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SEISMIC RISK REDUCTION OF LABORATORY CONTENTS

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SUMMARY

Loss estimates for various earthquake scenarios suggest that structural strengthening of buildings on the University of California, Berkeley campus will not prevent significant loss of function and downtimes caused by nonstructural damage. This paper will describe research focused on evaluating the contents of a modern laboratory building: the furniture, fixtures and equipment installed for the users. The contents were surveyed and coded according to their physical characteristics, location, value, hazard potential, and importance to research. A program for seismic restraint of critical objects was developed. Performance of selected contents was tested on shake tables at U.C. Berkeley and Irvine. Designs were completed for the anchoring of critical contents in the existing laboratory building. A key finding from this research is the recognition that seismic protection of many objects in complex buildings such as laboratories or hospitals cannot be accomplished with simplified details. The large accelerations expected in buildings, particularly in the top floors and in near-field locations coupled with large weights and unusual configurations of many of the objects typically require building-specific solutions for effective seismic protection. An effective tool to accomplish and maintain seismic protection of critical contents in these buildings is a building-specific manual that contains guidance to users and maintenance personnel concerning limitations and opportunities for anchorage inherent in the spaces, consideration for selecting objects to protect, and suggested details for common object found in the building. This research was supported by the Federal Emergency Management Agency (FEMA), the University, and the Pacific Earthquake Engineering Research (PEER) Center.

INTRODUCTION

The University of California, Berkeley, is a worldwide leader among universities in research, education, and public service. The central campus houses over 30,000 students, and more than 13,000 faculty and staff in more than 100 academic departments and 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. The annual campus operating budget is about $1 billion, and the sponsored research awards average about $400 million per year.

The U.C. Berkeley campus has done more than any other in the nation to address the threat of earthquakes. The campus has had a seismic corrections program in place since 1978. After a 1997 re-

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evaluation of building conditions, the campus created the SAFER Program and committed to spend about $20 million per year, for the next 20 years, to improve the structural conditions of campus facilities. To date, the campus has spent $250 million on seismic improvements.

A campus loss study by Comerio [1] addressed the economic impact of potential losses under various earthquake scenarios. In addition to the cost of repairs, it considered the time needed for repairs to make the campus habitable and operational. Even in a moderate earthquake, the study estimated that 19 percent of laboratory space could require more than 20 months for repair. In a magnitude 7.0 earthquake on the Hayward fault, the estimates ranged from 30 percent to 50 percent of all spaces needing more than 20 months for repair. Although the downtime estimates will clearly be reduced by the aggressive seismic strengthening program on the campus (see Table 1), the potential loss of habitable buildings remains a serious issue for the university.

Table 1. Seismic Rehabilitation Building Areas at U. C. Berkeley

Time Frame and Buildings	*Total Area Affected*
Pre-1997: Libraries, Residence Halls, Administration Buildings and Wheeler Hall	
In Construction 1997: Libraries, Residence Halls, Hearst Mining, McCone	1,257,084 s.f.
SAFER Projects Completed 2003: BAM, Barker, Barrows, Hildebrand, Latimer, Silver, Wurster	1,316,682 s.f.
Phase 2 SAFER currently under construction	971,669 s.f.
Phase 2 SAFER in design	95,700 s.f.
Phase 2 SAFER in planning stage	367,574 s.f.
Phase 3 SAFER planned	1,332,485 s.f.
	735,813 s.f.
TOTAL SEISMIC CORRECTIONS	
	6,077,007 s.f.

The university has three small programs aimed at mitigating nonstructural hazards in campus buildings. The first is a matching-funds program to encourage all units to reduce typical nonstructural hazards in offices and classrooms. This Quake-Bracing Assistance Program, or Q-Brace, has been in place for four years. The second of these programs focuses on the repair or replacement of light fixtures, ceiling systems, and audio-visual equipment in classrooms and libraries—high-occupancy spaces where the threat of a falling hazard is severe. The third is oriented toward the review of library shelving conditions. Although the efforts undertaken have been a remarkable first step in addressing life safety hazards, very little work has been done to evaluate the potential for damage in nonstructural components, such as cladding, partitions, ceiling systems, as well as building contents and mechanical, electrical, and plumbing systems. Further, generic anchoring details have never been designed for specific building conditions or for laboratory equipment, nor have the details ever been adequately tested.

Even though most contemporary building codes do contain provisions aimed at controlling damage to nonstructural (as well as structural) building systems, there are no similar requirements for other nonstructural components, such as a building's contents. Recent earthquakes have demonstrated that significant dollar losses and building closures can be attributed to damage to nonstructural systems and contents. Even if a building is structurally sound, broken pipes, overturned furniture and equipment, and broken ceilings and lights can make a building uninhabitable.

HIGH IMPACT BUILDINGS WITH A FOCUS ON LABORATORIES

In certain building types, such as museums, high-technology fabrication facilities, and research laboratories, the contents may be far more valuable than the building, and in some circumstances, may represent a potential hazard to the occupants and the general public. At the University of California, Berkeley, laboratories occupy 30 percent of the overall net usable space on campus. Fifty percent of the research on the U.C. campus is conducted in 7 buildings, 75 percent in 17 buildings. Seventy-two percent of the approximately $400 million in research funded each year is concentrated in science and engineering. The value of the laboratory contents is estimated at $676 million, or 21 percent of the total insured assets.

Equally important is the inestimable value of the research itself. Refrigerators and freezers contain irreplaceable specimens. Computer hard drives store data for research in progress. Laboratories represent both a concentration of research (as measured by annual funding) and a concentration of valuable equipment and ideas. In a preliminary PEER-funded study of laboratories on the campus, Comerio and Stallmeyer [2] estimated that the average laboratory contents were valued at $200 to $300 per square foot. By comparison, in a typical office space the value of the contents is usually $25 per square foot.

The research described in this paper focuses on the evaluation of the contents of a modern laboratory building, completed in 1978 for organismal biology laboratories. The contents inventory and mitigation plan was supported by FEMA through the Disaster Resistant University Initiative. Shaking table testing of critical contents, development of a manual for seismic improvements for laboratory contents, and research on the contribution of contents to building losses and performance design methods was supported by the PEER. The case study building inventory allowed us to analyze the types of contents that populate typical laboratories and develop focused mitigation strategies, while the testing program allowed us to assess potential damages and develop design details.

CASE STUDY BUILDING CHARACTERISTICS

The case study building is located in the southwest quadrant of the campus, within 2 km of the Hayward fault. The building is essentially rectangular in plan and is nominally 100 feet wide and 300 feet long, and 6 stories (plus a basement) high. The floors consist of a two-way concrete joist waffle slab, 24 ½” in depth spanning 20’-0” in the longitudinal direction and 22’-10” in the transverse direction to square concrete columns. A solid, concrete floor-slab 4 ½” deep spans between joist to compete the floor system.

The lateral force (seismic) resisting system consists of discrete interior concrete shear walls in the transverse direction and exterior concrete wall-frames (or “punched shear walls”) in the longitudinal direction as shown on the plans, Figure 1. These shear walls provide great lateral stiffness to the building, on the one hand preventing large lateral displacements between floors (“drift”), but on the other hand enabling the building to transmit and amplify strong ground motions to each floor level. Walls, other than the concrete shear walls, exterior walls, and shaft walls, are made of steel studs and gypsum board and are considered nonstructural (although, in some cases they can provide support for contents). Typically, ceilings are open with exposed mechanical piping in the laboratories. Some offices contain acoustical drop ceilings, but most are exposed. The floor is either vinyl tile or exposed concrete. The mechanical systems are sophisticated, as one would expect of a modern laboratory building.

The structural seismic performance of the building is expected to be above average for the campus, in the "life-safety" to "operational" levels in a range of moderate to extreme events [3, 1]. An evaluation of the nonstructural systems indicated a level of anchorage and bracing more complete than average for this vintage of building, confirming the expected low damage levels at least for the occasional shaking. However, in general, the seismic bracing installed for the larger pipe systems was judged relatively ineffective, leading to more expected damage to those systems and a greater chance of water damage from broken pipes.

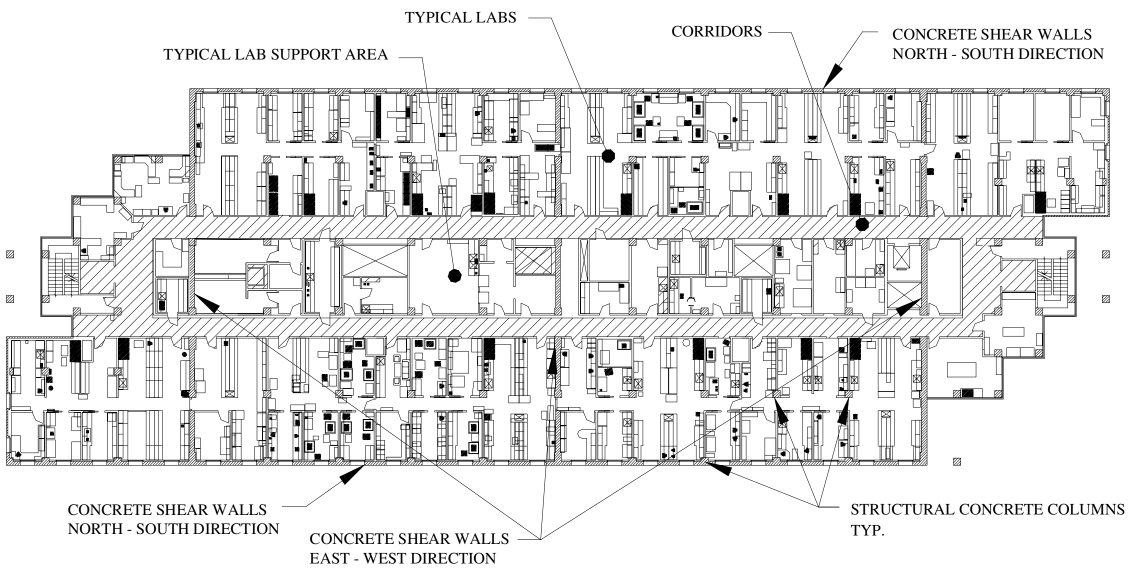

Figure 1. Typical Floor Plan 2nd through 5th Floors

CONTENTS INVENTORY

The building contents are typical of a wet laboratory: lab benches with storage shelving above, and very densely packed equipment. In total, there are about 10,500 items in the building, of which, 44% is furniture (laboratory benches, wall shelves, desk units, etc.) and 56% is equipment (tanks, cylinders, microscopes, computers, and other bench-top equipment, as well as heavy equipment such as refrigerators, freezers, incubators, and fume hoods).

There are about 15 different types of furniture and 95 different categories of equipment in the building. Shelving dominates among the furniture, and computer equipment (CPUs, monitors, printers, fax machines, and copy machines) all together represents some 1300 items (12 percent of the total and 22 percent of the equipment). Refrigerators and freezers together are the next largest group, with 4.5 percent of the total and 8 percent of the equipment, followed by centrifuges and microscopes, each representing about 3 percent of the total contents and 5 percent of the equipment. (See Table 2.)

Value

The contents were categorized according to their value as well as their potential for life safety hazards. The total value of the equipment is estimated at approximately $23 million [4]. Ninety-eight percent of the items are valued between $1,500 and $10,000. The majority of these are the bench-top microscopes, stirrers, mixers, and other small equipment. The remaining 2 percent of the equipment ranges in value from $10,000 to $1 million. These include specialized items such as confocal microscopes, valued at $500,000 each, and laser tables with visualization computers, valued at $1.2 million each.

Table 2. Common Types of Furniture and Equipment in the Laboratories

Furniture Type	*Number of Items*
Shelving Unit	2,022
Workbench	674
Cabinet	614
Desk	553
File Cabinet	385
Other	352
Total Furniture	4,600
Equipment Types	*Number of Items*
Monitor	557
CPU	544
Refrigerator	349
Centrifuge	319
Microscope	279
Equipment Rack	273
Mixer	266
Printer	212
Water Bath	141
Power Supply	139
Incubator	131
Gas Cylinder	122
Freezer	119
Fume Hood	104
Stirrer	102
Other	2,243
Total Equipment	5,900

Life Safety

Two assessments were made to evaluate the degree to which each item represented a life safety hazard. The first evaluated direct life safety, that is, risk of injury from the impact of a moving or falling object. Life safety can be threatened by heavy objects falling or tipping directly onto occupants, or by sliding or tipping into a position to block egress from a work area. The second assessment was on indirect life safety problems such as the release of hazardous materials, either directly by broken containment or by two or more released materials combining to create a hazardous substance or fire.

In the first assessment, each item in the database was coded as a potential falling hazard. The categories described in Table 3 are aimed at prevention of serious injury. A 20-pound object falling from 5 feet or more from the floor clearly could cause a death, but it is more likely to cause a serious injury. The breakpoint of 20 pounds is somewhat arbitrary but based on the State of California's code governing hospital construction.

The matrix in Table 3 demonstrates how the life safety priority and the risk will increase from the upper left to the lower right. The table also provides the recommended method for doing a retrofit design for each category—where items classified as B could use commercially available products, items classified as C and D should be designed by professionals. The locations that qualified as low, medium, or high risk were defined for consistent application. For example, a low-risk item might be floor-mounted with a low aspect ratio, while a high-risk item might be directly overhead.

Table 3. Life Safety Priority Levels Assigned to Furniture and Equipment

Weight[1]	*Risk of Location*		
	Low	Medium	High
< 20 pounds	A[2]	B	C
20-400 pounds	B	C	C
> 400 pounds	C	C	D

Notes:

1. The weight cutoffs are set by judgment. Those shown here are weights used for similar priority settings in building codes.
2. Importance levels:
   - A: No specific anchorage requirement; low priority.
   - B: Anchorage using a standard, commercially available product; moderate priority.
   - C: Anchorage designed by professionals; high priority.
   - D: Anchorage designed by professionals; highest priority.

For the assessment of indirect life safety hazards, a specialist from the campus office of Environment, Health and Safety (EH&S) visited each laboratory and noted potential associated chemical and biological hazards. This review was focused on conditions that could be hazardous in the event of an earthquake, separate from the regular EH&S inspections conducted to enforce basic safety standards. In the review undertaken for this study, associated chemical hazards were noted when hazardous materials could cause contamination, fire, release of poisonous gases, or other life-threatening conditions. Overall there were 333 conditions cited. These were coded as to whether the "fix" was administrative (e.g., moving the substance to a safer location) or whether some retrofit was required.

Importance

As the surveys of the laboratories were being conducted, the study team spoke with researchers in the laboratories to get an understanding of the kind of work they did. These conversations led to a more formal survey of research faculty and/or their lab managers to ascertain which of the items in their laboratories were critical to their research. The survey provided examples of "importance measures" (see Table 4) and asked researchers to list the equipment, data, animals, and storage systems that were critical to their ability to work. Overall, about 500 items were rated as critical to continuing research. Of these, about 30 percent are genetically designed animals, 20 percent are refrigerators and freezers containing fragile cell lines, 15 percent are microscopes, and 15 percent are CPUs where current data is stored.

Table 4. Importance Measures for Equipment and Materials in the Laboratories

Equipment replacement cost
Equipment replacement time (weeks, months)
Data or material replacement cost
Data or material replacement time (weeks, months)
Irreplaceability
Interruption sensitivity (can tolerate none, or very little)
Loss of research benefits (income, salutary applications)
Related hazards that may occasion long clean-up periods (chemicals, biohazard)

IDENTIFICATION OF CRITICAL FACTORS AFFECTING INVENTORY

Together, the detailed drawings documenting the equipment in each laboratory and the database provide a mechanism for understanding the number and types of equipment as well as the issues involved in planning for the seismic retrofit of laboratory contents. Any item designated important by the researcher is essential to continued research—whether it is an animal, a cell line that took years to develop, or customized equipment. Similarly, high-value equipment is essential because it may require a long lead-time for purchase or may require specialized equipment funding not always available to researchers. Life safety designations C or D imply real hazards to the occupants of the laboratories. Likewise, chemical hazards put not only the occupants at risk but also the larger community. Equally important, a chemical spill could add months or years to a building being out of service after an earthquake (even if the building has no damage) as a result of the time needed for clean-up.

Only 1,287 items (about 10 percent) are tagged as Important, Chemical Hazard, or Life Safety Priority D, or some combination of these codes. With Life Safety Category C, the total reaches 3,993 items. The High Value category was found to be a subset of those designated Important. There are only 65 items in the building valued at more than $20,000. Thus, the combination of Important, Chemical Hazard, Life Safety Priority C and D, and High-Value, puts the number of items that could be considered critical to operations at 40 percent of the total contents in the building. If this subset of items were to be seismically anchored, the overall benefit to limiting downtime would be significant.

The research team was initially surprised by the fact that the great majority of the equipment in the building had a replacement cost of less than $10,000. However, most of the bench-top equipment in biological research is small, and lab staff and students need many more ordinary microscopes and mixers than they need high-tech optics.

Although we have powerful examples of devastating losses to laboratory contents in past earthquakes, such as the loss of the Chemistry Building at Cal State Northridge in 1994 (caused by chemical fires), there is no statistical data on contents losses from past earthquakes. Ideally, we would like to develop a cost/benefit calculation to make the case for contents retrofitting, but there is no fragility information available to do such an analysis. Preliminary results from shake table tests of bench-top equipment suggest that the earthquake motions are amplified one to two times at the bench and that unanchored objects will slide into other equipment or off the bench. The tests on heavy equipment suggest that tall refrigerators and freezers will slide between 12 inches and 18 inches and may overturn in larger motions, especially if one of the legs buckles. Shake table testing of contents is difficult because displacement is normally limited by the particular table. The total travel of sliding objects and the probability of overturning may not be well represented by these results [5].

USING CRITICAL FACTORS TO TARGET RETROFITS

In evaluating the kind of equipment and furnishings that populate the laboratories of the U.C. Science Case Study Building, the three categories of critical factors—important, valuable, and a life safety concern (including falling and chemical hazards)—are the obvious first priority for a retrofit program. This applies not only to this case study building but also to any other science laboratory. It would be possible for any researcher to identify the critical items in his or her laboratory in terms of their importance to the research, their value, or the length of time needed to replace a unique item. The list of critical items could be combined with an assessment of potential life safety hazards to create a first-priority retrofit list. Other items could be added as the laboratory users deemed necessary.

The obvious response to the threat of damage from earthquakes is to provide restraint for all contents in the laboratory environment. There are two primary reasons why this may not always be necessary or appropriate: 1) cost and, 2) the potential effects of seismic restraint on the function of the element or the laboratory as a whole. Restraining a portable bench-top instrument, even with a quick-release system to facilitate changes in location, may reduce efficiency and may not be used by staff. Similarly, providing a docking station for wheeled equipment may take up space and inhibit movement in the room.

Given cost and functionality concerns, it is prudent to prioritize contents with respect to their potential to cause hazards or losses. We recommend here that the Life Safety category be considered first, then Importance, and finally Value, although any order could be used to evaluate the contents of a laboratory.

DESIGN ISSUES IN AHCHORING CONTENTS

The content of laboratories can include:

- Tanks and cylinders such as gas cylinders, cryogenic containers, and liquid tanks.
- Wheeled items such as tanks, racks, and benchtops, some that must be mobile on a daily or hourly basis, and some that are almost never moved.
- Larger equipment not related to the building's mechanical, electrical, or pluming systems such as refrigerators, freezers, dryers, and large incubators.
- Storage elements such as drawers, bookshelves, cabinets, storage racks, and shelving units, including contents that also vary widely in weight, fragility, and hazard level.
- Bench-top items such as computers (and accessories), microscopes, mixers, microwaves, water baths, centrifuges, and small incubators.
- Unique equipment and experimental set-ups,

With the exception of built in furniture or of an occasional tank with mounting legs, none of these items is designed by their manufacturer to be seismically restrained and therefore operational effects from the restraint itself must be considered. Negative effects from the restraint could include loss of mobility, loss of operational convenience, loss of manufacturer's warrantee, or potential seismic damage to the item caused by the restraint itself or its connection. Further, some of the contents listed above are themselves containers of equipment, supplies, or laboratory experimental material that is valuable or hazardous. The designer, therefore, must be aware of what is being protected. For example, if a refrigerator is rigidly anchored to the floor, the contents could still be destroyed from emptying on the floor, or if the door is positively latched, from being strongly shaken inside the unit.

The other primary consideration in seismic protection of lab contents is the selection of anchor points. Mechanical and electrical building service equipment is traditionally anchored to structural floors, but there are several arguments against adopting this practice as a standard in labs. Many lab managers prefer to not penetrate the floor sealing systems, or to deal with installation, removal and repair of concrete anchorages on a common basis. In addition, floor anchorage generally results in a rigid connection that transits large loads into the equipment and contents and also will probably damage the equipment frame.

Considering a typical lab cross section as shown in Figure 2, the partitions and permanent lab benches and cabinetry present a good option, at least for smaller elements. Partitions—typically steel stud and gypsum board— provide a convenient anchorage plane. Unfortunately, most lab partitions are minimally designed for cabinet loads and cannot accept seismic loading from heavier equipment (500- 1500 pounds). Still, most partitions that run past the ceiling level to the structure above can form an anchoring location for tank supports and other smaller equipment as well as a tether location for mobile carts, tanks, and racks. Seismic wall anchorages should always be placed directly into a stud or backing plate. Since this is often impossible, an external backing plate can be placed for convenience by screwing a piece of framing channel into three or more studs on the surface of the gypsum board. If these external backing plates can be made continuous, they serve a secondary function of spreading any load attached to them to several studs.

If stud partitions prove inadequate to provide seismic support, and floor anchorage is not desirable, vertical tubes or other structural members ("strongbacks") must be placed adjacent to the partitions running from floor to floor. In equipment halls, several strongbacks could be installed with horizontal framing channels to form an anchorage plane. In new buildings, the economic advantage of providing stronger studs to accommodate equipment anchorage should be considered.

Those elements not on the floor are mounted or rest on built-in furniture or portable benches and tables, on open shelving, or in cabinets. Built in benches and cabinets are usually well anchored to the floor and/or the partition walls and can be used to anchor most bench-top equipment with a variety of proprietary devices. Closed cabinets should have positive door latches. Open shelving generally has perimeter lips, but the 1.25" height usually used is probably inadequate to restrain most contents. To protect the contents of cabinets and/or shelving from damage, racks or other individual restraining devices are needed to prevent damage from sliding and overturning. Similarly, built in island benches are also typically well anchored. However the vertical shelving stanchions that extend upward from typical island benches are often under-designed. Seismic load in addition to the in-place shelving should not be placed on these stanchions without specific calculation. In new buildings these stanchions should be designed not only to adequately carry loaded shelving, but also to restrain benchtop equipment.

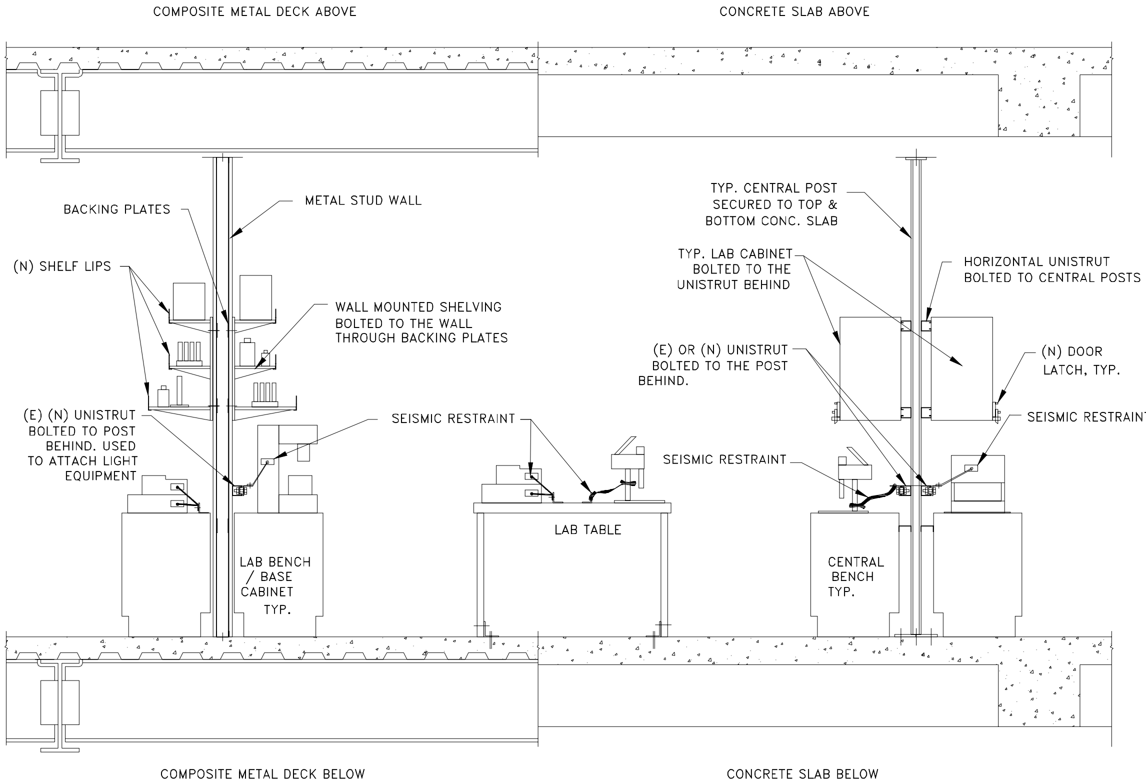

Figure 2. Typical Lab Cross-section

Refrigerators, freezers, and incubators approximately 32" x 32" x 80" tall and weighing between 600 and 1000 pounds are very common in modern laboratories and are difficult to satisfactorily restrain. As previously mentioned, restraint for such devices should prevent sliding and tipping while not damaging the framework of the equipment itself. It is also desirable to incorporate some level of flexibility into the restraint design to prevent transmission of high shock loads into the equipment and its contents. In addition, the restraint should be removable to allow movement of the equipment for maintenance or lab reconfigurations. Given studs of adequate strength in partitions, a detail can be developed using a commercially available strap attached to the equipment by stud bolts on a plate adhered to the side panel of the equipment with double back tape. The restraint can be removed by taking the wing nuts off the stud bolts. This arrangement will not allow "banking" of this type of equipment with zero spacing, but other reasonable and economical devices for this kind of equipment are not available, or require load testing.

An alternate to this detail is shown in Figure 3. The restraint provided by overhead "hangers" will prevent overturning or excessive sliding and will also reduce shock transmission. The semi-permanent hanger "ears" are unobtrusive and can remain on the units as they are moved around. The cost of the sizable strongbacks and overhead beam must be weighed against the cost of installation of unusually strong studs or of installing smaller strongbacks adjacent to the wall.

This system will be most economical if installed as part of the original building infrastructure. It will require engineered design for the specific location in which it will be implemented.

It is generally assumed that seismic anchorage of the majority of lab contents is not required by code, although a few jurisdictions have requested anchorage of racks and equipment over five feet tall. Similarly, enforcement of local fire and life safety regulations has resulted in special storage requirements for chemicals, and occasionally, requirements for anchorage of tanks, including Dewars. As a result, seismic anchorage of lab contents is most often a voluntary activity and is "designed" and installed by occupants, building maintenance personnel, or vendors of anchorage devices. Issues that are building specific are seldom properly addressed, including seismic loading, appropriate details for floor or overhead anchorage, details and limitations for anchoring to benchtops, shelving stanchions, or partitions, and guidance for use of proprietary anchoring devices. In addition, after an initial anchorage effort, there is little guidance for follow through when equipment or experimental set-ups are moved or areas are remodeled.

The results of this research suggest that a building specific anchorage manual is needed for any lab building in which the seismic protection of contents is taken seriously. At a minimum, this manual should include recommended anchorage details for the range of contents specific to the building with weight limitations for their use. For new buildings in which special accommodations have been added for anchorage, such as strong partition walls, special backing plates in partition walls, continuous framing channels behind benchtops, or overhead support devices, the proper use and limitations of these anchorage systems should be described.

A more complete manual should be written partially for the lab user, partially for building maintenance personnel, and partially for engineers who may be called to provide anchorage in unusual cases. This kind of manual should contain the following:

- Basic information about earthquakes and how the shaking causes damage
- The probable performance of the structure and the nonstructural systems of the building as well as the reliability of utilities serving the building.
- Recommended seismic loading for contents in various locations in the building
- Characteristics of the structure and limitations on location and types of anchors
- Characteristics of interior partitions or structural walls that could be used for anchors
- Characteristics of built in lab furniture
- Guidelines on how a lab occupant or supervisor could determine the contents with highest priority for seismic anchorage
- Typical details developed specifically for common equipment in the building for the anchoring conditions of the building.

The availability of such a document will encourage seismic anchorage, particularly the appropriate use of proprietary anchoring devices and any special features that may be built in to the building. In addition, the document will stay with the building, similar to an owner's manual, and outlive changes in lab managers or building administrators.

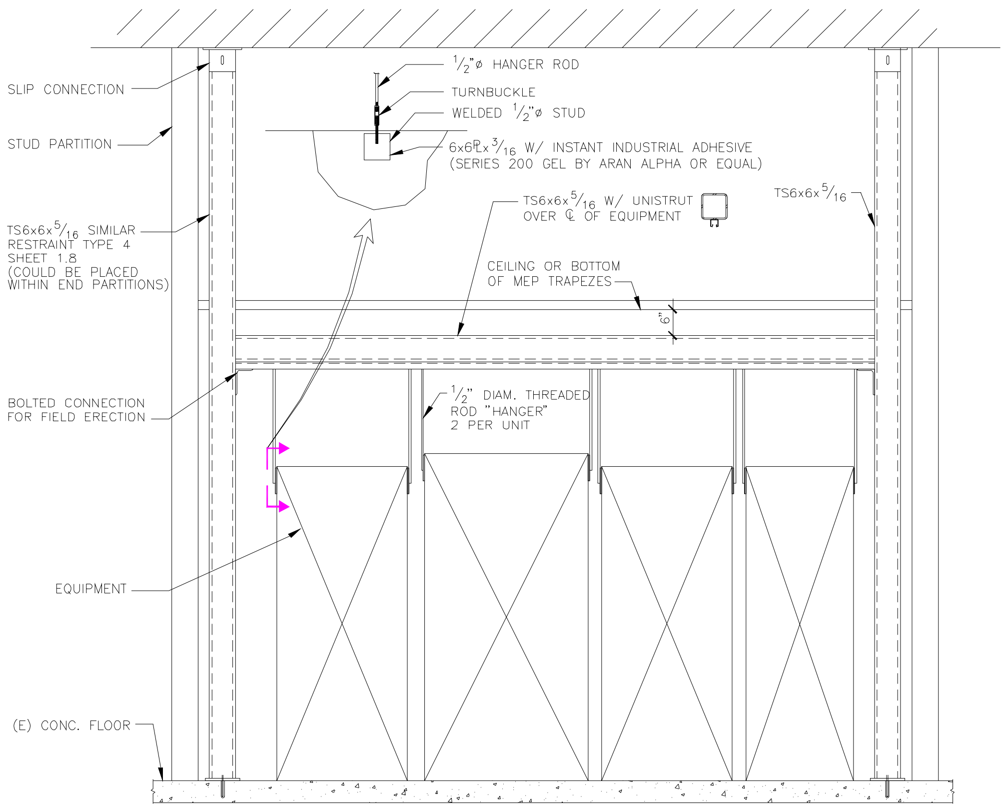

Figure 3. Alternate Equipment Restraint System in Equipment Halls

COST OF ANCHORING LABORATORY CONTENTS

A PEER sponsored study of the cost of seismic anchorage [2] in five prototypical laboratories on the U. C. Berkeley campus was used as the basis for estimating anchorage costs in the case study building. Estimates assumed union labor and retail pricing, but do not include contractor overhead markups. Cost reductions could be could be achieved if materials were purchased in quantity at wholesale prices.

The total cost to anchor all the equipment in the case study building would be $25 per square foot of laboratory space (or $20 per square foot of net useable building area). However, if anchorage were limited to the items in the three categories of critical factors—that is those tagged important, valuable, and life safety category C and D[3], then the number of items in need of anchorage would be about 4,000 (out of 10,500 total in the building). The cost to anchor these critical items would be $16 per square foot of laboratory space or $13 per net useable area. If a smaller sub-set of the critical items were anchored—those tagged important, with values over $100,000, and life safety category D—then the retrofit would be limited to about 1,300 items at a cost of $9 per square foot of laboratory space ($8 per square foot net).

[3] It should be noted that life safety category D included all items tagged as a chemical hazard.

CONCLUSION

The research described in this paper was conducted as part of the FEMA funded Disaster Resistant University Initiative and as part of the NSF funded PEER Center development of performance based assessment models. Our work focused on understanding earthquake losses resulting from damage to building contents and nonstructural systems. By documenting and cataloging the contents of a typical modern laboratory building, we found that 44 percent of the building contents were furniture and 56% percent is equipment. Fifty percent of the furniture is shelving units. Computer equipment forms the largest single equipment group (22 percent), followed by heavy equipment, such as refrigerators, freezers, and centrifuges (13 percent). The remainder of the equipment is primarily small benchtop items.

As part of the survey we recorded the replacement value of each item and found that ninety-eight percent were modestly priced items below $10,000, while the remaining 2 percent were highly specialized items with values up to $1 million. Scientists identified objects that were essential to their research, and invariably these were refrigerators and freezers that house fragile biological samples, data stored on computers and customized equipment. The research team evaluated items for life safety and chemical hazards.

These attributes—value, importance, and life safety—were used to set damage mitigation priorities. Ten to forty percent of the items in a laboratory building represent those that are most critical to research, most difficult to replace, and potentially, the most dangerous to occupants. If these items are carefully anchored, the building would be substantially safer and research operations would be protected.

Although the research team initially intended to develop universal anchorage details for various equipment types, we found that this was only possible for lightweight benchtop equipment. Heavy equipment and shelving require anchorage to the building walls, and as such, must be designed for the specific conditions. The building location, soil conditions, and structural system will affect the floor accelerations impacting the contents. Similarly, the materials used (particularly the stud dimensions and gauge in partition walls), as well as the construction detailing affect how anchoring of equipment can be done. There really are no simple solutions for contents anchoring. To do it correctly requires some knowledge of the building conditions and structural design [6].

Continuing work on the vulnerability of building contents losses and other nonstructural systems by PEER researchers will help to better define overall earthquake losses. Although there is much more work to be done on the role of contents and nonstructural systems in loss estimation, the research thus far has raised important questions: Will the anchoring of heavy equipment hurt the functionality of the equipment by damaging the internal components? Further, will the anchoring of such equipment transfer the load to the contents, making a “bio-shake” of fragile samples? Do we need to re-think the specifications of partitions and other critical anchorage components of laboratory buildings? Can architects and engineers take responsibility for anchorage of items not in the building design documents?

Obviously, we need to collect systematic data on contents losses and nonstructural losses after future earthquakes. Such data is essential to calibrate the tests as well as the loss models. In the interim, the research begun with these laboratory studies—research that can be transferred to other building types—establishes a model for categorizing and quantifying building contents. The research also provides a baseline for costs to assess mitigation strategies and provides a systematic method for including contents in loss modeling.

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