THE ECONOMIC BENEFITS OF A DISASTER RESISTANT UNIVERSITY

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SUMMARY

The Disaster Resistant Universities Initiative is intended to motivate and enable the nation's largest research universities to reduce and manage their vulnerability to hazards in their locals. Not only are universities unique organisations that serve their communities, states, and nation, but the federal government has an investment in them—annually, federal agencies fund about $15 billion in university research. The Federal Emergency Management Agency (FEMA) has begun a two-part program to support universities' attempts to reduce their potential losses in foreseeable disasters. At U. C. Berkeley, we are developing and implementing prototype loss estimation methods and strategic risk management plans that other universities can use in their own efforts. In Washington D. C. FEMA is working with Congressional staff and a coalition of other universities to establish new funding over the next ten years. The research component of the Disaster Resistant Universities (DRU) project attempts to quantify the losses and economic consequences of disasters on major research universities. Faculty from Architecture, Structural Engineering, and Economics, together with professional engineering and economic consultants, has developed a loss estimation model specific to campus settings. Then, using the capital loss projections with data on capital flows, the team is estimating the local economic impact of campus losses in three earthquake scenarios. In addition to traditional economic modelling, the methodology includes a specific component for assessing the impacts on significant research units and on human capital. This paper will describe the campus loss model and results for University of California, Berkeley, and will provide an overview of the economic impact modelling methods.

INTRODUCTION

Disasters in the last decade have captured national and international attention. While 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 improve methods of estimating disaster losses, and to plan for appropriate mitigation programs. As noted in the preface to a recently published theme issue on loss estimation in *Earthquake SPECTRA* (Vol. 13, No. 4, and November 1997): Loss estimation is in an exciting stage of development. 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, casualties, economic losses, and social impacts.

One of the most significant developments in earthquake loss estimation is the comprehensive HAZUS 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 characterising 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 standardised tools, it does not meet the needs of many specific applications.

Universities, for example, are unique and specialised in terms of 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, food service, small businesses (from retail stores to printing presses), hospitals, etc. Universities frequently have too many buildings to conduct complete, building by building assessments of

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hazards and potential losses, and yet, a campus is small enough to take into account individual building details pertinent to damage and loss functions, an approach that HAZUS does not yet contain. Similarly, universities have concentrated value, not only in terms of their facilities, and specialised contents, but also as a long-term public investment, their multi-year and inter-institutional research projects, and their critical pedagogic function. 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 nationally.

After the 1989 Loma Prieta earthquake, Stanford University came painfully close to suspending operations as a result of the damage it sustained. The experience led them to develop a building policy aimed at avoiding closure in future events. The Stanford policy was to fund retrofit on buildings identified as "necessary for survival," recognising that a core of campus buildings must be operational after a disaster, so that teaching and research can be continued. The policy goal was to limit damage to no more than 5%-20% of their total square footage.

After the 1994 Northridge earthquake, all the buildings at Cal State Northridge were closed. It is a tribute to the administration that the campus re-opened for classes one month later—using 450 trailers and other temporary buildings. Unfortunately, five years later, the campus still does not have a chemistry lab open and available. Across the country, hurricanes, floods, power outages, and fires, have interrupted operations at universities in North Dakota, Colorado, New York, and New Orleans. These and 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 40,000 students, faculty and staff in more than 100 academic departments and 40 organised research units. The central campus has 114 buildings on 177 acres, with 2.6 million square feet of classrooms, libraries, offices and research labs. In the 1998 fiscal year, the campus operating budget was approximately $998 million and sponsored research awards totalled $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.

THE BERKELEY CAMPUS LOSS MODEL

The University of California, Berkeley, and other universities, as well as the public and private investors in them need a more specialised method of evaluating their potential for losses and the impact of those losses in the region and in the nation. The research described below builds on the significant work already undertaken to identify and retrofit buildings on the campus. The campus has had a seismic corrections program in place since 1978, and has spent about $250 million on structural improvements. In 1977, 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 of California; Vision 2000 methodology for performance based design (Hamburger et.al. 1995). At that time, the engineers found that 27% 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. An Occasional or Level 1 Earthquake was defined as one with ground motion of moderate severity, with a 50% probability of being exceeded in 50 years. A Rare or Level 2 Earthquake was defined as a severe event (M 7.0) expected on the nearby Hayward Fault, with a 10% probability of being exceeded in 50 years. A Very Rare or Level 3 Earthquake was defined as one with extreme ground motion (M 7.25) on the Hayward Fault, with a 2% chance of exceedance in 50 years.

Non-Structural Data Collection

The building by building data collected in the 1997 structural survey of buildings became the basis for the expanded loss estimation model. With the structural data in hand, we developed a methodology for evaluating the non-structural components by building and by major use areas. In general, the approach was to evaluate cladding and glazing the building exterior, and architectural finishes, Mechanical, Electrical, and Plumbing (MEP), contents, and the potential for water damage for the building interior in each of the major use areas: classrooms, laboratories, offices, libraries, special/other (e.g. recreation and/or performance spaces), residential, and parking.

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 quality (or the extent of the 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 methodology. Thus, the cladding and glazing in each building were rated as High, Medium, or Low as a measure of their replacement cost value, and with a numerical performance index for each of the three earthquake scenarios. Similarly, architectural finishes, MEP, contents, and potential water damage were rated for classrooms, labs, and other sub-areas in each building.

Table 1: Comparison of U. C. Berkeley Structural Ratings with Vision 2000 Ratings

UCB Ratings Vision 2000 Performance Ratings

DESIGNATION	STRUCTURAL DAMAGE	NUMERICAL RATING	PERFORMANCE EXPECTATION	ANTICIPATE D DAMAGE
Good	Some Damage	10	Fully Operational	Negligible
		9		
		8	Operational	Light
		7		
		6	Life Safe	Moderate
		5		
Fair	Damage	4	Near Collapse	Severe
Poor	Significant	3		
Very Poor	Extensive	2	Partial Collapse	Complete
		1	Total Collapse	

For example, in one large concrete shear wall building, built in 1950, 57% of the assignable space is in labs, 32% in offices, 4% in classrooms, and remainder in special/other uses, in this case primarily storage. Structurally, it is rated 5, 4, 3 in the Level 1, 2, and 3 earthquakes, respectively. By the UC rating, the structural system of this building is considered “fair.” Adding performance ratings for the non-structural components allows for a more refined estimate of damage and losses. In this lab building example, cladding was rated as Low, 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 lab components were rated Medium, except for contents that rated High, because of the presence of highly specialised and expensive equipment. Here again numerical performance ratings were given to sub-component in each area. Lab architectural finishes were 7, 5, 4. Lab MEP systems were rated 6, 4, 3, etc. The numercial ratings were based on standardised definitions for each component, from Complete Damage at 1, to No Damage at 10, with descriptive examples for each rating value. For MEP, 8, 6, 4 was used as a standard rating for modern buildings with well braced pipes and lights; 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; 2 was used if a particular vulnerability was observed.

The engineering team met bi-weekly to compare their assessments and to refine definitions. In the end, the data was assembled for use in the loss estimate. Engineers also estimated the time needed for repairs in each building in each scenario. The lab building described above was estimated to need 6 months for repairs in the occasional scenario, and 24 months in either the rare or very rare scenario. This “downtime” estimate took into account that certain repairs could be done with campus facilities staff, and these could be done in a few weeks or months, with some areas of the building open for use. After a certain point, however, with more severe damage, repairs would require engineering evaluations, drawings, peer reviews etc., and this would push repair times to 24 months or longer. Under these conditions, it is likely that all or part of a building would be completely unusable until work was complete. Downtime plus component performance evaluations are key data points to be used in the loss model.

Translating Performance Ratings to Loss Curves

As the building data was assembled, the engineering team translated the structural and non-structural ratings into loss curves. There has been great deals of work already complete (ATC-13, HAZUS, etc.) to equate the damage observed in previous earthquakes to a percentage of structural loss. In the HAZUS methodology, slight damage is set as 2% of complete, moderate damage is 10% of complete, and extensive is 50% of complete, but damage costs 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% damage) in a particular earthquake scenario has a 21$ probability of actually being damaged 30%, a 16% probability of 50% damage (rating 4), an 18% probability of 10% damage (rating 6), etc.

Separate loss curves were developed for Architectural Finish, MEP, Contents, Cladding, and Glazing based on data available from recent earthquakes and on judgement by 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 (R squared .993) 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. This is somewhat more complex than a simple add-on because 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 was severe, then the damage percentages, and associated costs would be at or near 100% of replacement. In this case, water damage rated at 2 (severe) should not take losses over 100%. By 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

After a detailed review of new construction and seismic retrofit expenditures at UC over the last ten years, replacement cost spreadsheets were developed for the seven main building types in the study (predominant use classroom, lab, office, library, special, residential and parking). These 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, designed to be used at any UC campus. Adjustment factors were added to reflect: 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, and, the university related soft costs for design and management. In addition, multipliers were added to accommodate special building conditions, which 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 organised 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 the each sub-area. In general, the loss estimate in characterised as a percentage loss of each building component, based on replacement cost values for the building type. It is assumed that even a predominant use library building will have some offices or even 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 (1)

Exterior Component Loss sample formula (cladding and glazing):

Component % Loss x OGSF x Cost of Component by Building Type (2)

Interior Component Loss sample formula (architectural finish, MEP, fixed contents):

Component % Loss + (Potential Water Damage % Loss) x ASF x (ASF/OGSF) x Cost (3)

The sum of all these components plus the special feature factors, plus 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% if the damage to the structure was over a certain threshold. We looked at three thresholds, 40%, 50%, and 60%, plus a scenario with no step function (i.e. Simply using the losses as calculated). Thus, in each scenario, we looked at the results if structural damage was 40%, then all damage went to 100% replacement. Another sensitivity analysis was done to evaluate the use of the structural distribution function. For the final product, a very conservative estimate was done, using the distribution on the structural calculations and 60% structural damage as the step to 100% replacement.

Estimates of Losses and Time Needed for Repairs

The results of this loss estimate are shown in Tables 2, 3, and 4. It is surprising to note that classroom space on the main campus comprises a much smaller proportion of the total area that one might expect. In fact, the percentages are comparable to Stanford and other institutions. In reality, classrooms are scheduled 8-10 hours per day, and there are only a few large lecture halls in about six buildings on campus. Teaching also takes place in some lab space, and offices are used for meetings with students.

Table 2: Areas of Major Use on the Main Campus

USE	PERCENT
Classrooms	6%
Laboratory	30%
Office	30%
Library	16%
Other	19%
TOTAL	100%

Table 3: Estimate of Repair Costs

	Level 1: Occasional	Level 2: Rare	Level 3: Very Rare
Main Campus	$ 626 M	$ 1,502 M	$ 2,612 M

Table 4: Percent of Space Needing > 20 Months for Repair

USE	Level 1: Occasional	Level 2: Rare	Level 3: Very Rare
Classroom	6%	40%	78%
Laboratory	19%	49%	64%
Office	9%	53%	78%
Library	4%	28%	45%
Other	5%	30%	50%

It is interesting to note that the reason the library repair times are lower than other areas is that the new main library is an underground facility which will not suffer as much as other building types. As much of the space categorised, as other is performance or athletic space, this is designed for assembly, thus to higher standards. It is daunting to note the repair times needs for lab space, even in an occasional event. Separate estimates were done for parking and housing structures, and for campus infrastructure, but these are not included here simply for brevity.

THE ECONOMIC IMPACT MODEL

The economic impact component of the research is under way at the time of this writing, and as such, results are not available. In general, the loss data will be combined with information on the university capital flows, including operating expenditures, student expenditures, capital expenditures, retirement expenditures, and others from groups such as alumni and visitors. A 1989 Peat Marwick study estimated that over $685 million dollars was expended directly in the local and regional economy, and the university provides some 14,000 jobs. The direct and indirect impact of these expenditures implies that the university contributes%1.23 billion to the Bay Area economy and produces more than 20,000 jobs. The research team will update the economic numbers and use the three earthquake scenarios to evaluate the impact of these events.

In addition, we are surveying organised research units on campus to understand what proportion of the grants received require campus lab space for their work, and to understand the relationship between lab space losses and the impact on research. We are also looking at the retention of business and engineering students in the region as a measure of the impact of the potential reductions in students on campus to the local job market. Anecdotally, one-thirds of the nation's biotechnology industries are located within 35 miles of the Berkeley and Stanford campuses. We know that the universities are a significant part of the change from manufacturing to knowledge based industries, but it is extremely difficult to estimate the precise economic impact of the contribution. As a crude estimate, we believe that the Level 2 earthquake would have approximately the same impact on the region as a mild recession.

CONCLUSION

Although it is difficult to draw conclusions mid-way in a study, the results of the loss estimate have underscored the need to emphasise that planning for post-event recovery is as important as planning for seismic mitigation improvements. The campus is already committed to a program of upgrades to improve the life-safety of all buildings on campus. We believe the data from the non-structural building evaluation will help the campus to set priorities for non-structural and infrastructure improvements that could substantially lower the repair times in labs and classroom spaces. Equally important, is the need to begin the process of a strategic loss reduction and risk management plan for UC Berkeley. This will include creation of a strategic facilities masterplan, funding and staff time for the enhancement of emergency management capacity, improved communication systems, information and education programs for faculty, staff, and students, as well as, business resumption planning processes for teaching, research and business operations.

Improving the conditions of buildings and infrastructure is only one component of the long-range plan for sustained operations. For the campus to function after an earthquake, we must consider what is necessary for teaching, research, and business management in those strained circumstances. Thus, the planning process will include not only facilities managers, engineers, and architects, but also the faculty senate, high-placed administrators, and liaisons to the city government and local businesses—large and small.

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