, 40 percent, 50 percent, and 60 percent, plus a scenario with no step function (i.e., simply using the losses as calculated). Another sensitivity analysis was done to evaluate the use of the structural distribution function. Ultimately, we used a financially conservative estimate, including the probabilistic distribution of the structural loss calculations and a 60 percent structural damage threshold for triggering the increase in repair costs to 100 percent replacement.

Estimates of Losses and Time Needed for Repairs

Using the 60 percent step as the basis for our calculations, the cost of repairs in an Occasional earthquake is about $720 million. In the Level 2 Rare earthquake scenario, the costs rise to $1.7 billion. In the Level 3 Very Rare scenario, the total cost of repairs is estimated to be $2.9 billion. It is important to put these rather precise estimates into a more realistic range of possibilities. The sensitivity analysis suggests that the value of losses for the core campus could range from $500 million to $1 billion in the occasional or moderate earthquake, comparable to the losses in 1994 at California State University, Northridge. The Rare earthquake scenario—a M 7.0 on the Hayward fault—has repair costs ranging from $1 billion to $3 billion. The Very Rare scenario—a M 7.25 on the Hayward fault—could have repair costs that range from a low of $1.5 billion to a high of $4 billion. These estimates are not surprising. Indeed the highest estimates represent 30 to 40 percent of the full replacement value of campus buildings and contents at about $8.8 billion. See Tables 2 and 3.

We analyzed how the closure of different kinds of spaces—classrooms, laboratories, libraries, offices—would affect their operations. In the Occasional earthquake, the impact of building closure is not severe. In every case, except the laboratories, the percentage of space affected is less than 10 percent. Nineteen percent of the laboratory spaces are threatened with closure for more than twenty months. This is clearly a reflection of the poor condition of many of our current laboratory buildings, and of the sensitivity of their contents. In the Rare and Very Rare scenarios, the portion of laboratory space which could be closed ranges from 49 to 64 percent. It is daunting to note the repair times for laboratory space, even in an Occasional event. Research facilities are the backbone of campus research activity and many are vulnerable to long term closures.

The library repair times are lower than other areas. This is because the new main library is an underground facility that will not suffer as much damage as other building types, and because many of the other library buildings have been strengthened. Much of the space categorized as “special/other” also has lower downtimes. A significant portion of the special/other category is performance or athletic space, newer buildings, designed to higher standards for the assembly of large numbers of occupants.

The research team estimated the potential downtime of individual buildings based on their conditions in 1999. In an earthquake, building damage and the time needed for repair will vary, depending on the location of the epicenter, and the duration and directivity of the ground motions. The overall downtime for the campus will be less than the estimates for the individual buildings or spaces, because it is unlikely that all buildings will be damaged exactly as estimated.

Under the circumstances of the Rare earthquake scenario, the research team believes that present conditions could force the campus into a short-term closure. Although a limited schedule of classes could be resumed using temporary trailers, we estimate that it would take two years before a normal schedule could be resumed. In a Very Rare earthquake (M7.25), 50 to 75 percent of all campus space could need more than twenty months for repair, which could close the campus for up to one year. It is likely that it could take four years for a return to pre-earthquake standards of operation.

These estimates are based on current conditions in 1999. Obviously, as buildings are renovated, their conditions are improved and downtimes are reduced. By 2006, ten major central campus buildings will have completed seismic retrofits. Another fifteen buildings are slated for seismic repairs by 2011, reducing the potential for building closure substantially. For example, based on 2006 projections downtimes drop to a range from 25 to 35 percent in the Rare earthquake scenario, and range from 40 to 60 percent in the Very Rare scenario. By 2011, the downtimes drop substantially more, reflecting to changes due to the building repairs. See Tables 4 and 5.

Space Use and Number of Occupants

Two additional measures were germane to the loss estimate, 1) how buildings were used and 2) how many people used them. For a preliminary understanding of the way space is used on campus, we simply divided each building into its sub-areas of major use. Classrooms include all campus and departmental classrooms. The laboratory category includes only working laboratory space, not support space. Special/other includes everything other than residential or parking. Overall, there is approximately 5 million net or assignable square feet (ASF) of space in core campus buildings: 6 percent in classrooms, 30 percent in laboratories, 29 percent in offices, 16 percent in libraries, and 19 percent in other spaces, such as the student union, food services, performance space, and storage. This allocation of space is not significantly different from other universities.

We were initially surprised at the low percentage of space in classrooms. We found, however, that the space use at UC Berkeley was comparable to that of Stanford University and other institutions. A review of “gateway courses” (introductory courses in sciences and humanities required for entry into most upper division courses in majors) makes it clear that much of the lecture hall style of undergraduate teaching is concentrated in a few buildings: Dwinelle, Evans, Le Conte, Lewis, Pimentel, Valley Life Sciences, and Wheeler. Moreover, it is important to recognize that classrooms are used throughout the day for scheduled classes, unscheduled study sections, meetings etc. At the same time, a great deal of teaching takes place in laboratory sessions (in science courses) and in offices used for office hours, tutorials, and meetings. Thus, it is less surprising that laboratories and offices dominate space use on the campus. See Figure 3.

Contents

The type of contents in a building and their value contribute to the estimation of loss. We have added the location of hazardous materials into the database and added value to the loss calculation where these materials could add to building damages. Similarly, we used the campus data on "equipment values" and the insurable assets database to estimate the value of contents in each building—allowing a review of the spaces in which content value was a crucial aspect of potential losses. Not surprisingly, the buildings with high content values include many research laboratory buildings such as Cory, Hildebrand, Valley Life Sciences, and the Life Sciences Building Addition. Furthermore, buildings with art collections and rare books also rank high on the contents value. The Hearst Memorial Gym, a poor building structurally, ranks very high in contents value because the Lowie Collection of anthropological art and artifacts is stored in the basement. See Figure 4.

Occupants

Counting the number of people in buildings ought to be as easy as measuring space, but, in fact, it is fraught with complexity. University buildings have classrooms that are scheduled by the central campus as well as classrooms that are managed by departments. Classrooms are often used outside the regularly scheduled hours for student meetings, faculty meetings, informal study sessions, etc. Similarly, some faculty work in their offices, others travel between laboratories, libraries, and other specialized campus spaces. In order to avoid double counting, and to be able to compare buildings, the Office of Space Management and Capital Programs devised a method for estimating building occupancy on an annual basis. We adopted this methodology for the study, and we added an estimate of the number of building occupants in a single peak hour (sometime between 10 A.M. and 2 P.M.) during the semester.

The Equivalent Continuous Occupancy (ECO) Calculation is an abstract number used to measure the population at risk in any given building during an earthquake. It represents the number of persons theoretically occupying a building on a continual basis—for 24 hours a day, 365 days a year. The ECO provides a means to account for actual varying use. For example, one person present in a building for 8 hours a day, 52 weeks a year would contribute .33 to the ECO for that building. The following shows the calculation of this ECO.

$$\underset{\text{[Hrs per Week/Total hrs per Week]}}{56/168} \times \underset{\text{[Wks per Yr/Total Wks per Yr]}}{52/52} \times \underset{\text{Persons}}{1} = \underset{\text{ECO}}{.33}$$

Accounting for all building occupants in all spaces of a building, a total ECO for each building can be calculated. This total building ECO is the number of persons who may be occupying a building at any given hour of any given day, distributed on an annual basis.

The core campus buildings with the highest ECOs are similar to those with the highest number of occupants during peak hours. At UC Berkeley, buildings with the highest ECO numbers include Dwinelle, Valley Life Science Building, Barrows, Etcheverry, Cory, Evans, Tolman, Wheeler, Wurster, LeConte, Latimer, Moffit, and Tan. As a point of comparison, the ECO for each of these buildings is greater than that of Memorial Stadium—a space which holds some 75,000 people, but is only occupied about twelve afternoons for four hours each.

IV. ECONOMIC IMPACTS ON THE CAMPUS AND THE COMMUNITY

The economic impact of potential earthquake damages to the UC Berkeley campus is of equal concern to the physical destruction of buildings and infrastructure. University of California, Berkeley is one of the most prestigious research institutions in the nation, ranked first among public universities overall, and twenty-second out of 1,625 institutions in the dollar volume of federal grants in science and engineering. The University of California, Berkeley has the greatest number of science and engineering graduate students of 611 institutions surveyed by the National Science Foundation.

In the immediate aftermath of seismic activity, the principal economic outputs of the university—the educational services provided to students and the research products produced by faculty, staff, and students—are disrupted for a considerable period. Students who would have matriculated are denied the opportunity to graduate, or at the very least, the completion of their education is delayed along with their entrance into the labor market. Scientific research, which would have been completed is lost, or at least delayed. Public service, which would have been provided by faculty and staff, is not undertaken.

The short-term consequence of this disruption affects the local economy. The inputs to the research process that would have been purchased locally are not ordered. The stimulating effect of student spending upon the local economy is eliminated. In short, the disruption to the educational process has a multiplier effect upon the local economy, as the capital flow provided by the university is eliminated, or at least muted, for some time.

In the longer run, the consequences for the output of research and scholarship at UC Berkeley are less clear. Since so much of research is cumulative, the disruption of the routine caused by a major earthquake could lead to a permanent contraction of scholarly research at Berkeley. Activities currently undertaken on the Berkeley campus could move to other universities and other regions, permanently reducing the output of this university. Worse still, some of these productive activities might be eliminated altogether as the physical conditions facilitating scholarly and scientific collaboration are destroyed.

Finally, the role of the University in attracting productive talent to the region and in increasing the supply of human capital and trained graduates in California could be affected as a result of a major earthquake. This could have, perhaps, the most serious consequences for economic welfare in the state, for example, if California loses the "next" Silicon Valley to another state or region.

To understand the impact of the three earthquake scenarios in economic terms, we chose to examine three crucial aspects of the university's contribution to the region: 1) the impact of losses on research, 2) the impact of losses on the regional economy, and 3) the impact of losses on human capital. Parts one and two were undertaken by the Sedway

Group, a well known real estate and economic consulting firm in the Bay Area, in consultation with George Goldman of Agricultural and Resource Economics. Professor John Quigley, of Economics and Public Policy, reviewed the consultants' work and participated in the human capital analysis section.

It should be noted that we did not include casualty estimates, nor did we include the economic impact of the loss of life. This does not imply a lack of concern about life-safety issues. Rather, it recognizes that the campus has already created a policy specifically aimed at improving the life safety of campus structures, and that the methods of assessing and valuing potential casualties are controversial and problematic.

Research Impacts

Some of these economic impacts can be estimated reliably, and some cannot. We have chosen a conservative strategy to address these effects and used well-established techniques to investigate the impacts that are measurable. We rely upon campus records from the Sponsored Projects Office (SPO) which track the external grants and contracts for university research by individual research unit—that is, the campus department or organized research unit.

We used SPO data to rank the campus research units on the basis of their six-year average annual research income. We selected the top twenty-five units for a survey, asking how much research took place on the central campus, and in which buildings. We also checked what portion of their dollars went to salaries, equipment, and supplies.

The volume of this research, which averages over $350 million per year, is traced to almost 200 different campus research units or departments. These research units, in turn, are traced to their physical locations on the Berkeley campus. In this way, research output is allocated to the various buildings on the Berkeley campus in which it is undertaken. Note that this strategy measures research output rather conservatively and applies a commercial standard to the value of the academic research produced on campus. The value of research is estimated by its input costs. See Tables 6 and 7.

We found that 74 percent of the sponsored research dollars are expended in central campus buildings, with 72 percent of all research concentrated in twenty-five research units, primarily in science and engineering. The most significant finding in this survey was the concentration of research in a few buildings. Of all sponsored research, 25 percent takes place in just two central campus buildings, comprising only 5 percent of the assignable square feet on the campus. These two buildings are Cory Hall and the Life Science Building Addition, both of which have laboratory space as their dominant use. Only another five buildings, with 7 percent of the assignable square feet, comprise the next 25 percent of all sponsored research. These five additional buildings, three of which are dominated by lab space, include Koshland Hall, Soda Hall, Warren Hall, University Hall, and Stanley Hall. Another ten buildings, with 22 percent of the assignable square feet, comprise the third increment of 25 percent of sponsored research. See Tables 8 and 9.

Overall, 75 percent of all sponsored research occurs in only seventeen central campus buildings, with a cumulative total of 33 percent of the central campus assignable square feet. These seventeen buildings comprise less than 20 percent of all campus buildings, demonstrating the high degree to which the University's research is locationally concentrated. Of these seventeen buildings, 75 percent are laboratory buildings. In the Occasional earthquake scenario, four of these buildings may be inoperable for twenty to forty months. In the Rare earthquake scenario, twenty-one buildings that house top ranked research units (receiving 51 percent of the University's annual research dollars) could be down for repairs for an extensive period. In the Very Rare scenario, twenty-eight buildings with 70 percent of the research activity could be out of service for an extended period. These figures clearly indicate that the bulk of campus research could be destroyed or seriously disrupted in the event of a large magnitude earthquake (> M7.0) on the Hayward fault.

The aggregate loss in research output depends upon the downtime associated with each building and the extent to which research could be moved to other buildings and facilities. The allocation of research output to specific buildings links the effects of various earthquake scenarios upon campus structures to their effects upon the quantity of research lost as a result of damage to those buildings and structures. Under the Occasional scenario, it is estimated that $25.4 million in research output is disrupted (out of some $355 million per year, which is produced). Under the Rare scenario, the research disruption is estimated to be $87 million, while under the Very rare scenario it is estimated to be $121.8 million.

Community Impacts

The loss to the local economy depends upon the economic linkages between campus expenditures (including the research activities undertaken on the campus) and the local, regional, and national firms which supply the inputs used to generate academic and research output. Similarly, the loss to the local economy because the university is closed to students and others depends upon the spending patterns of those students and the further linkages among the firms and industries, which are stimulated by this consumer spending.

A 1989 Peat Marwick study estimated that over $685 million was expended directly in the local and regional economy, and that the University provides some 14,000 jobs. The direct and indirect impact of these expenditures indicates that the University typically contributes $1.23 billion to the Bay Area economy each year and produces more than 20,000 jobs. While the Peat Marwick study examined the entire University's impact on the larger nine county Bay Area region, this study is more focused, examining the impact of the central campus, approximately 68 percent of all University space. Likewise, for the purpose of our study, the local economy was defined as Alameda, Contra Costa, and San Francisco counties.

To estimate the building-specific losses on the local economy, we analyzed campus salaries, benefits, utilities, and other expenditures as assigned to campus buildings, and the nature of the earthquake impacts on staffing and payroll. We used the technique of input-output analysis to estimate the aggregate economic effects of these reductions in output—contractions in research and educational services—during the period in which University operations are reduced or curtailed. These aggregate losses to the local economy are quite large indeed, annually peaking at $15.4 million, $147.9 million, and $860.8 million in reduced gross sales under the three scenarios.

In the event of a Very Rare earthquake, the only economic scenario in which a year-long campus closure was considered, the first year losses in three counties include approximately 8,900 jobs, $680 million in personal income, and $861 million in sales. For completeness, we also estimated the net stimulus provided by the rebuilding of campus facilities. Although the losses would be offset in the larger economy by the increase in construction jobs generated, it is important to note that the losses and gains are in very different sectors of the economy.

Because the majority of construction (about 80 percent) on the campus is undertaken by contractors in the three local counties, resources are supplied from inside the local economy. It should be noted that the positive economic benefits of reconstruction describe an optimistic scenario in which resources are available to the university for repair and recovery. If post-earthquake repair funding is not forthcoming from the state or federal government, the negative impacts continue indefinitely.

Human Capital Impacts

We can only speculate about some of the other economic effects of these earthquake scenarios on the larger economy of the region and the state. To the extent that students whose education is disrupted drop out of higher education, the supply of educated labor in California is reduced. To the extent that earthquake damage causes a delay in the completion of education, the state suffers a short-term loss in human capital and in productive capacity.

The University plays a powerful role in augmenting human capital in the state by attracting talented young men and women from other states—indeed, from throughout the world—who then settle in the state. We investigated the role of the University in attracting human capital to California by analyzing the residence patterns of professional students in UC Berkeley's College of Engineering and Haas School of Business. We analyzed the geographical locations of successful applicants to these schools and the locations (i.e., the postal zip codes) in which they have chosen to reside after graduation. It is clear that the residence pattern of the alumni of these professional schools is clustered closer to campus than is the residential pattern of these individuals at the time of their application to UC Berkeley. See Table 10.

Professional school graduates, at least engineers and the MBAs, are far more likely to reside in California and to reside at distances closer to northern California. The loss of the University, its research facilities, and its educational facilities, threaten the capacity to import talented human capital from elsewhere. When it is recognized that a single alumnus with a masters degree contributes roughly $1 million to the state gross domestic product and $100,000 in state tax revenue (in present value terms over a lifetime), this effect may be large indeed.

Overall, the economic analysis suggests that when a university is located in a large metropolitan area with a complex and dynamic economy, the impact from an institutional closure is not entirely represented by the immediate loss of jobs and local sales. Much more important is the university's contribution of highly trained professional workers to the regional economy. If the University of California, Berkeley were forced to close, the interruption of that supply of professionals would have a dramatic impact on the region. Furthermore, the University itself would suffer. Short-term closures and reduced research capacity will affect the retention and recruitment of faculty and students. Not only would UC Berkeley lose a cohort of scholars, but the loss of prestige and institutional rank would be permanent.

V. CONCLUSIONS

For every complex problem, there is a simple solution. And it is always wrong.
H. L. Mencken

The University, the surrounding community, and the State of California, grew rapidly in the post-war decades. Large modern buildings were built in an era when there were few earthquakes, and no urban-centered earthquakes. Unfortunately, recent earthquake experience in major cities in California, Japan, Mexico, Turkey, and Taiwan has demonstrated that many of the 1960s era modern buildings will suffer significant damage in earthquakes. Similarly, recent earthquake experience has also demonstrated that structural improvements are not the only solution to the earthquake problem. The potential economic losses, as well as the business and social disruption caused by major urban earthquakes, can also have devastating consequences. The first and obvious solution to the earthquake threat is to improve building conditions, and the SAFER Program is a crucial effort to do so. However, as this study demonstrates, other issues are equally critical to the university.

The University of California, Berkeley remains vulnerable to earthquake losses, despite its laudable and extraordinary commitment to improve the life safety of hazardous buildings. This vulnerability can be attributed to three key factors. First, even buildings considered “fair” in the 1997 structural evaluation may be subject to considerable nonstructural (contents) damage. Under current conditions, structural and nonstructural damage could close 50 to 75 percent of campus space for up to one year after a magnitude 7.0[5] or larger earthquake on the Hayward fault. Secondly, among the seventeen buildings in which 75 percent of the research is concentrated, the same proportion of space, that is 50 to 75 percent, is likely to be significantly damaged and closed after a major seismic event. This will seriously disrupt existing research and limit the capacity to take on new research for a long period. Finally, one third of the replacement value of the campus is in its contents—books, technical instruments and research equipment, art, specimens—all highly susceptible to damage and essential to the teaching and research mission of the University.

Although the loss to buildings and contents represents 30 to 40 percent of the replacement value of the campus, the greatest potential losses, in academic and economic terms, would result from a substantial quake that forces even a partial campus closure. This study adds a business-oriented perspective to the traditional development of natural disaster loss-reduction measures for universities. It suggests a comprehensive approach that includes educating the campus community about the many aspects of, and possibilities for loss reduction.

[5] Based on ground shaking estimates used in the Rare scenario earthquake, that is, with a ten percent probability of exceedance in a fifty year period, also known as an earthquake with a 475 year return period.

Specific to the University of California, Berkeley, the SAFER Program's goal to improve life safety in campus buildings should expand to include policies on above-code standards for some new buildings, policies and assistance for campus-wide business resumption and disaster recovery planning, comprehensive nonstructural hazard mitigation, and campus community education and training—all of which are necessary to the maintenance of its tradition of academic and research excellence. The ongoing success of the SAFER Program can be enhanced by implementing the following recommendations:

1. A policy to look beyond the life-safety criteria for seismic retrofits to the concomitant importance of limited damage in teaching, research, and library space, and limited damage to critical infrastructure in order to insure continued operations after a large earthquake. Such an approach would include a priority system for all campus construction (retrofits, demolitions, and new construction) that balances life safety, loss reduction, and ongoing operational needs.
2. A campus-wide nonstructural mitigation program aimed at loss reduction in laboratories, libraries, classrooms and offices.
3. A strategic campus plan, encompassing academic and physical planning, as well as business resumption planning, that uses the seismic retrofit program to improve the quality of teaching and research activities for the future. The current master planning effort, the New Century Plan, must maintain its focus on seismic safety as the driver for many of the changes on campus in the foreseeable future.

In order to have a campus that remains one of the nation’s most prestigious academic institutions, the University of California, Berkeley should continue the program of structural retrofits for existing buildings and consider, for each retrofit or new project, constructing above code to ensure post-earthquake functionality in the structure. In addition, the seismic improvements to structures should be one part of a comprehensive risk management program. For any major teaching and research institution where operations are threatened by natural disasters, hazards mitigation and post-disaster recovery strategies must be a regular part of the ongoing planning in every academic department and management unit.

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FIGURES AND TABLES

TABLES

FIGURES

Table 1 Comparative Cross Reference on Various Seismic Performance Ratings

U. C. BERKELEY RATING			SEAOC VISION 2000 RATING			ATC-20
Designation	Structural Damage	Hazard to Life	Numerical Rating	Performance Expectation	Anticipated Damage	
Good	Some Damage	Not Significant	10	Fully Operational	Negligible	GREEN
			9			
			8	Operational	Light	
			7			
			6	Life Safe	Moderate	
			5			YELLOW
Fair	Damage	Low	4	Near Collpase	Severe	
Poor	Significant Damage	Appreciable	3			
			2	Partial Collapse	Complete	RED
Very Poor	Extensive Damage	High	2	Partial Collapse-Assembly Areas		
			1	Total Collapse		

Table 2 Sensitivity Analysis of Core Campus Loss Estimates

WITH DISTRIBUTION FUNCTION			
Step function: assume full replacement cost for buildings with damage greater than:	occ	rare	very rare
40%	$ 991,961,964	$ 3,004,354,969	$ 4,009,170,705
50%	$ 755,561,600	$ 2,413,590,341	$ 3,551,402,041
60%	$ 625,561,680	$ 1,501,837,504	$ 2,611,723,428
no step function	$ 557,224,747	$ 1,098,411,717	$ 1,573,604,604
# of buildings needing full replacement under step functions:	occ	rare	very rare
40%	16	63	89
50%	5	41	70
60%	1	12	37

Table 3 Summary of Losses for U. C. Berkeley

	Occasional	Rare	Very Rare
Structures	$ 625,561,680	$ 1,501,837,504	$ 2,611,723,428
Residential	$ 82,239,832	$ 176,887,597	$ 215,763,384
Parking	$ 12,463,197	$ 23,379,160	$ 33,547,970
TOTAL	$ 720,264,710	$ 1,702,104,260	$ 2,861,034,781

Table 4 Summary of Space Use in Five Major Categories

	ASF by Occupancy[1]		AUASF by Occupancy[2]			ASF by Building's Dominant Type[3]		AUASF by Building's Dominant Type[4]	
	Square Footage	Percent	Square Footage	Percent		Square Footage	Percent	Square Footage	Percent
Lab	1,609,804	32.5%	1,435,537	28.5%	Lab	1,907,736	37.9%	1,906,993	38.0%
Class	199,496	4.0%	293,261	5.8%	Class	284,435	5.6%	284,435	5.7%
Library	800,593	16.1%	786,286	15.6%	Library	560,975	11.1%	560,877	11.2%
Office	1,433,966	28.9%	1,566,741	31.1%	Office	1,538,239	30.5%	1,503,010	30.0%
Spe-oth	681,705	13.7%	929,009	18.4%	Special	750,280	14.9%	750,053	14.9%
Spectel	235,176	4.7%[5]	26,938	0.5%[6]	Residential[7]	12,645	0.3%	12,645	0.3%
Total	**4,960,740**	**95.3%**	**5,037,772**	**81.0%**	**Total**	**5,054,310**	**100%**	**5,018,013**	**100.0%**

NOTES:

1. **As given in 1997-1998.**
2. **Adjusted for use per Table 2.3 and increased to include areas under construction such as Hass Pavilion, Hearst Mining, etc.**
3. **Adjusted to include areas under construction by dominant building type with residential included.**
4. **"As Used" areas by dominant building type. Variations result from small inaccuracies in "As Used" areas and rounding.**
5. **Special Telecommunication includes all equipment rooms.**
6. **Includes only computer hubs.**
7. **On core campus only.**

Table 5 Percent of Space Needing >20 Months for Repairs

Conditions in 1999[1]

Use	Scenario O	Scenario R	Scenario VR
Classroom	5%	44%	78%
Laboratory	19%	52%	66%
Office	9%	50%	72%
Library	4%	28%	38%
Telecom	2%	46%	50%
Other	11%	36%	50%

Conditions in 2006[2]

Use	Scenario O	Scenario R	Scenario VR
Classroom	0%	26%	61%
Laboratory	1%	26%	40%
Office	5%	38%	59%
Library	1%	23%	33%
Telecom	1%	45%	49%
Other	7%	31%	45%

Conditions in 2011[3]

Use	Scenario O	Scenario R	Scenario VR
Classroom	0%	3%	38%
Laboratory	0%	13%	26%
Office	2%	15%	36%
Library	0%	6%	16%
Telecom	1%	11%	16%
Other	0%	14%	29%

1) Buildings under construction in 1999 were rated as if they were finished.
2) Based on projections that 10 additional main campus buildings will have completed seismic repairs by 2006.
3) Based on projections that 15 additional main campus buildings will have completed seismic repairs between 2006 and 2011.

Table 6
Distribution of Adjusted Sponsored Research Volume
By Number of Study Buildings and ASF
University of California at Berkeley
Fiscal Years 1994 - 1999
Constant 1999 Dollars

Cumulative Percent Of Research Volume	Research Volume	Number of Study Buildings	Amount	ASF Percent of Total	Cumulative Percent
^ 1 - 25 %	$54,847,240	2 (1)	247,279	5%	5%
26 - 50 %	61,504,957	5 (2)	333,971	7%	12%
51 - 76 %	59,736,918	10	1,094,356	22%	33%
76 - 100%	59,898,636	46	2,082,914	41%	74%
^None	0	42	1,295,790	26%	100%
Totals	$235,987,751	105	5,054,310	100%	100%

Notes:

(1) Buildings include Cory Hall and LSB Addition.
(2) Buildings include Koshland Hall, Soda Hall, Warren, University Hall, and Stanley.

Sources: Exhibit 4, Appendix One; and Sedway Group.

Table 7
Allocation of Adjusted Sponsored Research Awards
By Dominant Building Use (1)
Annual Average Research Awards
Fiscal Years 1994 - 1999
Constant 1999 Dollars

Dominant Building Use (1)	ASF		Sponsored Research Awards	
	Sq. Ft.	Percent	Amount	Percent
Lab	1,867,610	37%	$164,995,499	70%
Office	1,607,843	32%	53,045,687	22%
Special Other	756,718	15%	15,181,003	6%
Library	530,576	10%	65,485	0%
Classroom	278,918	6%	2,700,076	1%
Residential	12,645	0%	0	0%
Total	5,054,310	100%	$235,987,751	100%

Notes:

(1) Reflects dominant building use. Most buildings include other uses, but research volumes were assigned only to the dominant use for study purposes.

Sources: Exhibit 4, Appendix One; and Sedway Group.

Table 8
Study Buildings Housing the Top-ranked Research Units (1)
Annual Adjusted Research Volume Generated By The Top-Ranked Research Units (2)
University of California at Berkeley
Fiscal Years 1994 - 1999 (3)
Constant 1999 Dollars

CAAN	Building Name	Adjusted Annual Research Volume (2)	Top-Ranked Research Units (4) 1	2	3	4
1325	Cory Hall	$31,120,270	Electronics Research Lab (**)	Institute of Transportation Studies	Eng. Systems Research Center	Physics
1225	LSB Addition	21,527,387	Molecular & Cell Biology (**)			
1796	Koshland Hall	17,056,740	Plant Biology (**)	Molecular & Cell Biology (**)		
1237	Soda Hall	12,729,357	Electronics Research Lab (**)			
1809	Hildebrand	7,783,766	Chemistry (**)			
1443	Warren	7,741,480	Public Health (**)			
1793	Barker	7,416,637	Molecular & Cell Biology (**)	Eng. Systems Research Center		
1783	Etcheverry	7,257,629	Eng. Systems Research Center (**)	Institute of Transportation Studies	Env.l Eng. & Health Sciences Lab	
1782	Latimer Hall	6,868,029	Chemistry (**)			
1594	University Hall	6,021,151	Public Health (**)			
1323 A & B	Davis old & new	5,363,345	EERC (*)	Env. Eng. & Health Sciences Lab	Institute of Transportaton Studies	
1538	Stanley	4,163,232	Molecular & Cell Biology (*)	Physics		
1419	Donner Lab & Addition	4,136,461	Molecular & Cell Biology (*)			
1406	Valley Life Sciences Bldg	3,857,235	Integrative Biology (*)			
1321	Mclaughlin	3,297,751	Institute of Transportation Studies (*)			
1382	Morgan Hall	3,009,765	Nutritional Sciences (*)			
1774	Tolman	2,881,592	Education - Extramural Research (*)	Psychology		
1371	Haviland	2,580,493	Public Health (*)			
1808	Tan Hall	2,289,343	Chemistry (*)			
1292	Lewis	2,289,343	Chemistry (*)			

continued . . . .

Table 8
Study Buildings Housing the Top-ranked Research Units (1)
Annual Adjusted Research Volume Generated By The Top-Ranked Research Units (2)
University of California at Berkeley
Fiscal Years 1994 - 1999 (3)
Constant 1999 Dollars

CAAN	Building Name	Adjusted Annual Research Volume (2)	Top-Ranked Research Units (4) 1	2	3	4
1229	NW Animal Facility	2,086,662	Psychology (*)			
1220	Birge	1,869,360	Physics (*)	Space Sciences Lab		
1302	Minor Addition	1,822,148	Optometry (*)			
1302F	Minor	1,800,657	Optometry (*)	Institute of Transportation Studies (*)		
1410	Giauque Lab	1,373,606	Chemistry (*)			
1405	LeConte: Old and New	1,125,782	Physics	Space Sciences Lab		
1377	O'Brien	888,213	Eng. Systems Research Center	Env. Eng. & Health Sciences Lab		
1346	Mulford	860,164	Public Health			
1375	Hesse	753,659	Env. Eng. & Health Sciences Lab	Eng. Systems Research Center		
1790	Evans Hall	347,509	Ctr. for Pure & Applied Mathematics (*)	Env. Eng. & Health Sciences Lab	Space Sciences Lab	
1356	Gilman	208,122	Chemistry			
1376	Hilgard Hall	66,396	Env. Eng. & Health Sciences Lab			
1760	Campbell	54,924	Space Sciences Lab			
1372	Hearst Memorial Gym	51,611	Integrative Biology			
1318	Edwards Field	50,956	Integrative Biology			
	Total	$172,750,775				

Notes:
(1) These are the central campus buildings in which the top-ranked sponsored research units conduct their research activities.
(2) This research volume applies only to the top-ranked research units. Select buildings have greater research volumes when all research units are taken into account, as presented in Exhibit 4, Appendix One.
(3) Research volumes reflect annual averages for fiscal years 1994 - 1999, in constant 1999 dollars. However, research dollars are allocated pursuant to fiscal year 1999 activities.
(4) For each building, units are presented from largest to smallest with respect to allocation of research dollars. Hence the unit listed under the column heading "1" has the greatest amount of research activity for the identified building, among the top-ranked research units. Units designated with (**) have an annual average research volume of $5.0 million or more assigned to this building. Units designated with (*) have an annual average research volume of $1.0 to $4.9 million assigned to this building.
Sources: Exhibit 4, Appendix One; and Sedway Group.

Table 9
Buildings Rank-Ordered by Volume of Research (1)
Percent of Research Volume and Structural Ratings and Downtimes By Earthquake Scenario
Adjusted Annual Average Sponsored Research Awards (2)
University of California at Berkeley
Fiscal Years 1994 - 1999
Constant 1999 Dollars (3)

	Building Identification			Percent Research	Structural Rating (7)			^Downtime (8)		
Rank (4)	CAAN	Building Name	ASF (5)	Volume (6)	Occasional	Rare	Very Rare	Occasional	Rare	Very Rare
	1325	Cory Hall	125,257	13.3%	5	4	3	6	24	24
	1225	LSB Addition	122,022	9.9%	8	7	6	1	2	3
	1796	Koshland Hall	91,533	7.2%	8	6	5	2	4	6
	1237	Soda Hall	60,090	5.4%	8	6	4	0.25	4	12
	1443	Warren	44,057	5.4%	6	3	2	2	36	36
	1594	University Hall	95,880	4.4%	7	5	4	0.25	6	12
	1538	Stanley	42,411	3.7%	5	3	2	4	24	36
	1809	Hildebrand	86,757	3.3%	2	2	2	40	40	40
	1793	Barker	53,720	3.1%	4	3	2	24	40	40
	1783	Etcheverry	112,141	3.1%	7	5	3	0.50	4	24
	1782	Latimer Hall	115,864	3.0%	4	3	2	24	40	40
	1774	Tolman	138,425	2.7%	5	3	2	6	40	40
	1323 A & B	Davis old	13,249	0.3% (9)	7	3	3	2	20	36
		Davis new	90,803	2.0% (9)	6	4	3	1	40	40
	1790	Evans Hall	156,846	2.2%	5	3	3	4	20	40
	1406	Valley Life Sciences Building	269,670	2.1%	8	6	5	2	4	8
	1419	Donner Lab	15,299	0.9% (9)	7	5	4	0.5	4	20
		Donner Lab Addition	14,902	0.9% (9)	5	2	2	4	36	36
	1302F	Minor	26,680	1.7%	8	6	5	0.25	2	4
	Total		1,675,606	74.6%						

Notes:
(1) Includes buildings with a cumulative total of 75 percent of adjusted annual average sponsored research.
(2) Reflects annual average research dollars during the fiscal year 1994 - 1999 time period. Building allocations are pursuant to pattern of research exhibited during fiscal year 1999.
(3) Research volumes are presented in current 1999 dollars.
(4) Rank-ordered relative to volume of adjusted annual average sponsored research, from largest to smallest. Includes only buildings with the largest percentage allocations of research, cumulatively totaling 75 percent.
(5) ASF indicates Assignable Square Feet.
(6) Percent of adjusted annual average sponsored research awards allocated to study buildings, totaling $236 million.
(7) See footnote 1 on Exhibits 10, 11, and 12, Appendix One.
(8) See footnote 4 on Exhibits 10, 11, and 12, Appendix One.
(9) See footnote 7 on Exhibits 10, 11, and 12, Appendix One.. The cumulative percentage of research in Davis old and new totals 2.4 percent, and the cumulative percentage of research in Donner Lab and Addition totals 1.8 percent.

Sources: Exhibit 4, Appendix One; Appendix Two; and Sedway Group.

Table 10 California Residents: At Application and After Graduation and Benefits to California Provided by Geographic Sorting

Residents at Application and after Graduation

Haas School of Business						
	Graduating Class					
	1993	1994	1995	1996	1997	1998
At Application	71%	82%	77%	77%	67%	63%
At Graduation	79%	81%	87%	91%	88%	83%

College of Engineering						
	Graduating Class					
	1993	1994	1995	1996	1997	1998
At Application	N/A	71%	76%	79%	81%	N/A
At Graduation	N/A	75%	77%	75%	78%	N/A

Benefits to California

Earnings of Workers with Masters Degrees[1]	25-34 years	$ 45,930.00
	35-44 years	$ 68,956.00
	44-55 years	$ 62,744.00
	55-64 years	$ 67,582.00
Present Value of Increased State GDP[2]		$ 994,031.00
Present Value of Increased State Tax Receipts		$ 99,403.00
Increased Probability of Living in California (percentage points)		20.2

[1] Current Population Survey, 1998, Table P-32

[2] At 5 percent real interest rate with an assumed tax rate of ten percent

Figure 2

Structural Performance Rating for a Rare Earthquake by Building

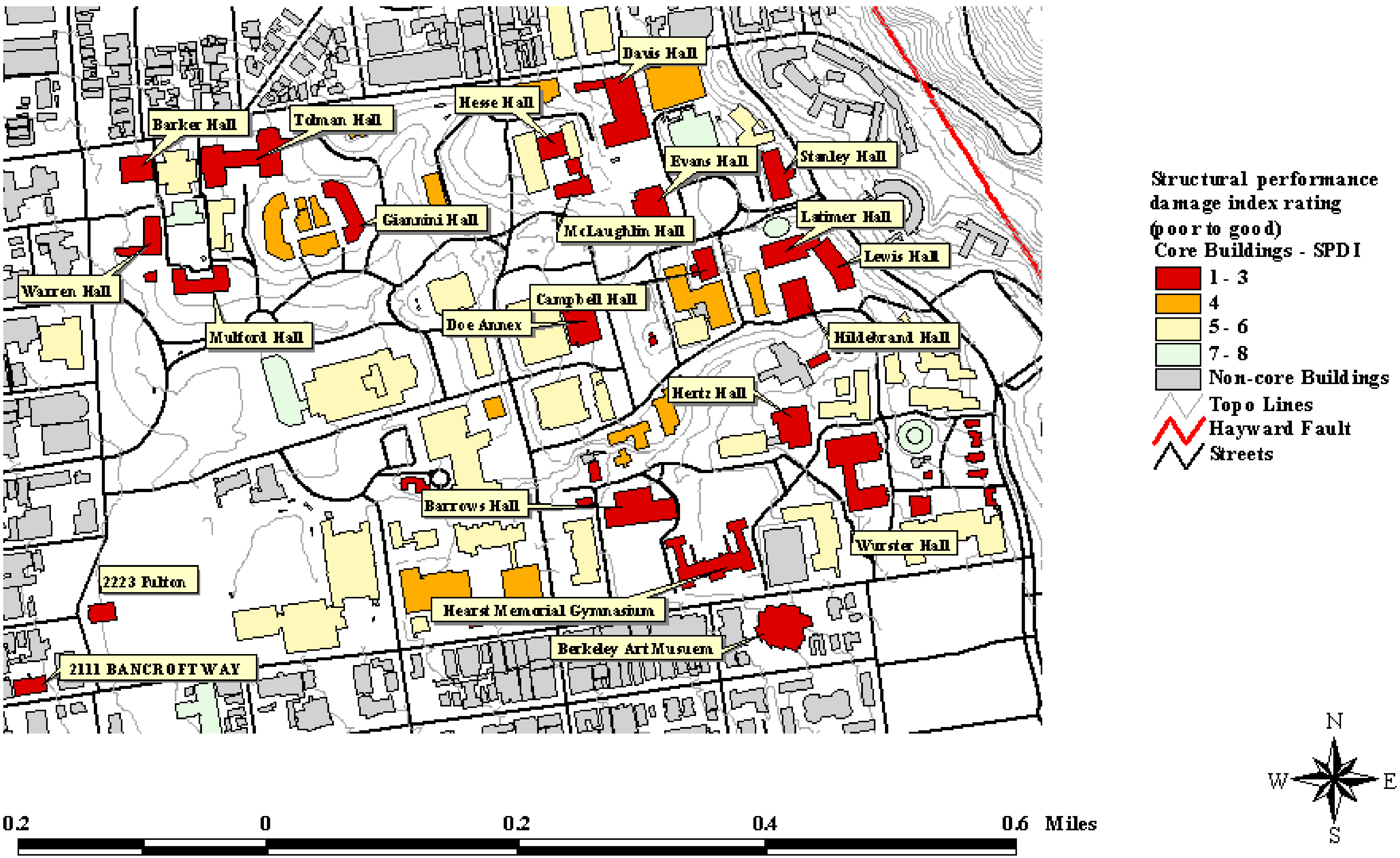


Figure 3
Core Campus Buildings by Dominant Use

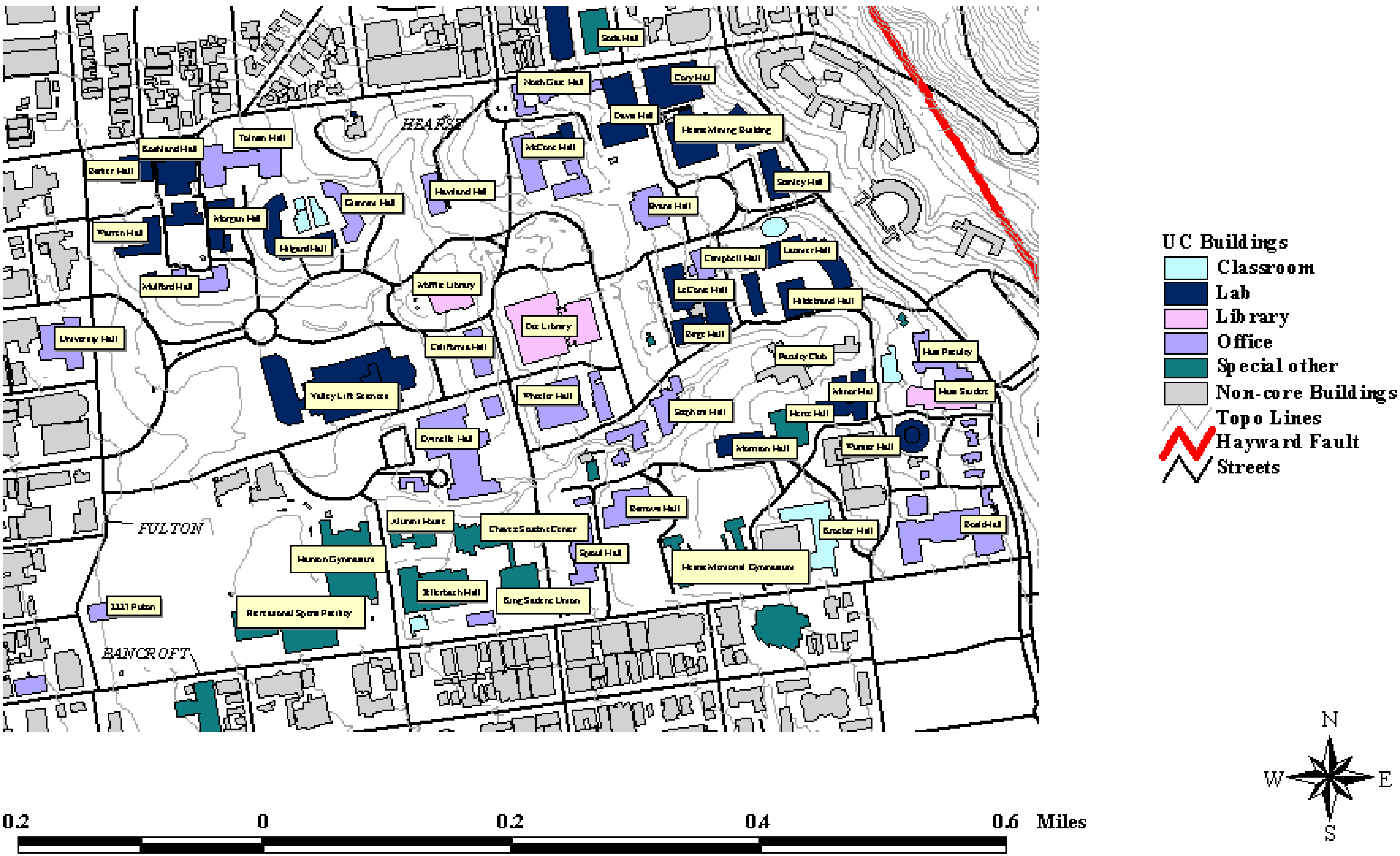
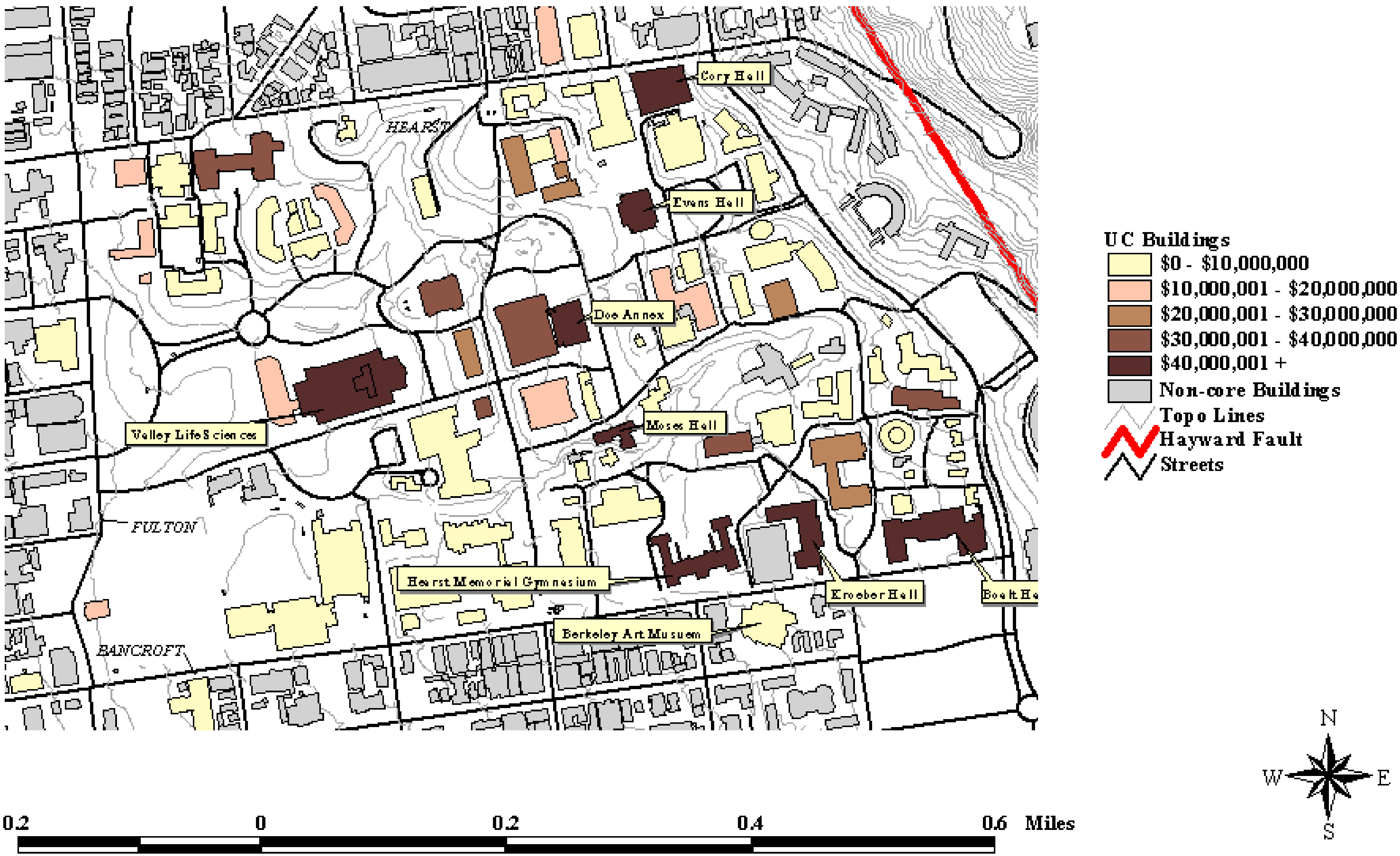
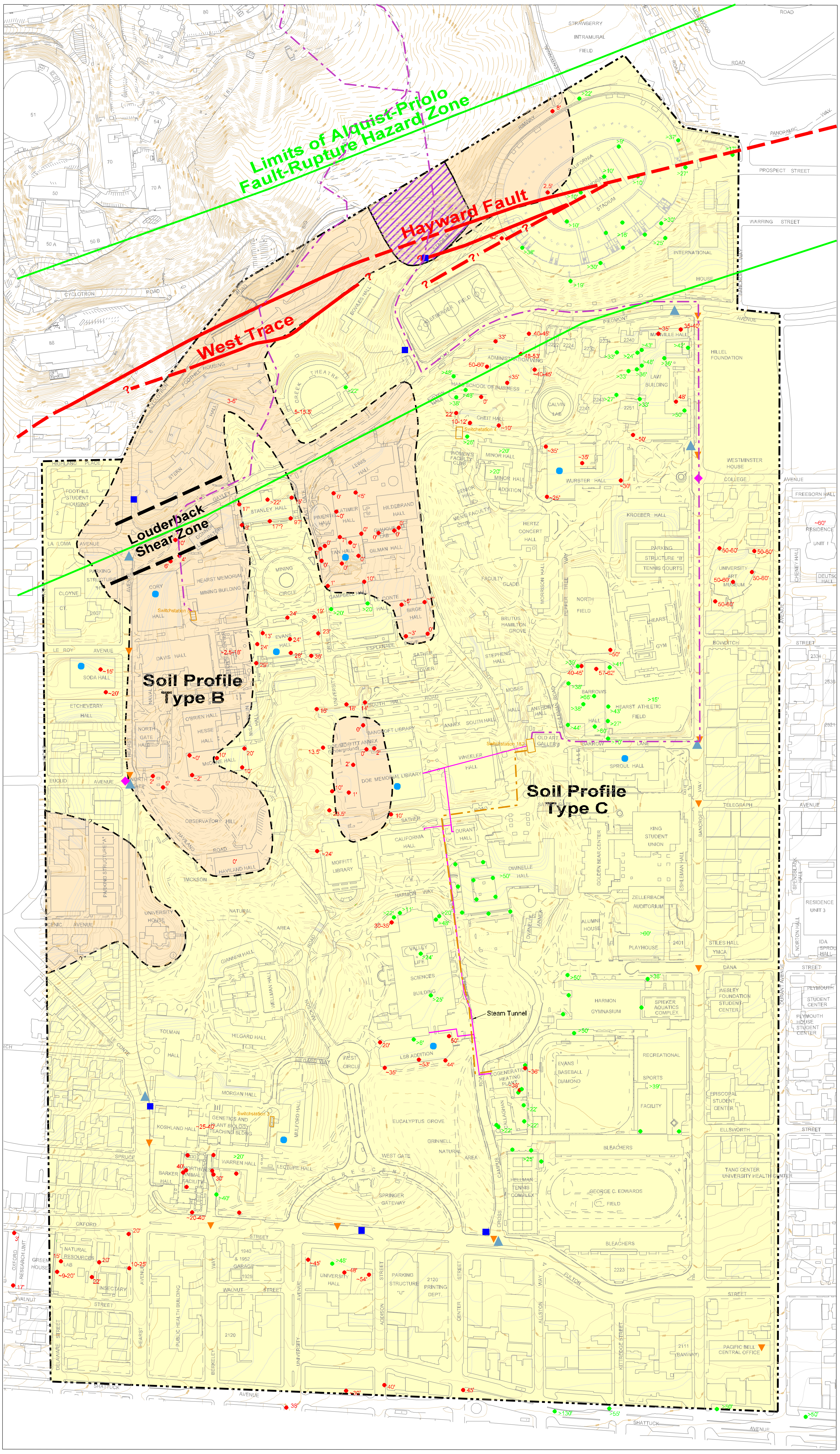
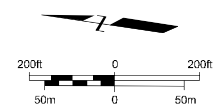


Figure 4
Value of Non-Fixed Contents by Building





LOCATION MAP



EXPLANATION

Active traces of Hayward fault; solid where well located, dashed where projected or location is uncertain, queried where existence is uncertain. Location of Hayward fault from HLA (1988a), Lienkaemper (1992), and Geomatrix (1999b)

Approximate width of Louderback shear zone as observed in the Lawson Adit. See text for additional information

Boundary of central campus study area

Area of potential earthquake induced landsliding. Areas of potential landsliding are not mapped outside of the study area

10' Geotechnical boring; depth to bedrock from present ground surface elevation or basement of building shown in feet

>50' Geotechnical boring that did not encounter bedrock. Total depth of boring from present ground surface elevation or basement of building shown in feet

SUBSURFACE UTILITY CONNECTIONS

Points of entry to UC Berkeley campus for natural gas distribution pipelines

Primary interface between EBMUD and UC Berkeley water distribution systems

Primary and backup points of entry for UC Berkeley campus internet connections (U.S. Sprint fiber optic cable)

Points of entry to UC Berkeley campus for Pacific Bell telephone cables

Buildings that contain distribution hubs for campus internet connections

PG&E 12kv feed

Cogeneration Plant 12kv feed

GENERAL HAZARD NOTE:

Significant liquefaction, differential compaction, landsliding, and flooding hazards have not been identified within the central campus. Surface-fault rupture and landslide hazards are not mapped outside of the central campus study area. See text of report for further discussion of hazards.

SITE CLASSIFICATIONS

The soil conditions within the central campus classify as soil profile types S_B and S_C as defined in the 1997 Uniform Building Code (ICBO) and the 1997 NEHRP provisions (BSSC, 1997). The soil profile type shown for each building was assessed based on available borehole data and limited information on the depth of building foundations. Additional site-specific studies or assessment of the depth of bedrock below foundations may indicate additional areas where the appropriate soil profile type is S_B.

NOTES:

See Appendix A for a list of geotechnical reports reviewed for this study. Individual borings have not been plotted for some facilities where the depth to bedrock could not be determined. Many additional borings have been drilled into bedrock in the area east of Gayley Road and Stadium Rim Way.

Utility inter-connections and distribution hubs are approximately located based on available drawings and written descriptions.

Base map provided by Physical Plant, University of California, Berkeley.

GEOLOGIC HAZARDS AND SITE CLASSIFICATION
Central Campus, University of California
Berkeley, California

GEOMATRIX	Project No.	Figure
	4951	1