PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Implementation Manual for the Seismic Protection of Laboratory Contents: Format and Case Studies

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Abstract

Previous work at the University of California, Berkeley, identified the presence of a wide variety of equipment, tanks, material storage systems, and experimental setups in campus laboratories (Comerio and Stallmeyer, 2002). Development of a family of details to seismically restrain such contents revealed different physical conditions in the labs of each building that significantly affected the details (Comerio, 2003). In addition, interest in “do-it-yourself” seismic protection of contents generated by the Q-Brace Program on the campus resulted in extensions to the program that sometimes produced ineffective restraint or anchorage.

To maintain an ongoing and effective seismic restraint program for contents in laboratories, for each building a “user's manual” is needed that takes into account differences in equipment, supplies, and other contents, and the capacities of floors, walls, benchtops, and overhead structures for use in providing such restraint. This report suggests a format for such manuals that will require input from a seismic engineer for initial preparation, but, for most conditions, will allow implementation without further engineering input. In addition to documenting the opportunities for seismic restraint in the laboratories unique to each building and typical details for ongoing use, the suggested format includes information about the expected overall seismic performance of the building and its utilities to enable emergency planning by the researchers. Also included are suggestions for methods of prioritizing contents for receiving protection from seismic shaking. Two example building case studies are included in the report.

Acknowledgments

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Contents

List of Figures

List of Tables

Foreword

Background

The research for this report is a part of two larger efforts: (1) the Pacific Earthquake Engineering Research (PEER) Center's research program on developing a methodology for analyzing performance-based design and (2) the Disaster Resistant University (DRU) initiative funded by the Federal Emergency Management Agency (FEMA) and the University of California, Berkeley. Coordination between these research programs allowed researchers to share data in a case study of an existing building (UC Science Testbed Committee, 2002), and develop guidelines for the seismic protection of laboratory contents (Comerio, 2003).

The DRU initiative developed a methodology for hazard assessment and loss estimation, as well as for the evaluation of economic impacts. These are published in a report: *The Economic Benefits of a Disaster Resistant University* (Comerio, 2000). The central finding of this study was that the University of California, Berkeley, remained extremely vulnerable to earthquake losses, despite its extraordinary commitment to improving the life safety of hazardous buildings. The vulnerability was attributed to three factors. First, buildings whose structural systems were expected to perform reasonably well in earthquakes would be subject to significant damage to nonstructural components, including both nonstructural systems and building contents. Second, research laboratories were concentrated in less than 20 percent of the campus buildings, and more than half of these were likely to be closed after a major seismic event. Finally, one third of the replacement value of the campus is in its contents—books, technical instruments and research equipment, art, artifacts, specimens—all highly susceptible to damage and essential to the teaching and research mission of the university. Based on these findings, the study recommended continued investment in life safety improvements to buildings and infrastructure, a damage mitigation program focused on loss reduction for building contents (particularly in libraries and research laboratories), and a strategic plan for business resumption.

[1] The nonstructural components of a building are the cladding, glazing, partition, finish materials, mechanical, electrical, and plumbing systems. Contents are items purchased and installed by the owner. When researchers estimate earthquake damage, however, the value of damage to contents and nonstructural systems are often conflated to one category labeled nonstructural (i.e., all damage that is not attributed to the structural system).

The second stage of the DRU initiative focused on the mitigation of hazards in research laboratories.

At the same time, PEER researchers wanted more details on losses related to both nonstructural components and contents for its performance models. PEER funded a case study of laboratory contents as part of a larger review of nonstructural losses (Comerio and Stallmeyer, 2001). This study detailed the types of equipment and contents found in university laboratories and developed prototypical anchoring designs and preliminary installation cost estimates for a variety of laboratory conditions found in chemistry, physics, biological science, and computer science departments.

PEER then coordinated with the DRU evaluation of a modern science laboratory building at UC Berkeley to test the PEER performance-assessment methodology. The FEMA/UC effort focused on developing specific mitigation solutions for the laboratory contents; the PEER research involved surveying the building contents in detail, modeling the building's structural performance, and testing key equipment with shake table tests to provide fragility functions for the loss models. The outcomes from both projects will inform planning for the protection of laboratory contents and provide an analytic data set for future efforts in performance assessment and loss modeling. This report provides technical guidelines for the seismic protection of laboratory contents and two case study examples of the application of those guidelines to an existing building and to a building under construction.

ORGANIZATION OF DOCUMENT

The main body of this document is intended to act as a format for the development of a manual to provide seismic protection of laboratory contents for a Specific Building. It is written for preparers of such manuals, expected to be engineers experienced in seismic design. On the other hand, the audience for the completed building-specific manual is expected to be building occupants, building staff, or campus service staff generally unfamiliar with seismic effects. Examples of such completed manuals are found in the Appendices.

Normal text in the body is general in nature and, if appropriate, can be transferred essentially unedited into a building-specific manual. [Bracketed text gives suggestions to the preparer concerning building-specific data that must be included to maximize the usefulness for the eventual users and to assure appropriate technical content.] The authors of this document take no responsibility for the technical adequacy of manuals prepared according to the guidelines presented. In general, bracketed text should be edited out of the completed building-specific manual.

1 Introduction

[It is recommended that the following serve as an introduction for a manual developed for a Specific Building.]

It is generally understood that earthquakes damage man-made objects by causing the ground to shake. More specifically, any one spot on the ground moves rather randomly in all directions as the waves generated by the fault rupture pass by, as is shown by the trace in Figure 1. In general, the intensity of the motion, that is the tendency to cause damage, increases with the magnitude of the earthquake, the nearness of the site to the fault rupture, and the softness of the ground at the site. For more information on seismic ground motions, refer to US Geological Survey web site at **www.usgs.gov**.

Buildings respond to this shaking by swaying back and forth (in fact, in all directions, similar to the ground, but it is simple to think about most buildings swaying in one or both of its major orthogonal directions). Commonly, the building's dynamic properties are sympathetic with the ground shaking, and the motion is amplified within the building, getting larger in floors higher in the building.

Earthquake damage in buildings is normally categorized as structural, nonstructural, or contents damage. Structural damage occurs when the sideways motion in the building is more than the columns, beams, braces, or structural walls can take without harm, usually indicated by concrete or masonry cracking and steel stretching or buckling. The nonstructural category refers to permanent or semi-permanent building components other than the structure such as cladding, partitions, ceilings and mechanical, plumbing, and electrical systems. Damage to these components can occur due to excessive movement between two adjacent floors (fracturing a partition that is connected to both), or by high accelerations that create large horizontal forces (breaking a pipe spanning between two adjacent supports or causing equipment to move off its base). Contents comprise everything else in the building, including furniture, non-building-related equipment (copy machines, autoclaves, refrigerators, computers and microscopes), supplies (paper, glassware, chemicals, etc.), and work products (computer software and data and experiments). Contents are most typically damaged by forces created by building accelerations that cause the item to slide or tip over.

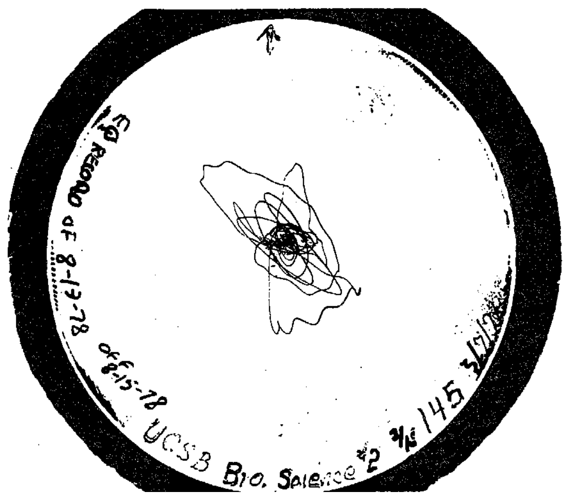


Fig. 1. Seismoscope Record from Biological Sciences II, UCSB

Examples of contents in laboratories include:

1. Tanks and cylinders such as gas cylinders, cryogenic containers, and liquid tanks;
2. Unique equipment and experimental setups;
3. Equipment not related to the building's mechanical, electrical, or pluming systems such as refrigerators, freezers, dryers, dishwashers, and large incubators;
4. Storage elements such as drawers, bookshelves, cabinets, storage racks, and shelving units, and their contents; and
5. Benchtop items such as computers (and accessories), microscopes, mixers, microwaves, water baths, centrifuges, and small incubators.

Most regulations that control the design and construction of buildings contained in the local building code include requirements that minimize or control damage to the building's structural and nonstructural systems (although some parts of the US in lower seismic zones do not require seismic design of nonstructural systems), but have no requirements for contents. This is probably due to the variability of contents and typically, the small effect of damage on public safety. However, 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 occupants and the general public.

As an example, at the University of California at Berkeley, laboratories are 30 percent of the overall campus space. The value of their 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. These are the knowledge base of the university.

The potential loss of building operations is a serious issue for a university. However, the dollar value of the equipment, computers, and other contents in laboratories, the priceless nature of experiments in progress, the value of research supported annually, and the immeasurable value of the contribution to knowledge represented in university laboratories make them an obvious focus for mitigation of nonstructural hazards [Comerio and Stallmeyer, 2001].

The seismic motion of the building will cause the contents to tend to slide or turn over depending on the ratio of height to base width and the friction between the base and support surface. The configuration of some items will cause them to rock on their base and the combination of rocking and sliding can result in the item “walking” some distance. Any of these responses can be damaging to the item or to nearby items—or occupants. Tipping over can cause direct damage to sensitive equipment, spilling of contents, or can lead to a secondary fall off of a counter or shelf. Broken or spilled chemical containers can result in harmful releases or dangerous chemical combinations. Heavier items falling from a shelf will injure occupants. Sliding or walking of heavy equipment will also cause harm to occupants.

Conventionally, seismic protection is afforded contents by anchorage, bracing, or restraining, to prevent damaging movement. However, if all damage is to be avoided, the characteristics of the item must be considered to ascertain appropriate protection measures. For example, rigidly anchoring equipment at its base may impart large accelerations into the mechanism potentially resulting in internal damage. Similarly, anchoring a refrigerator or freezer to the floor will almost certainly cause the door to fly open and the contents to be emptied to the floor. Adding a positive door latch will keep the door closed but may not prevent the contents from being thrown about inside the box and being damaged. In this case, close-fitting racks may be also be needed to prevent damage. Appropriate seismic protection measures therefore depend on the physical characteristics of the item and its support, as well as acceptable performance in an earthquake. In some cases, the mobility needed for the function of small items coupled with their low cost and low potential hazard will result in the conclusion that seismic anchorage or bracing "is not worth it."

For items deemed extremely valuable due to their dollar worth or rarity, all sources of seismic damage must be considered. As mentioned above, some sensitive equipment may be internally damaged if merely anchored down. Experiments that require outside utilities need back-up provisions because it is likely that in large events, some utilities will be disrupted. Lastly, the total building environment should be considered. Concerns about the structural performance of the building may be obvious, but secondary hazards from failure of nonstructural building systems must also be considered, ranging from lack of function of the mechanical systems to physical damage from falling ceilings or broken pipes.

This manual gives guidance for providing seismic protection for the contents of typical research laboratories in the [Specific Building]. Acceptable methods of anchoring to the floors, overhead structure, benchtops, and structural walls and partitions are given, as well as limitations for their use. Some of the methods detailed herein can be installed directly by the user of the laboratory. Some will require the more skilled labor of experienced building or campus maintenance personnel. Some lab contents will be of such large weight or unusual configuration that anchorage details will require custom design by an engineer experienced in providing seismic protection.

2 Building and Site Description

[This section is intended to familiarize the reader with the building and its site, both to provide a convenient reference for information on configuration and to document the level of risk for failure of systems important to laboratory safety and function that are not covered in this manual, such as utilities, the structure itself, and the building's nonstructural systems.]

2.1 BUILDING SITE AND OUTSIDE UTILITIES

[A location plan should be included showing seismic hazards other than strong shaking such as nearby active faults or areas of liquefaction. The site plan, at larger scale, can be used to shown the overall building configuration and the relationship to nearby structures as well the types and locations of utilities serving the building.]

[Written descriptions of these features should also be documented, including, when available, expected effects on a typical laboratory from unusual seismic hazards and the reliability of utilities to be in service after a seismic event.]

2.2 BUILDING CHARACTERISTICS

2.2.1 Description

[The building should be described in terms of area, height, basic material, and gravity and seismic load-carrying systems. Floor plans should be included showing basic room layout and/or basic structural framing elements. The framing of a typical bay is also often useful. Since the systems are important to seismic performance of individual labs, the building's nonstructural systems such as partitions, ceilings, light fixtures, and the distribution of building service systems (mechanical, electrical, plumbing and communication) should also be described in general.]

2.2.2 Expected Seismic Performance

[The expected seismic performance of the structure should be described. Although this can be done by relating the structural design to current or past code compliance, this is not effective for communicating expected performance to the occupant. Expected performance levels for various potential seismic events taken from performance-based-design documents such as Vision 2000 (SEAOC, 1996) or FEMA 356 (FEMA, 2000), are much more useful in this regard. See Table 1 for performance levels used in Vision 2000. These performances can be related to frequent events (return of about 30-50 years), rare events (the event normally considered in codes with a return of about 500 years), and a very rare event (sometimes termed the “maximum credible event” with a return of between 1000 and 2500 years, as appropriate for the site).]

[Expected damage to architectural components and building service systems, especially those that will significantly affect life safety or function within the laboratory spaces should also be described.]

Table 1. Damage States and Performance Level Thresholds

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

2.3 SEISMIC DESIGN REQUIREMENTS

[The seismic design requirements for lab contents applicable to this building should be discussed. The material below not in brackets should be generally applicable and can probably be included for most buildings.] Building codes like the Uniform Building Code (ICBO, 1997) contain requirements for anchoring many architectural and building service system components to the structure for seismic forces. The applicability of these anchoring requirements to contents is vague and the boundary between nonstructural building components and contents is blurred. For example, no components that could be classified as contents are listed in the code other than storage racks and floor-supported cabinets over six feet in height. Traditionally, items classified as contents are installed by the owner or user after construction is complete and there is little jurisdictional control. [One exception to this general practice is medical equipment in hospitals in California, where equipment with a "permanent" connection to the building utility systems is ruled to require seismic anchorage. In labs, this rule would require anchorage for fume hoods or equipment with connections to gas lines, but little else. Currently, building departments are not generally extending their jurisdiction to control installation of lab equipment. However, due to overlaps with control of storage of chemicals, gases, and other potentially hazardous materials included in fire codes, some agencies in charge of fire safety are taking an increasing interest in seismic safety of lab contents. Fire codes are separate from building codes, but they are often adopted in one document by states or local jurisdictions. In California for example, Part 9 of The California Code of Regulations (CBSC, 2002) is the California Fire Code, whereas Part 2 is The California Building Code (CBSCa, 2001). It is recommended that anchorage design requirements and details be reviewed and coordinated with the local agency that controls fire or environmental safety.]

For nonstructural components, building codes require anchorage to sustain specified lateral forces measured as a percentage of element weight. It is reasonable to apply the same rules to contents. This proportion of weight used is sometimes referenced in terms of the acceleration of gravity, g (e.g., 0.5g meaning 50% of component mass), but is more accurately simply written as 0.5 Weight (or 0.5W). The magnitude of the code loading for nonstructural components, termed F_p in most codes, is dependent on the location of the building relative to potential source faults, site soils conditions, and the height of the component within the building. Also in the formula for F_p, as shown in Table 2, is an importance factor, I_p, intended to give additional reliability for anchorage of important equipment or other components. Additional factors include a_p, a measure of dynamic amplification of seismic forces created by flexibility of the component, and R_p, a measure of ductility or toughness of the connection. Maximum and minimum loadings are also specified that override the results from the formula.

Although for most components in this manual, a_p will be 1.0 and R_p will be either 1.5 or 3.0, this formula should be applied by an engineer knowledgeable in seismic design and is given here for general information only. [C_a should be determined for the Specific Building and Column 1 and 2 of Table 2 modified accordingly.]

[The NEHRP Provisions (BSSC, 2001), a national source document for future codes, contains a method of determining appropriate design forces for nonstructural elements based on dynamic analysis of the building. In this case, floor motions (a_i) are determined directly from a modal or time history dynamic analysis and can be substituted for the code values at each floor. If such analysis results are available, appropriate loads can be entered into columns 3 and 4 of Table 2.]

Table 2. Design Forces for Components and Contents in CSB 1 Using R_p = 1.5

Floor	a_i per UBC %g[1]	Design Force per UBC, %W[2]	a_i from non-linear analysis, %g	Design Force from analysis, %W[2]
Roof	240	160	99	65
7	200	133	71	50
6	180	120	67	45
5	160	106	70	45
4	130	86	70	45
3	110	74	68	45
2	82	56	61	.42
Ground	.6	.42	56	.42
Basement	.6	.45	NA	.42

Notes

1. $a_i = C_a\left(1+\frac{3h_x}{h_r}\right)$ or as derived from dynamic analysis

2. Design Force percentage of Weight = $\frac{a_i a_p}{R_p / I_p}$

a_p =1; I_p =1; R_p = 1.5.
Min = 0.7 x Ca = .7 x .6 = 0.42

[Based on the code requirements or the building specific analysis, the preparer of the manual may decide to recommend, for simplicity, a single percentage of weight to be considered by users for installation of standard anchorage devices. As seen in the sample details of Section 5, most details can be given with a component weight limitation, with the required seismic loading already considered. Floor by floor variation of loadings, however, may be needed to avoid overly conservative details (strongbacks for example) throughout the building, or to design custom details.]

3 Seismic Anchorage in the Lab Environment

[This section is intended to provide background for users or installer inexperienced in seismic anchorage as well as to document specific conditions within the labs of this building.]

Most seismic protection of contents consists of restraint against sliding or tipping during the building motion induced by an earthquake. This restraint is obtained by attaching the item to a stable building component that itself is strong enough to resist the shaking and provide anchorage. Anchorage details must be conservatively designed and be reliable because it is likely that they will be in place for months or years, and will be fully tested only once — by the earthquake. This section describes building components in the [Specific Building] that can be used for anchorage, including floors, ceilings, and overhead structure, walls and built-in furniture. [Section 3.1 describes anchor types often used for seismic protection of contents and caveats for their use. The material should apply to most buildings. Section 3.2 is intended to describe the lab environments in the Specific Building to provide guidance for users when anchoring both to structural floors, walls, and overhead structure, and to elements often considered nonstructural such as partitions, ceilings, or built-in furniture. Section 5 is intended for specific details for anchorage of various contents and limitations on their use for the Specific Building.]

3.1 ANCHOR TYPES

3.1.1 Concrete

Anchorage to concrete slabs is achieved by drilling a hole and inserting one of a variety of bolts made for this purpose. Mechanical-type drilled-in anchors expand against the sides of the hole to provide a tight and secure fit (Figure 2). Many of these types of anchors are sensitive to installation procedure to achieve their rated value. Care must be taken to drill the right diameter and depth of hole and to tighten the nut in accordance with manufacturer's instructions. Chemical anchors are installed by filling a narrow annulus around the bolt with specially formulated epoxy (Figure 3). The epoxies are normally two-part mixes that must be combined immediately before installation. Systems are available that require hand mixing, that automatically mix the two parts in special caulking guns, and that place the two chemicals in a cartridge that is placed in the hole, broken, and mixed in place. The rated value of chemical anchors is also sensitive to installation procedure, and the type of drill used and cleaning of the hole must be strictly in accordance with manufacturer's instructions.

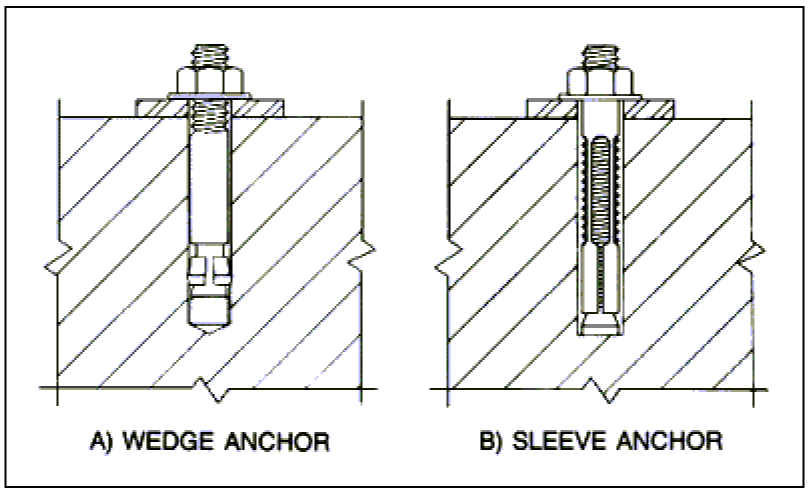
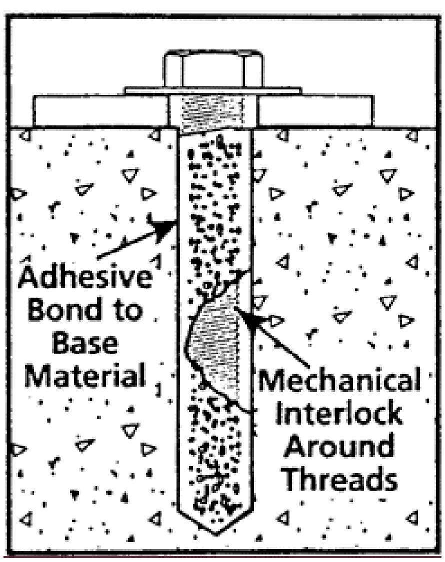


Fig. 2. Typical Expansion Anchors



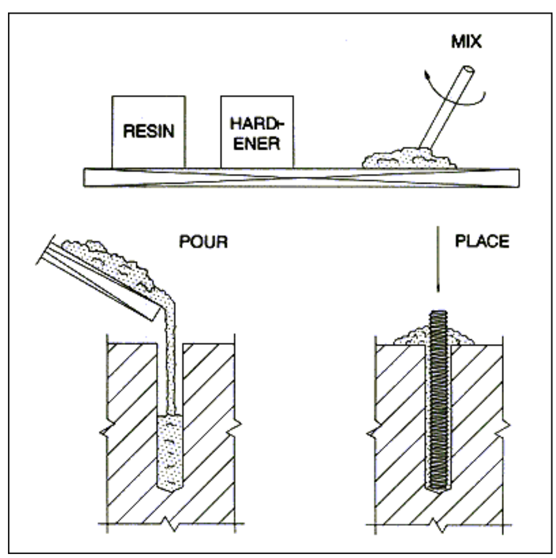


Fig. 3. Typical Chemical Anchors

3.1.2 Metal

Items are connected to sheet metal or steel with bolts, sheet metal screws, or welding. Welding requires a high level of expertise, and cumbersome equipment, and is not normally used for seismic anchorage of contents. Use of bolts requires pre-placed holes of the correct size in the items to be connected. Sheet metal screws can be installed through predrilled holes of the correct size, or, more conveniently and more reliably, can be "self-drilling." (See Figure 4.) When using self-drilling sheet metal screws, it is important to use the correct type and size for the application in accordance with manufacturers instructions.

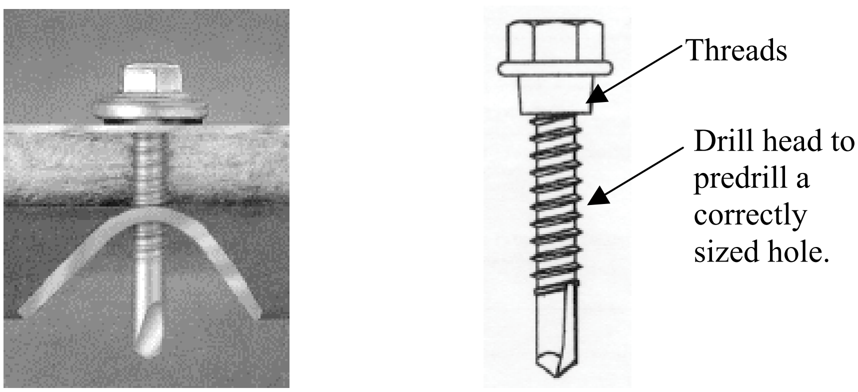


Fig. 4. Typical Self-Drilling Sheet Metal Screws

3.1.3 Wood

Wood screws are normally used to connect seismic anchorage to wood because of their high tensile load capacity and their removability. Larger wood screws may also need a pre-drilled hole to facilitate installation and to prevent splitting.

3.1.4 Adhesives

A wide variety of adhesives are available for wood, metal, and plastics, and even concrete, including glue, epoxy, and double-backed tape. Considerations for use of these products as attachment of seismic restraint are discussed below:

Nondestructive removability: In most circumstances of restraining contents, it will be desirable to remove the restraint with a limited amount of damage to surfaces of the item as well as the restraining building element. Many adhesive products will permanently damage surfaces. Instant industrial adhesives based on cyanocrylate, for example, provide extremely high strength, but are difficult to work with and are difficult to remove without damage or use of powerful solvents.

Resistance to environmental effects: The strength of some adhesives, notably epoxies, degrade when exposed to sunlight or certain chemicals, or with aging. The characteristics of the adhesive should be investigated although the information may be difficult to obtain from manufacturers.

Sensitivity to installation and overall reliability: Most adhesives are sensitive to installation procedures and the manufacturer's recommendations must be strictly followed. For example, when raised computer floors came into use, the small pipe- or tube-columns used for support were installed by gluing the column's steel base plate to the structural floor. Although in the ideal case these connections were very strong, their installation conditions varied widely, and ultimately the adhesive connection was judged unreliable to resist seismic forces, and building codes now require bolted connections.

Industrial double-backed tape (VHB™ by 3M®) is often used in commercial seismic restraints for contents because of its convenience and potential strength. Other than cleaning of surfaces, no installation instructions are normally given. However, 3M recommends applying a pressure of 15 pounds per square inch of area to gain full contact and adhesion. For light countertop devices that consist of small plates with double-backed tape, this pressure (about 25 pounds for a 1.5 inch square plate) may automatically be applied by a user. However, a 2x3 inch plate would require 90 pounds of pressure, unlikely to be applied without specific instruction particularly on a vertical surface.

Strength ratings: For nonindustrial adhesives test results are seldom available to determine reliable strengths in different circumstances of use. Although each and every seismic restraint need not be designed, the range of expected seismic loadings are known and should be considered if preapproved restraints are used. In this situation, preapproval implies that details have been designed specifically for the conditions and seismic loading of the building.

However, the load rating of any device should be carefully examined, particularly if the rating is dependent on an adhesive. Consider the case of double-backed tape for attaching flat plate elements or angles to a benchtop, cabinet wall, or to a flat surface of the component itself. Such an installation is shown in Figure 5. Loading *T*, pure tension, shown in Figure 5a, assumes the load is applied either to the exact center of the plate, or uniformly across the plate (which is seldom the case). Double-backed tapes commonly used for seismic restraints will hold 100 pounds per square inch (psi) of contact surface in such a loading case. Figure 5b shows a similar pure loading case in shear, where the load *V*, is applied almost in line with the adhesive (practically impossible to achieve), and tests have shown that the tape will also hold 100 psi for this loading case. Figure 5c shows the more common case in actual applications, where the load is applied to the edge of the plate, tending to “peel” the plate from the substrate. Loading capability of the tape for this case is considerably smaller, as little as 20 psi. Loading similar to the *T* case, but at an angle to the plate, or the *V* case, where the load may be located an inch or more above the surface of the adhesive, can also cause significant reductions to the 100 psi “rating” of the tape. Similarly, this tape is not at all intended for constant loading (a hanging weight for instance), and the load capacity drops to less than 5 pounds per square inch in that situation. Details suggested in this manual, using these kinds of adhesives take these characteristics in account.

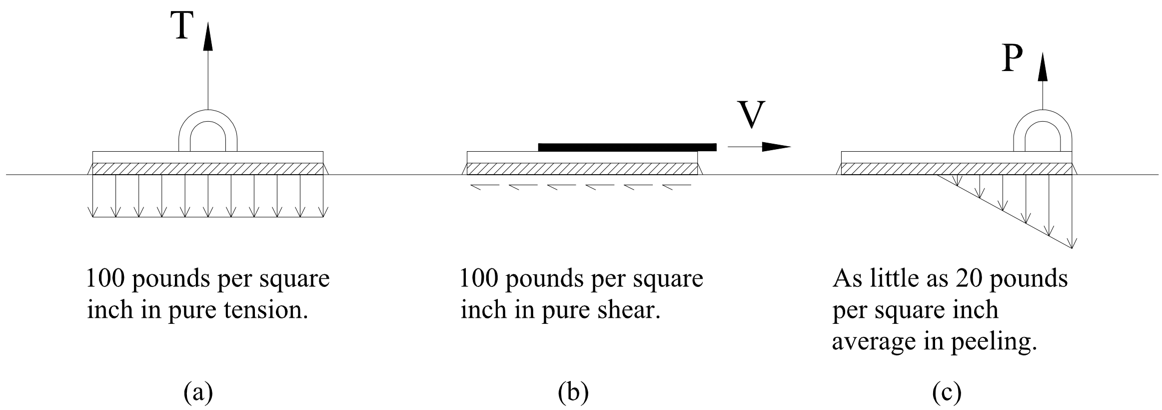


Fig. 5. Adhesive Installation and Loading

3.1.5 Various Connectors for Gypsum Wall Board or Plaster

Nonstructural walls in buildings, often called "partitions," are most often made up of steel or wood vertical "studs" spaced at one to two feet apart and covered with ½" to 1" of gypsum wall board or plaster. There are many fasteners manufactured to attach light loads to these surfaces such as plastic plugs that expand when a screw is inserted or "mollybolts" and "butterfly" anchors that open up to create a threaded nut on the inside face of the wall. These anchors are intended for pictures, light shelving, or other decorative items, are dependent on the integrity of the gypsum board or plaster for their strength, and, in general, should not be used for seismic anchorage. However, plaster surfaces, depending on the thickness of plaster and the style of lath, can be quite strong, and can be suitable for seismic anchorage for smaller loads. In instances where such uses are unavoidable and backing plates are not available, a simple testing program can establish reliable tension loads for various styles of anchors. A safety factor of 3 against pullout, established by test, is recommended.

3.2 COMPONENT ANCHORAGE LOCATIONS IN [THE SPECIFIC BUILDING]

[Typical conditions in laboratories should be described. Cross sections through typical labs and equipment halls should be included showing the typical floor and overhead structure, nonstructural walls or partitions, ceilings or other systematic overhead substructures such as utility distribution system supports, and built-in furniture such as benches and wall cabinets. It is important to identify any systems that have been provided in the building for anchorage of laboratory contents or equipment. For example, steel backing plates are sometimes placed in all partitions at certain heights, a continuous restraint channel placed along the back of lab benches, unistrut equipment supports installed on walls or partitions, or overhead steel grids placed with capacity for additional loads. It is also important to identify components that might be used for anchorage by a well-intentioned user that have limited or no capacity. Based on the potential anchoring locations shown on the typical sections, the following subsections can be used to describe capacities, limitations, or other caveats for installation of seismic anchorage of contents.]

3.2.1 Anchorage to Floors

[Thickness of floor slab, location of key reinforcement, special finishes or overlays, and limitations and caveats for anchoring to the floor structure should be described and shown in sketches. Of particular importance is placing appropriate limitations on drilling in floors of prestressed concrete construction. Tendons in such floors are prone to fracture and sudden release of energy from tensioning if hit by drilling tools.]

3.2.2 Anchors to Overhead Structure

[Similar to subsection 3.2.1, the overhead structure that will be used to connect strongbacks or suspension systems should be described. In concrete joisted floors, key reinforcement is probably located near the centerline of joist soffits that should be avoided. As mentioned above, it is important to place appropriate limitations on drilling in floors of prestressed concrete construction. In steel-framed systems, guidance on attachment to steel beams, or recommendations to avoid such attachments should be given. For example, mechanical and electrical systems are sometimes hung from steel beams with steel clips that slip over the edges of flanges and are held in place with spring friction or set screws. Such clips have an unreliable pull-off capacity and should not be used for seismic anchorage. Removal of fireproofing for attachment of anchorage to steel beams is also an issue that should be addressed.]

[In general, anchorage to suspended ceilings should be avoided. It is also not recommended to attach anything to the mechanical, electrical, or piping utilities in the building. However, pipe trapezes normally may be used to support light loads (less than 20 lbs), or more, if it is determined that the trapezes have excess capacity.]

[If a systematic suspended grid system is provided in labs for support of utilities or lab experiments, capacities and limitations should be determined and specified.]

3.2.3 Anchors to Concrete Walls or Columns

[Conditions and limitations should be described similar to subsection 3.2.1.]

3.2.4 Anchors to Steel Columns or Braces

[Conditions and limitations should be described similar to subsection 3.2.1.]

3.2.5 Anchors to Partition Walls

Typical partition walls in most laboratory buildings are constructed with metal studs. A metal stud wall partition consists of metal tracks at the top and bottom of the wall, metal studs, and blocking or backing plates. The top and bottom tracks are continuous horizontal channels bolted to the concrete slab above and the concrete floor below at specific intervals. The studs run vertically between the top and bottom tracks at a nominal spacing and are positively attached to the bottom track with sheet metal screws. The studs may be similarly attached to the top track, providing a larger lateral capacity, or they may be unattached to allow for vertical differential floor deflections or wind and seismic lateral drift of the building. Metal stud walls are typically covered with gypsum board or plaster. See Figure 6.

[The stud sizes and partition types used in the Specific Building should be described. The following or similar text can be used.]

Nonstructural walls are steel stud partitions consisting of [specify] spaced generally at 16" on center spanning vertically between floors. Continuous channel-shaped steel tracks support the studs top and bottom. The studs are positively attached to the floor track with screws and are only laterally restrained at the top track to allow for differential movement between floors [verify]. Connections to steel stud walls must be attached either directly to a stud or through a backing bar. Connection to the studs is limited by location and surface area. Normal backing bars are steel plates or channels installed at the time of original construction under the gypsum board spanning between studs. The only internal backing bars installed in this building during construction were located at known anchorage locations such as built-in cabinetry or shelving [verify]. Backing bars also can be installed when construction is complete, but wall finishes must be locally removed and replaced in a significant area of wall. When anchoring contents in locations with no internal backing bars, it is more common to add an external backing bar on the surface of the wall consisting of a unistrut element extending across three or more studs and attached directly to them with self-tapping screws. The elements of a steel stud wall are shown in Figure 6.

It is difficult to anchor most floor-supported equipment to the floor because it is not designed for such anchorage (exceptions include some tanks and other equipment that have legs and mounting holes suitable for bolting to the floor). The attachment itself may damage the equipment, and anchorage loads during an earthquake can damage the frame, the mechanisms, or the contents. The partitions in laboratories are conveniently located to provide restraint not only for floor-mounted equipment and moveable tables and racks, but also for heavier bench- and table-mounted equipment. However, the typical stud size and gauge used in this building may limit the use of partitions as a source of seismic restraint, particularly in the upper floors where seismic loads are highest. These limits are indicated in the seismic anchorage details recommended for the building in Section 5. In many cases, the installation of new vertically spanning structural elements, called "strongbacks," may be necessary to provide seismic restraint for heavy and tall floor-mounted equipment such as refrigerators, freezers, and incubators.

[In older buildings partitions may be constructed of trussed steel studs with little or no flange area for attachment of cabinets, equipment, or external backing bars. Often these studs are combined with metal lath and plaster. Special details will have to be developed in this situation to provide for secure attachments. Older partitions may also be of unreinforced masonry, such as hollow clay tile of various thickness and configuration. The capacity of such partitions to support seismic anchorage must be established for each building by an engineer.]

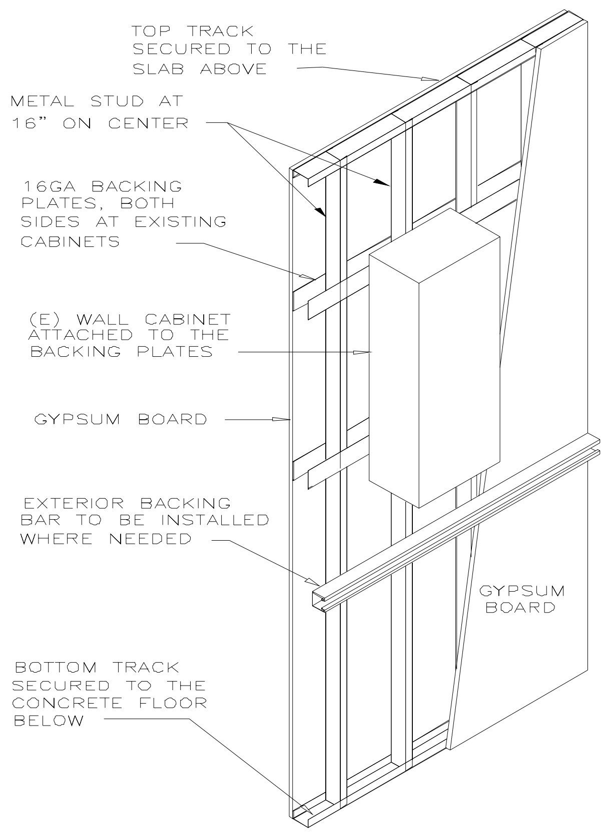


Fig. 6. Typical Metal Stud Wall

3.2.6 Anchors to Built-In (Anchored) Lab Furniture

[A common component of a laboratory is the island bench. It typically consists of back-to-back benches located at the center of the lab space, with shelving or cabinets suspended above the working surface by steel standards either cantilevering from the base cabinets or spanning from floor to floor. A similar single benchtop and cabinet arrangement is often placed against a structural wall or partition. Sketches of typical bench furniture should be included.]

[If this furniture is part of the original construction, it is invariably anchored to the structure and, in past earthquakes, has not shown a tendency to fail its anchorage and move around. This furniture can be, in turn, used as a base to restrain benchtop equipment or the contents of shelving and cabinets. The support standards for shelving and cabinetry over a central bench, especially the cantilever-type can be vulnerable to damage and should be analyzed for their ability to provide lateral support for contents other than light storage or for serving as an anchor point for benchtop equipment. If furniture has been moved around or brought in as part of a remodel, its anchorage should be investigated, and its capabilities to restrain itself or to serve as an anchor point for other contents should be noted in this manual.]

[Floor-mounted wall cabinets or shelves should be investigated to determine anchorage to the wall and security of shelf mounts. If such furniture is anchored and stable, it can also be used to anchor light objects. Freestanding storage cabinets and/or file cabinets, even if seismically restrained for their contents should not be used as an anchor point for other objects unless an analysis of the specific conditions is run.]

4 Guidelines for Providing Seismic Protection

[The information given in this section was developed as part of the research documented in Comerio, 2003. It should be applicable to most labs.]

Examples of items considered "user-supplied" contents are given in the Introduction. Protection of these items against damage caused by earthquake shaking, even though such shaking may be rare, may be desirable to avoid the following types of losses:

- Life safety of occupants: Life safety can be threatened by heavy objects falling or tipping directly onto occupants, or by sliding or tipping into a position that blocks egress from a work area. Life safety risks can also be created in a laboratory by release of hazardous materials, either directly by broken containment, or by two or more released materials combining to create a hazardous substance.
- Protection of data, other results of experiments, or ongoing experiments: Data or other results of experiments may be one of a kind, difficult to "back up," or take years to replace. Ongoing experiments may represent investment of enormous time and/or resources. Even if protected from direct physical damage due to shaking, interruption of certain utilities or supplies could damage or ruin future results.
- Protection of valuable or hard-to-get equipment: Specialized equipment in labs often represents a large investment that should be protected, or may be difficult or time consuming to replace, or both.

The obvious response to the threat of damage from earthquakes is to provide restraint for all contents in the laboratory environment. The two primary reasons why this may not always be necessary or appropriate are cost and the potential effects of seismic restraint on the function of the element or the lab as a whole. Costs of providing seismic protection to the complete contents of typical labs could cost as much as $20 per square foot. Restraining a portable benchtop instrument with a quick-release system to facilitate changes in location may affect efficiency and is likely to not always be implemented by staff. Providing a docking station for wheeled equipment may take up space and inhibit movement in the room. In addition, in areas of lower seismicity, serious damage is far less likely and only the highest priority items may warrant protection.

It is therefore prudent to prioritize contents with respect to their potential to cause losses in the three categories discussed above. It is possible to develop evaluation systems that will result in a single priority rating for each element based on concerns for all three types of losses, but such systems are complex and require many qualitative judgements.

Rather than complex evaluation systems that combine the potential for each type of loss, it is suggested that a simple linear system be used that considers the risk presented by each element in each category in turn. It is recommended that *Life Safety* issues be considered first, then *Importance*, and *Dollar Value* third, although any order could be used. Any element that is judged high priority in the first category need not be considered for the second and third categories, and so on.

Considerable judgment will be required by the users to place the contents of their lab into one or more priority levels, but the systematic approach suggested will greatly assist the process. Some users may conclude that all the contents of their lab should be provided with seismic restraint. Studies of five labs at UC Berkeley concluded that the cost of providing complete seismic restraint ranged between $10 and $16 per square foot of lab. It is recommended that $15 per square foot be used for a budget figure. Based on subsets of priorities developed from consideration of potential losses discussed above, costs of providing seismic restraint can be estimated as a proportion of this $15 per square foot figure (e.g., if approximately 50% of all items will be restrained, assume it will cost $7.50 per square foot). The costs of providing various levels of seismic restraint must be weighed against the potential damages and losses to arrive at an appropriate scope or work for each situation.

Additional guidance for setting priorities within each category is given below.

4.1 LIFE SAFETY

"Life safety" is a well-known phrase dealing in general with the health and welfare of people. In earthquake engineering, an acceptable state of life safety is somewhat undefined but is normally interpreted as the prevention of deaths—and possibly life-threatening injuries—but certainly not prevention of all injuries. In other words, considering the rarity of seismic events, providing an injury-free environment is not considered cost-beneficial—if possible at all. There is little data from which a direct relationship can be made between seismic restraint of laboratory contents and seismic protection intended by the building code with respect to life safety. The guidelines in Table 3 are aimed at prevention of serious injury as opposed to life-threatening injury, although the distinction may be subtle. Being struck by a 20-pound object falling from 5 feet or more from the floor clearly could cause a death, but is more likely to cause a serious injury. The limit of 20 pounds and the height of 5 feet are both arbitrary limits and are taken from the State of California's code governing hospital construction. Similarly, the size and weight of unrestrained floor-mounted equipment that could become dangerous during earthquake shaking is unknown. 400 pounds is often used, but the source and validity of this weight is questionable. 200 pounds is suggested in this manual. Lastly, building codes and other standards sometimes consider a permanent connection to utility systems (gas, water, and power.) as a trigger for seismic protection, presumably due to the potential secondary hazard from breaking such a connection. The guidelines in Table 3 therefore should be considered judgmental and are given for general guidance.

There is virtually no guidance available for limits on the sliding of large and heavy objects. Sliding, presumably with considerable friction between the device and the floor, is differentiated from rolling, such as the case with a heavy, wheeled cart or tank. Once set in motion from impact with a wall or lab bench, the wheeled device has little to slow it down and could become a dangerous projectile. On the other hand, friction at the base of the nonwheeled object will quickly slow and stop the movement and additional movement will come only from additional seismic floor motions. If overturning is unlikely and prevention of sliding is not required to prevent breakage of connected utilities, the level of risk to life safety is unknown, but probably small. The device could pin an occupant against a wall or other fixed object and could even create crushing injuries, or, could gradually slide into a position to block an exit. These events are unlikely but possible. The benefits of restraint of such elements must be weighed against the "costs," including the cost of providing restraint itself, potential disruption of operations, and potential increased damage to the contents of the device due to transfer and possible amplification of floor motion from the anchorage.

Any items that are determined to present a *Life Safety* risk, and will be restrained for that reason, can be set aside from evaluation for *Importance* or *Dollar Value*.

Table 3. Life Safety Risk Levels

Of Concern	Intermediate Concern	Low Concern
• Potential spill of hazardous substance or chemical combination into hazardous substance • Item weighing 20 lbs or more stored or mounted 5 ft or more above floor • Countertop equipment permanently connected (hard wired or plumbed) to building or laboratory utility systems • Freestanding storage racks, or cabinets over 5 ft tall • Floor mounted equipment weighing more than 200 lbs, over 5 ft tall, or with width less than 2/3 of height • Wheeled equipment, tanks, or racks normally weighing over 200 lbs (including contents): – when over 5 ft tall or with width less than 2/3 of the height • Other items judged by users to be dangerous to occupants in earthquake shaking	• Countertop items weighing 50 lbs or more • Unrestrained storage cabinets or racks less than 5 ft tall and with width less than 2/3 of height • Wheeled equipment, tanks, or racks normally weighing over 200 lbs (including contents): – When less than 5 ft and with width greater than 2/3 of height (could be tethered when not in use) • Items on wheels weighing less than 200 lbs	• All items not fitting, or similar to, other categories

4.2 IMPORTANCE

Importance in a lab environment is not always proportional to size and weight. The importance of an item with respect to its value as data, results of experiments, or in saving, protecting, or maintaining data, other results of experiments, or ongoing experiments can be judged only in each lab. Importance can be assigned in any number of priorities, but complexity of the rating system is directly proportional to the number of categories. One lab decided that this rating could be simplified into only two characterizations: “important” or “not important.” Assuming that important items will be seismically protected, these items can be set aside from evaluation for *Life Safety or Dollar Value.* See Table 4 for suggestions for parameters to determine relative importance.

4.3 DOLLAR VALUE

Similar to *Importance*, the threshold for concern about dollar losses from damaged equipment or other items in the laboratory can be set only by the individual lab or institution. The time that replacement would take should also be considered, although this issue may also be considered under *Importance*. Since many fairly common computers, microscopes, and similar equipment are valued at $5000 or less, this figure could be used to describe the lowest priority category (assuming *Importance* is judged independently). An upper value, for example, of $100,000 or $250,000, to which the highest priority is assigned, should also be set. Setting such high and low figures creates three categories for priority of seismic protection.

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 non or very little)
Loss of research benefits (income, salutary applications)
Related hazards that may occasion long clean-up periods (chemicals, biohazard)

5 Recommended Anchorage Details

[This section introduces the details of anchorage and restraint developed for this building.]

This section describes detailed anchorage and restraint for most contents of labs in the [Specific Building]. Lab users can install some of the restraint details, but some details will require installation by experienced trades-persons that are part of the building staff, the university staff, or are employed by private contractors. Very specialized lab equipment or experimental setups may be heavier, larger, or of a configuration that do not fit into the categories covered. Seismic restraint for these items must be custom-designed by a civil or structural engineer experienced in earthquake engineering.

Contrary to anchorage of most mechanical and electric building systems equipment, it is not generally recommended to restrain owner-furnished contents by bolting to the floor [verify]. Exceptions include tanks with mounting legs, certain cylinder restraint products that are designed with plates and bolt holes for floor mounting, and the base connection of strongbacks. Most floor-supported equipment is mounted on wheels, leveling legs, or a framework not designed to anchor the weight of the equipment for earthquake loads. Unless the manufacturer certifies the base of such equipment for such anchorage, it is recommended to provide restraint from existing partitions or to install steel strongbacks. In addition, it is desirable to minimize drilling holes into the floor structure which both compromises the moisture proofness of the floor, may form a trip hazard, and will be hard to satisfactorily repair when no longer needed.

[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 restrain. The most flexible and least obtrusive restraint details can be developed if the backing partition wall can be used for support. In new buildings, special structural elements designed to provide this restraint, possibly integrated with surrounding walls, should be considered in locations where this type of equipment is expected. One such system that will prevent overturning or sliding by overhead “hangers” is shown in Figure 8. In buildings where seismic loadings don’t exceed 0.5W, partitions may be able to provide such restraint. However, typical interior backing bars, even if installed, are not detailed to distribute loads from a single heavily loaded stud to adjacent studs, and exterior, continuous backing bars (e.g., unistrut) still may be necessary for this purpose.]

[It is recommended that attachment to most equipment that has sheet metal housing be accomplished with double-backed adhesive tape, (for example, 3M’s VHB). Loading on such pads should be kept as nearly as possible to pure shear and should be limited to about 40 pounds per square inch of adhesive material. A variety of such attachments can be accomplished depending on conditions and how frequently the element to be anchored must be used. For elements that have handles (such as carts) or legs (such as racks), straps can be used effectively. It is suggested herein that adequate restraint can be accomplished for most equipment with one strap each side located at about 2/3 of the height. Although this configuration does not completely restrain the base of the equipment, little movement is possible due to geometric confinement. Two straps per side can also be used at about 1/3 and 2/3 of the height.]

[Anchorage details to floors can be developed but more violent shaking of the equipment and contents should be expected. In addition, large anchorage forces could damage the base of equipment. Other, energy-absorbing details can also be developed to provide restraint against large movements while minimizing shaking of equipment and contents. Such details may require tests to ensure effectiveness.]

[Similar restraint methods can be used for countertop equipment using the back partition wall, or the counter itself, as a restraint point. Other support points, such as vertical stanchions for island shelving should be checked carefully for adequacy before use.]

[The following details should be customized for the conditions in the building such as type of overhead structure, type and size of partitions, and bench/shelf construction. Maximum recommended loads should be placed on each detail.]

[Many of the sample details were originally developed as part of a survey of labs at UC Berkeley (Comerio and Stallmeyer, 2001). In that study components and restraint details were grouped into five categories: tanks (T), heavy equipment (H), Benchtop equipment (B), shelves (S), and unique setups (U). Prefixes T, H, B, and S have been reused here, but are obviously arbitrary.

General Notes

1. Intent of Basic Restraint: [Recommended to include]
   The details shown are intended to prevent excessive movement of the various elements during strong earthquake motion. This restraint is expected to protect occupants from injury and significantly reduce the incidence of functional damage to the component.

   A. Protection of Functionality: In addition to the Basic Restraint, continued functionality of restrained components following an earthquake is primarily dependent on the susceptibility of the component to damage from shocks transmitted through the restraint or, for smaller benchtop equipment, from potential overturning. Functionality may also depend on continued utility services such as water, electricity, or gases that are not addressed by these details.

   B. Protection of Contents: In addition to the Basic Restraint, the contents of shelving, racks, refrigerator/freezers, incubators, etc., must be protected from falling from storage location.

   1) Shelving: Typical shelving is provided with perimeter lips approximately 1 1/2" high. For sensitive contents, or for contents with heights of 3" or more, lips of one half the height of the contents should be installed. For further protection, protective racks or trays separating individual contents should be installed on shelves.

   2) Refrigerator/Freezer: These components should be provided with a positive door latch. For further protection, protective trays separating individual contents should be used on interior storage racks.

2. Materials, Fabrication, and Installation: [Customize for specific application. Example shown.]

   A. Prefabricated restraint devices: Devices noted "Worksafe" are references to Worksafe Industries products. Alternate manufacturers of similar products shall certify equality of load capacity.

   B. Slotted channels: Devices noted "Unistrut" are references to Unistrut Corporation products. Alternative manufacturers of identical products are available.

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: NOTES	SCALE: NO SCALE SHEET: D1

C. Fabricated Steel components (structural steel tubes and connectors): Fabrications shall comply with the Code of Standard Practice for Steel Buildings and Bridges.

1) Materials:

i Steel Plates, Shapes, and Bars: ASTM A 36

ii Steel Tubing: ASTM A 500

iii Steel Pipe: ASTM A53

2) Fabrication:

i All welders shall have passed AWS (AWS D 1.1, Structural Welding Code) qualification tests for the welding processes involved and, if pertinent, have undergone recertification.

ii Shear and punch metals cleanly and accurately. Remove burrs.

iii Ease exposed edges to a radius of approximately 1/32 inch.

iv Shop Primer: Fast-curing, lead- and chromate-free, universal modified-alkyd primer complying with performance requirements in FS TT-P 664; selected for good resistance to normal atmospheric corrosion and ability to provide a sound foundation for field-applied topcoats.

D. Fasteners:

1) Bolts and Nuts: Regular hexagon-head bolts, ASTM A 307, Grade A, with hex nuts, ASTM A 563.

2) Self-drilling screws for metal-to-metal or wood-to-metal: ITW Buildex TEK Screws or equal.

3) Lag Bolts: ASME B18.2.1

4) Wood Screws: Flat head, carbon steel, ASME B 18.22.1

5) Expansion Anchors to Concrete: Anchors with current ICBO/ICC approval for use under conditions called for (diameter, embedment, through metal deck, etc.). Install in strict conformance with approval requirements and manufacturer's recommendations. Twenty-five percent of anchors shall be torque tested in accordance with approval requirements.

6) Epoxy Anchors: Anchors with current ICBO/ICC approval for use under conditions called for. Select to minimize chemical off-gassing. Confirm with occupants that use is acceptable prior to installation. Do not use in overhead configuration. Install in strict conformance with approval requirements and manufacturer's recommendations.

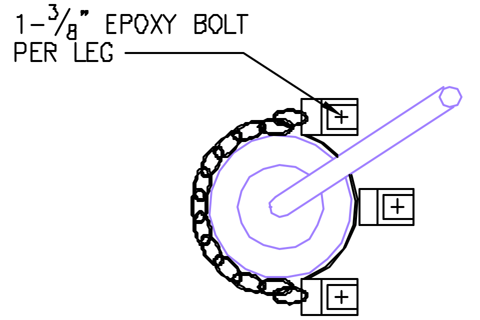
7) Adhesive double-backed tape: 3M® VHB™ (does not gain full strength for 72 hours)

i For use on plates less than or equal to 4 square inches: Clean surfaces with isopropyl alcohol/water or heptane. Remove protective sheet immediately before applying. Apply with as much pressure as possible and hold to allow full contact and adhesion.

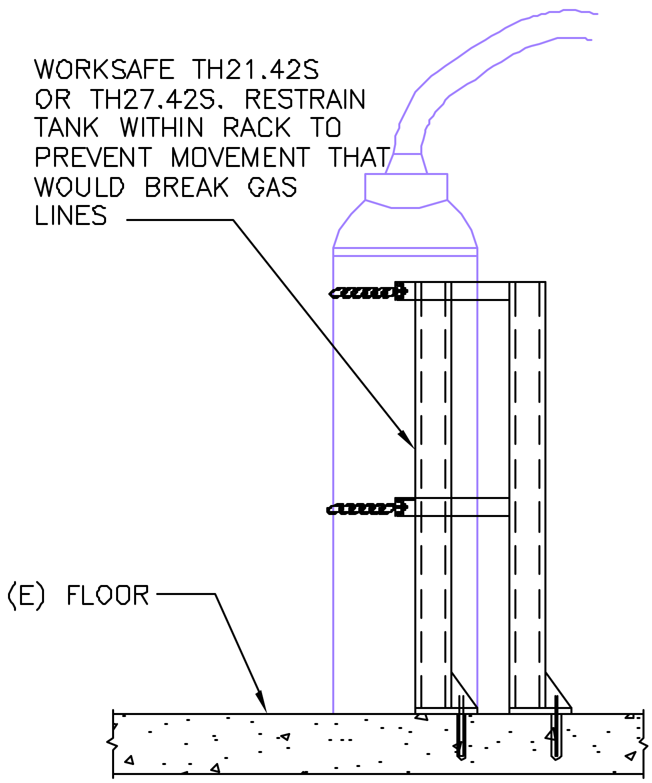
ii For use on plates greater than 4 square inches: Plate shall have one pad factory applied. An identical pad shall be field applied to the target surface. After cleaning the surface, the field pad shall be applied incrementally while applying pressure with a metal or wood squeegee slightly wider than the pad. The entire surface will then be rolled with a 1" wide wood roller with firm pressure. The strap plate shall then be applied with as much pressure on the two pads as possible applied with a roller over the strap plate.

E. Exterior backing bars: Slotted channel members as called for in details, directly connected to the flanges of three metal studs minimum. The end of the slotted channel shall be extended 1" minimum and 6" maximum beyond the centerline of the outside stud. Exterior backing bars may be installed over 4 or more studs to provide a wall attachment location for various equipment. Stud locations shall be determined with a metal detector or probing. Connection of backing bars for use with seismic details shown here to gypsum board, plaster, or other wall surface material is not permitted without design by Engineer.

[NOTES FOR SPECIFIC BUILDING
CONFIRM APPLICABILITY OF DETAIL
FOR ATTACHMENT TO FLOOR.]



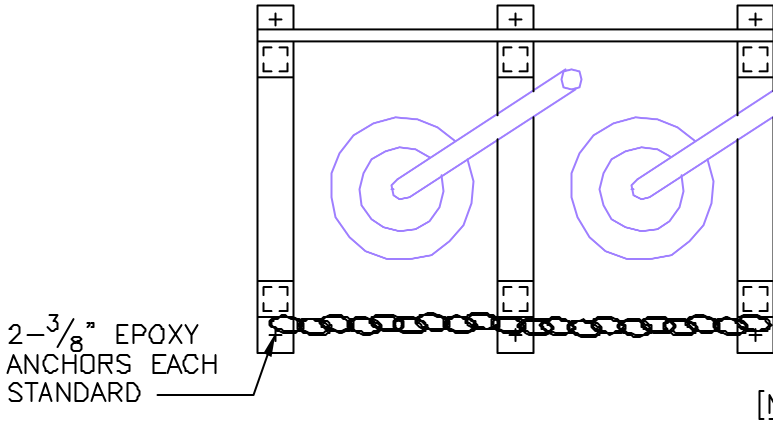
TOP VIEW



DETAIL T1

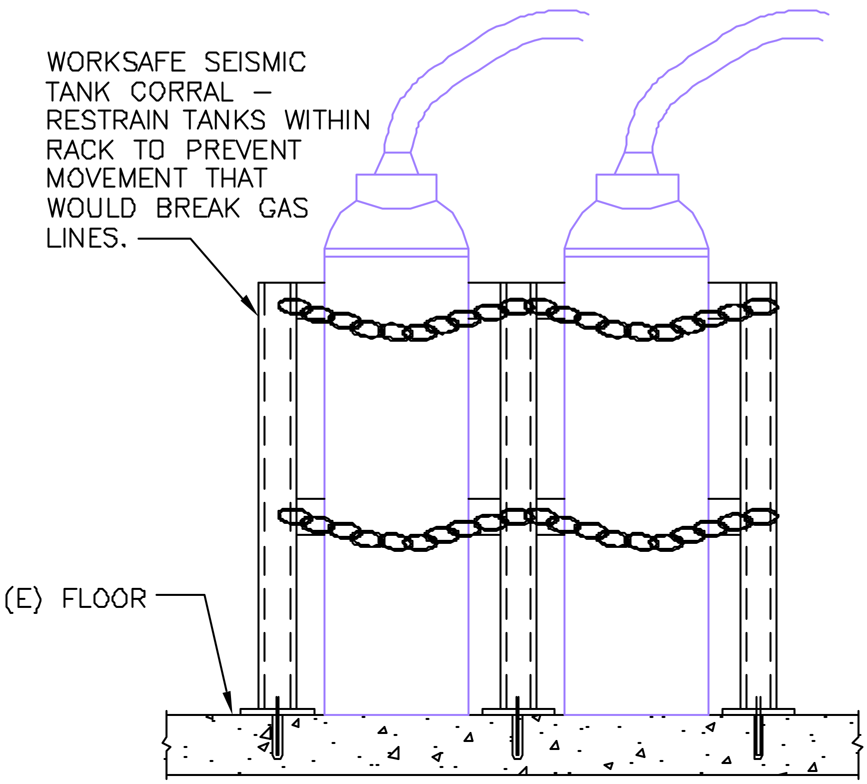
GAS CYLINDER RESTRAINT
(FREESTANDING – SINGLE CYLINDER)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D4**



TOP VIEW

[NOTES FOR SPECIFIC BUILDING
CONFIRM APPLICABILITY OF DETAIL
FOR ATTACHMENT TO FLOOR.]

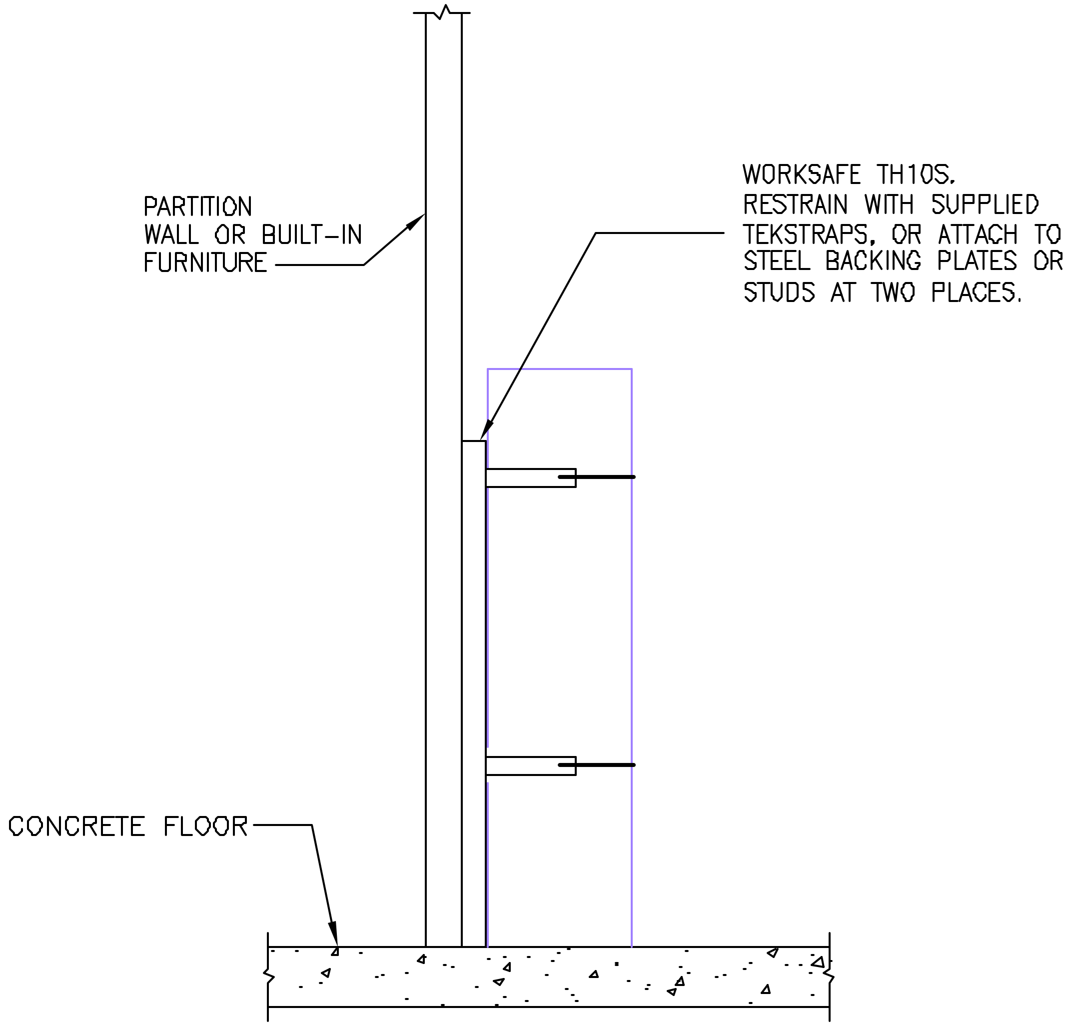


DETAIL T2

GAS CYLINDER CORRAL
(FREESTANDING – MULTIPLE CYLINDERS)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE
		D5

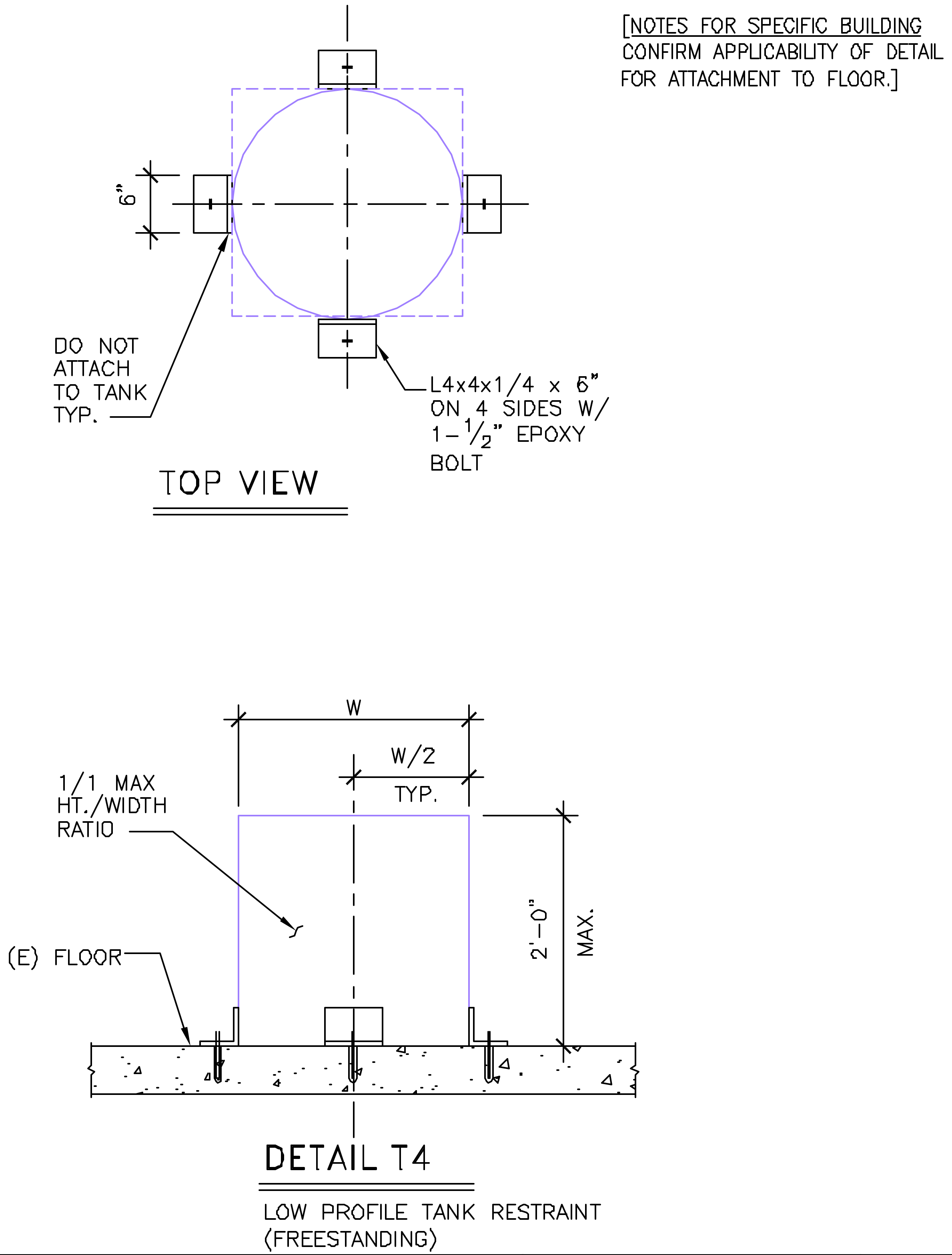
[NOTES FOR SPECIFIC BUILDING
CONFIRM APPLICABILITY OF DETAIL
FOR ATTACHMENT TO FLOOR.]



INDIVIDUAL TANKS
10–12" DIAMETER

DETAIL T3

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE **D6**

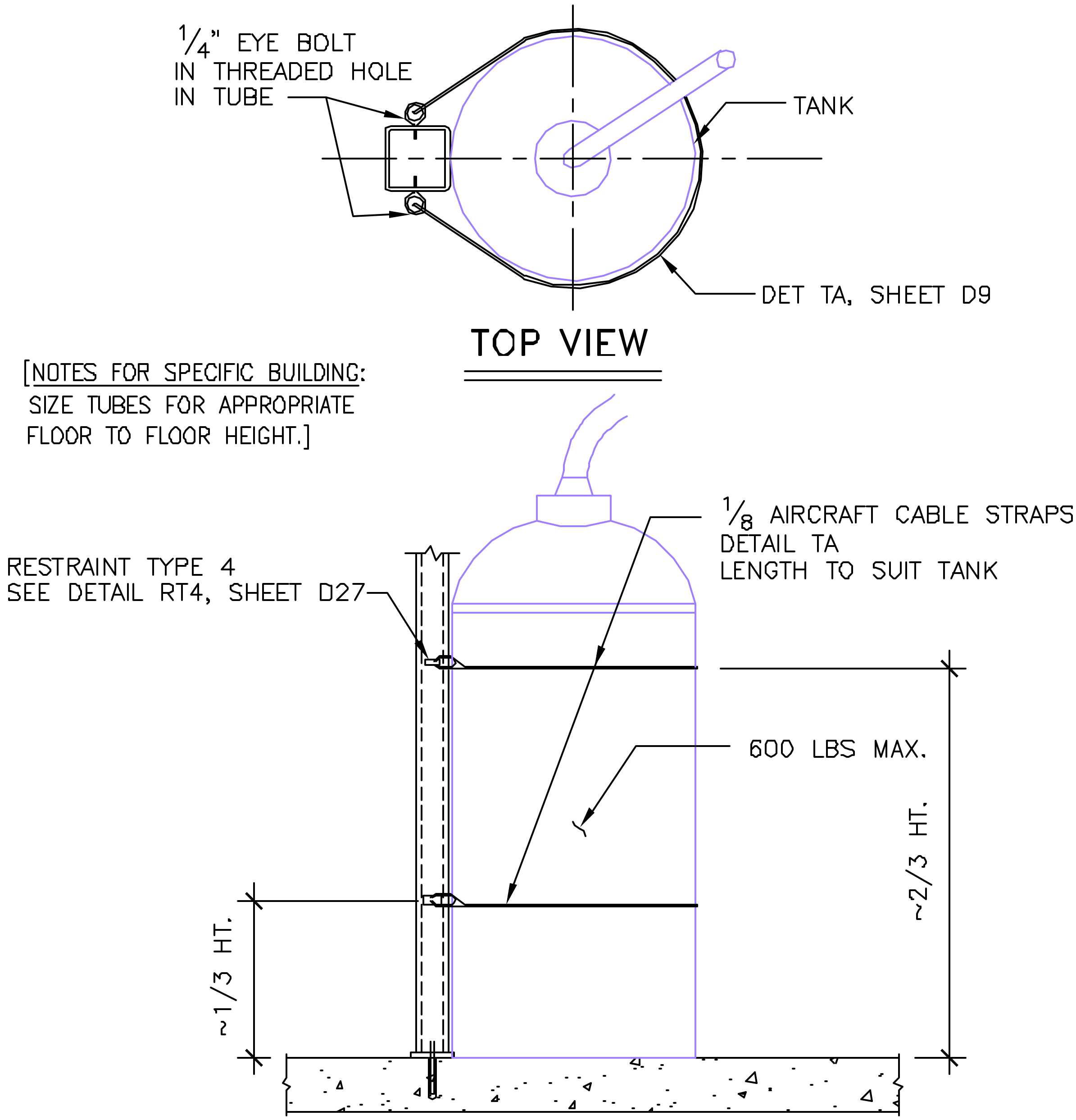


IMPLEMENTATION MANUAL FOR THE
SEISMIC PROTECTION OF LABORATORY CONTENTS
FORMAT FOR SPECIFIC BUILDING

TITLE: **TYPICAL TANK RESTRAINTS**

SCALE: NO SCALE

SHEET: **D7**

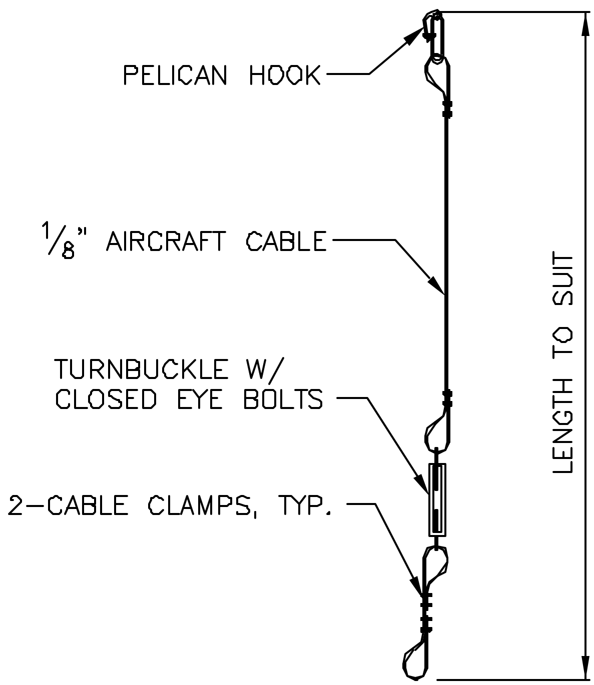


NOTE: IF TANK HAS BUILT-IN BASE OR LEGS, IT CAN BE
BOLTED TO FLOOR W/ 3 MIN. 1/2" EPOXY BOLTS.

DETAIL T5

LARGE TANK RESTRAINT
(FREESTANDING)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D8**



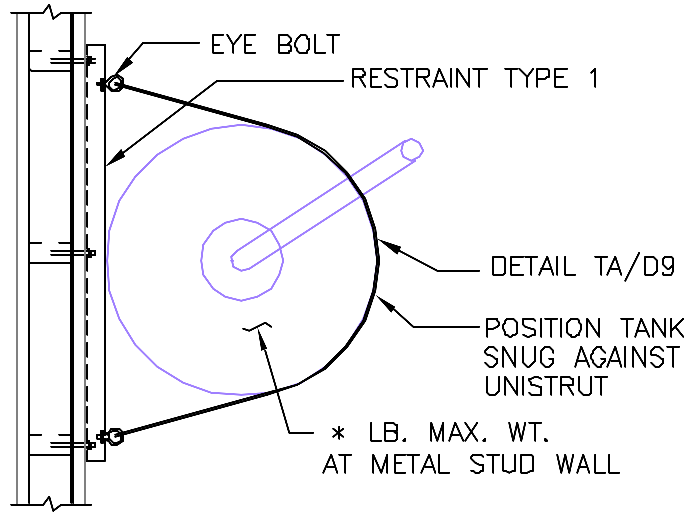
NOTE: IF LENGTH IS MADE SUCH THAT CABLE IS TIGHT WHEN PELICAN HOOK IS ENGAGED, TURNBUCKLE CAN BE ELIMINATED

AIRCRAFT CABLE STRAP

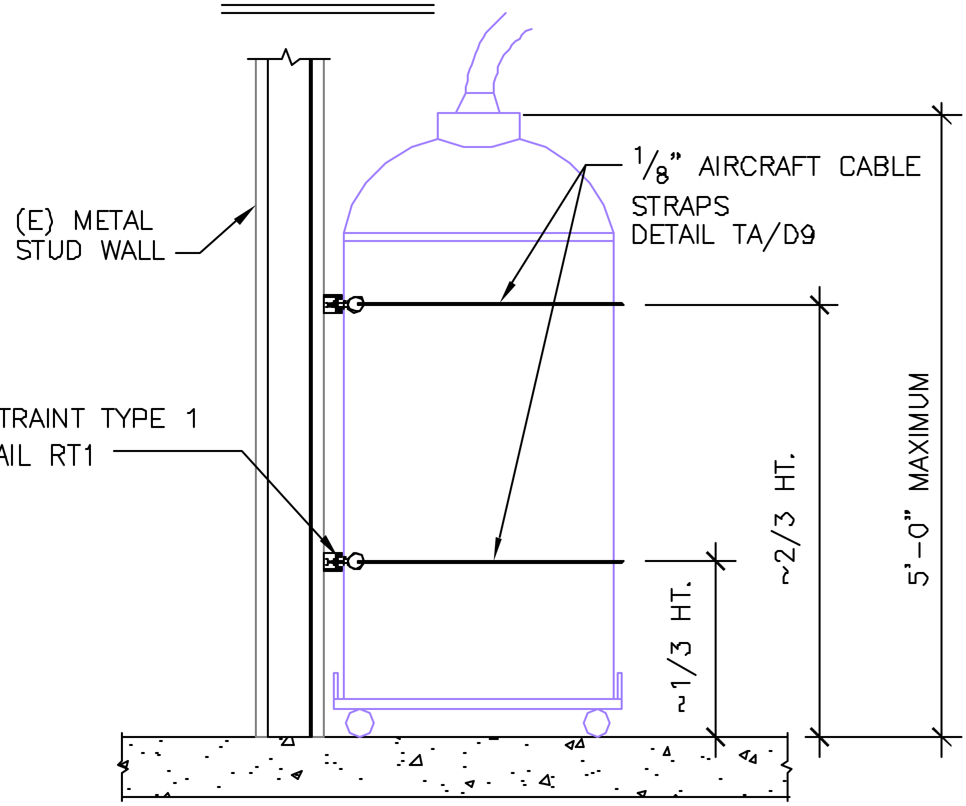
DETAIL TA

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D9**

[NOTES FOR SPECIFIC BUILDING
DETERMINE MAXIMUM WEIGHT *
OR OTHER LIMITATIONS FOR
THIS DETAIL BASED ON CAPACITY
OF STUDS OR TOP TRACK.]



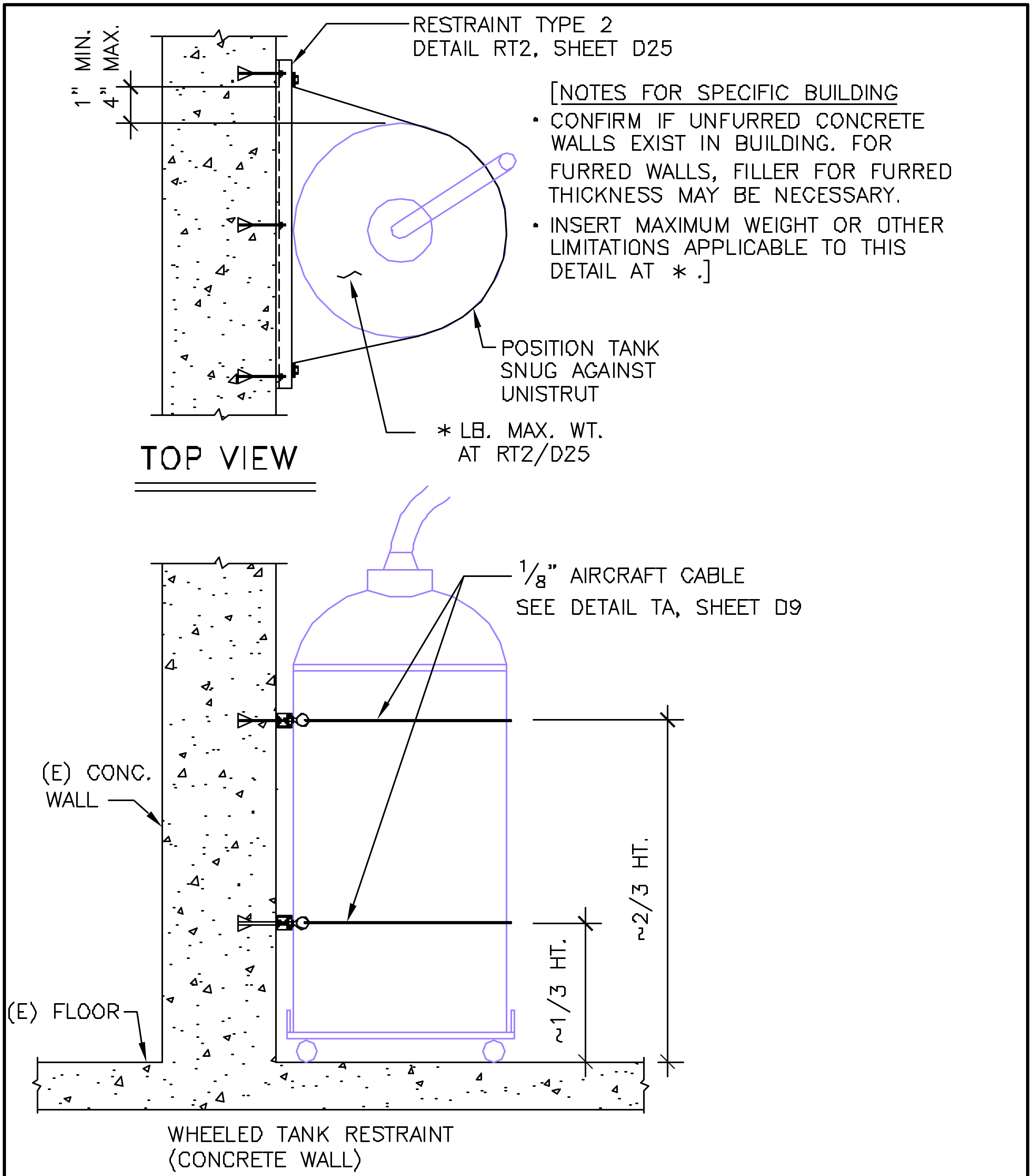
TOP VIEW



WHEELED TANK RESTRAINT
(METAL STUD WALL)

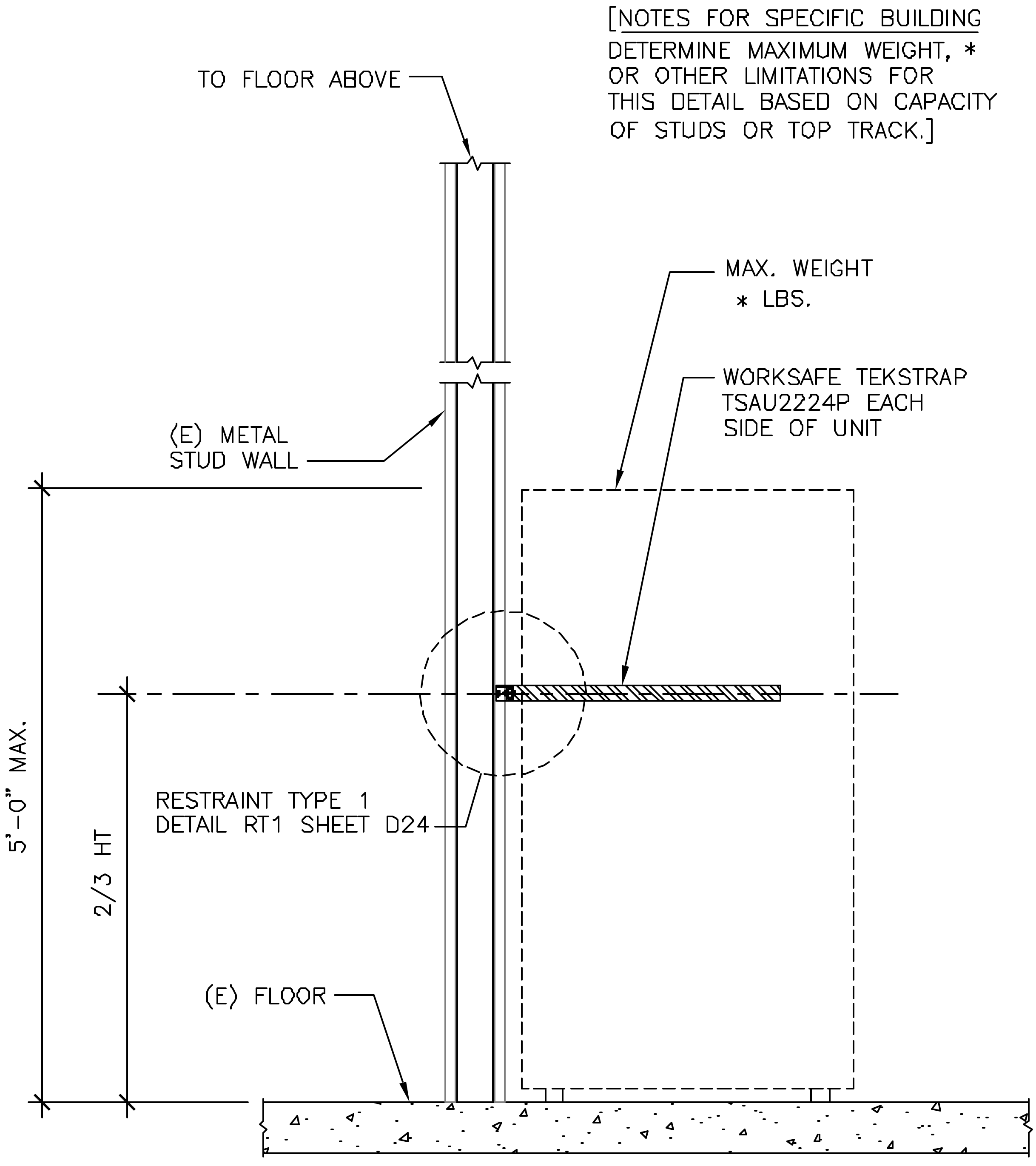
DETAIL T6a

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D10**



DETAIL T6b

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D11**

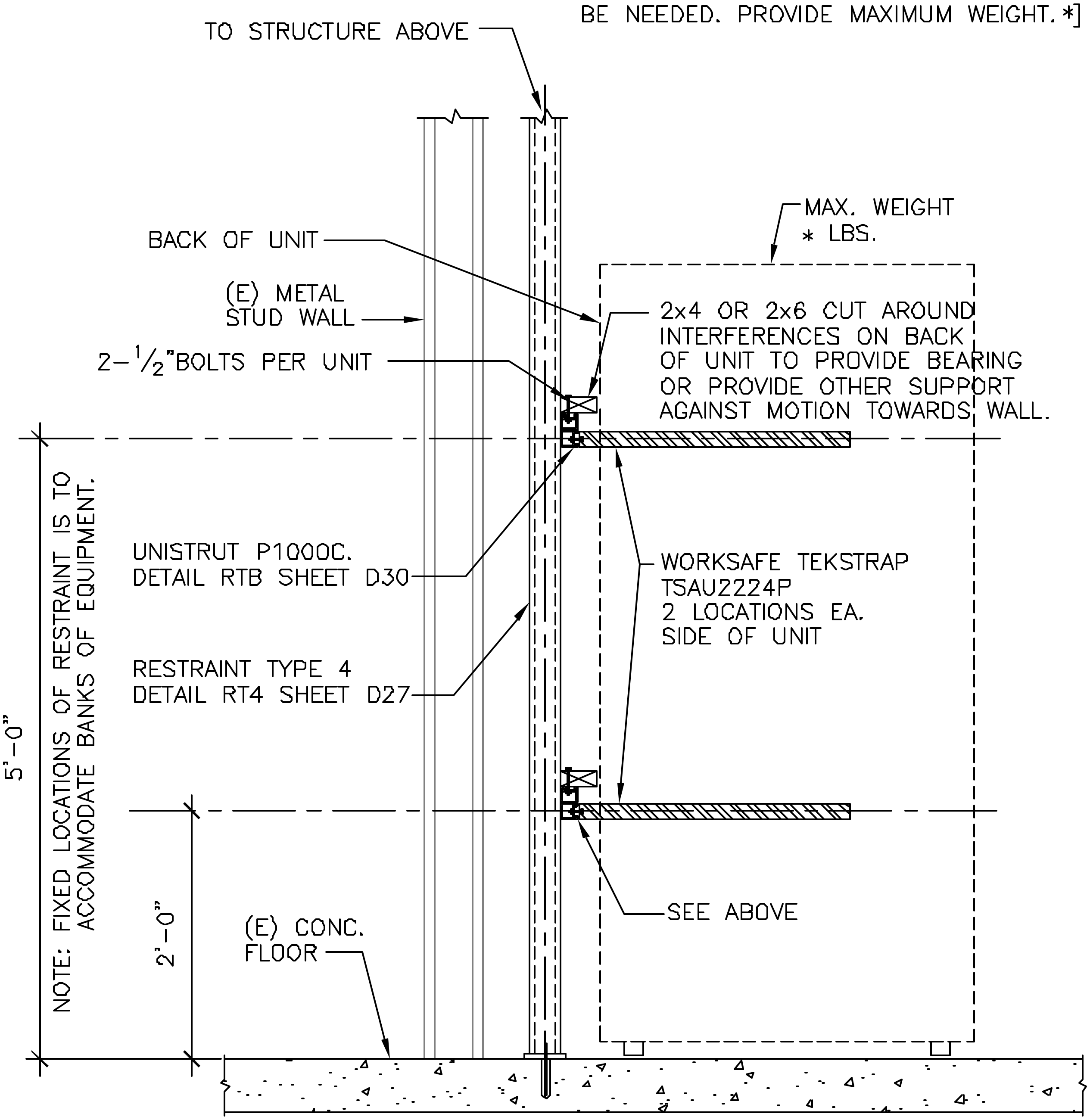


DETAIL H1

RESIDENTIAL STYLE REFRIGERATOR

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL LARGE EQUIPMENT RESTRAINTS**	SCALE: NO SCALE SHEET: **D12**

[NOTES FOR SPECIFIC BUILDING
CONFIRM THAT STUD WALL SYSTEM
IS INADEQUATE TO RESTRAIN LARGE
EQUIPMENT. THIS DETAIL MAY NOT
BE NEEDED. PROVIDE MAXIMUM WEIGHT.*]

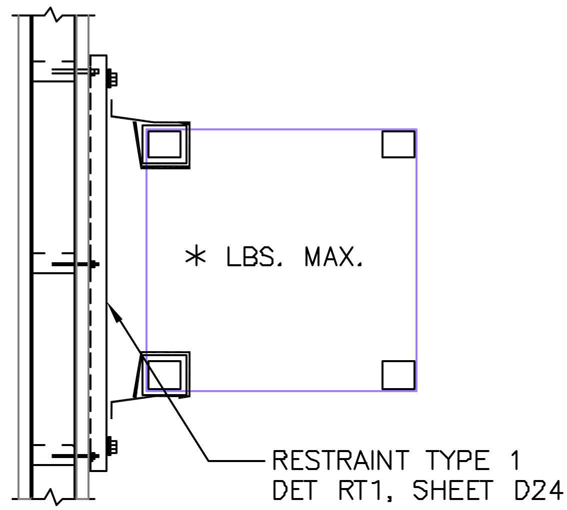


DETAIL H2

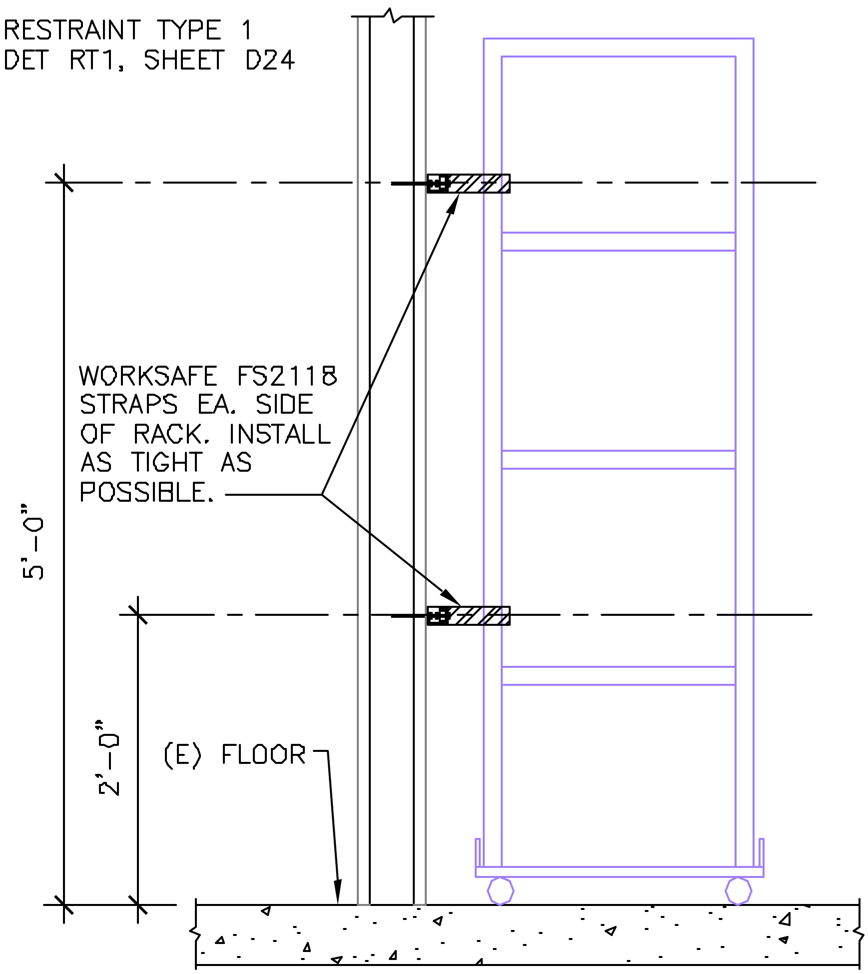
LARGE REFRIGERATOR/FREEZER/INCUBATORS

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL LARGE EQUIPMENT RESTRAINTS**	SCALE: NO SCALE SHEET: **D13**

[NOTES FOR SPECIFIC BUILDING
CONFIRM THAT STUD SYSTEM IS ADEQUATE TO SUPPORT THIS DETAIL. PROVIDE MAX. WT. *]



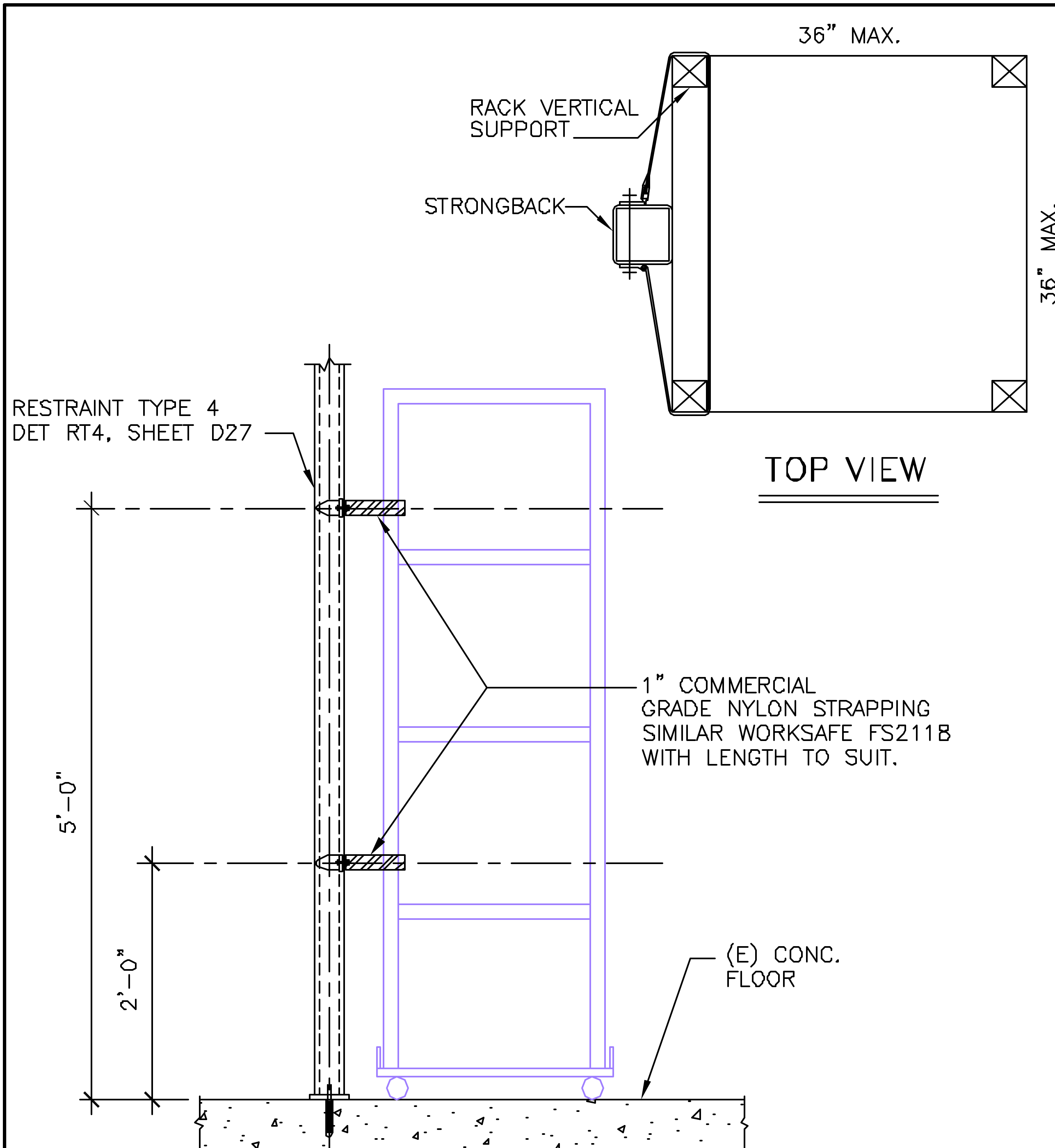
TOP VIEW



DETAIL H3a

WHEELED RACK RESTRAINT
(ADJACENT TO WALL)

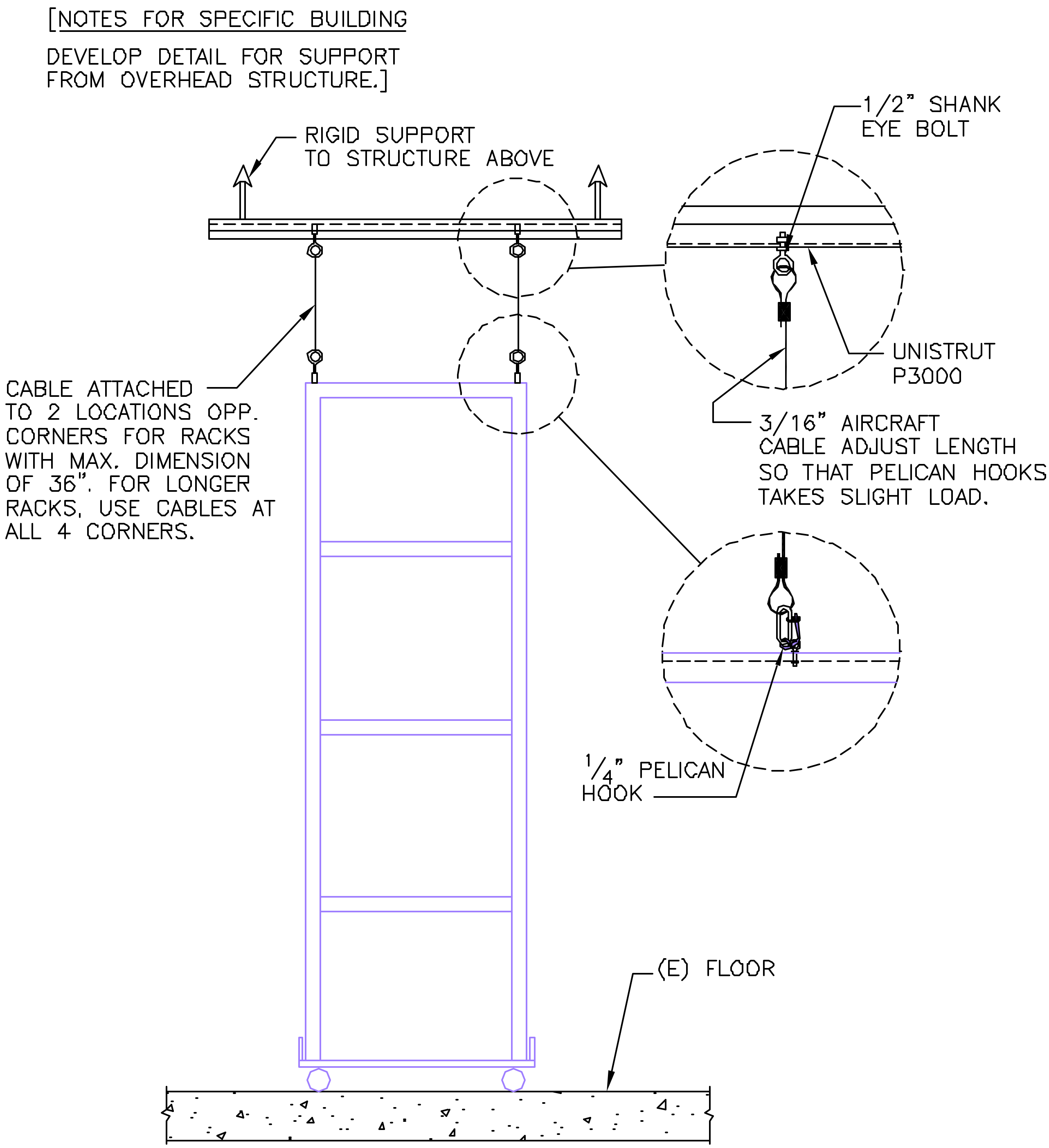
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **WHEELED RACKS**	SCALE: NO SCALE SHEET: **D14**



DETAIL H3b (SEE ALSO H3c)

WHEELED RACK RESTRAINT
(FREESTANDING)

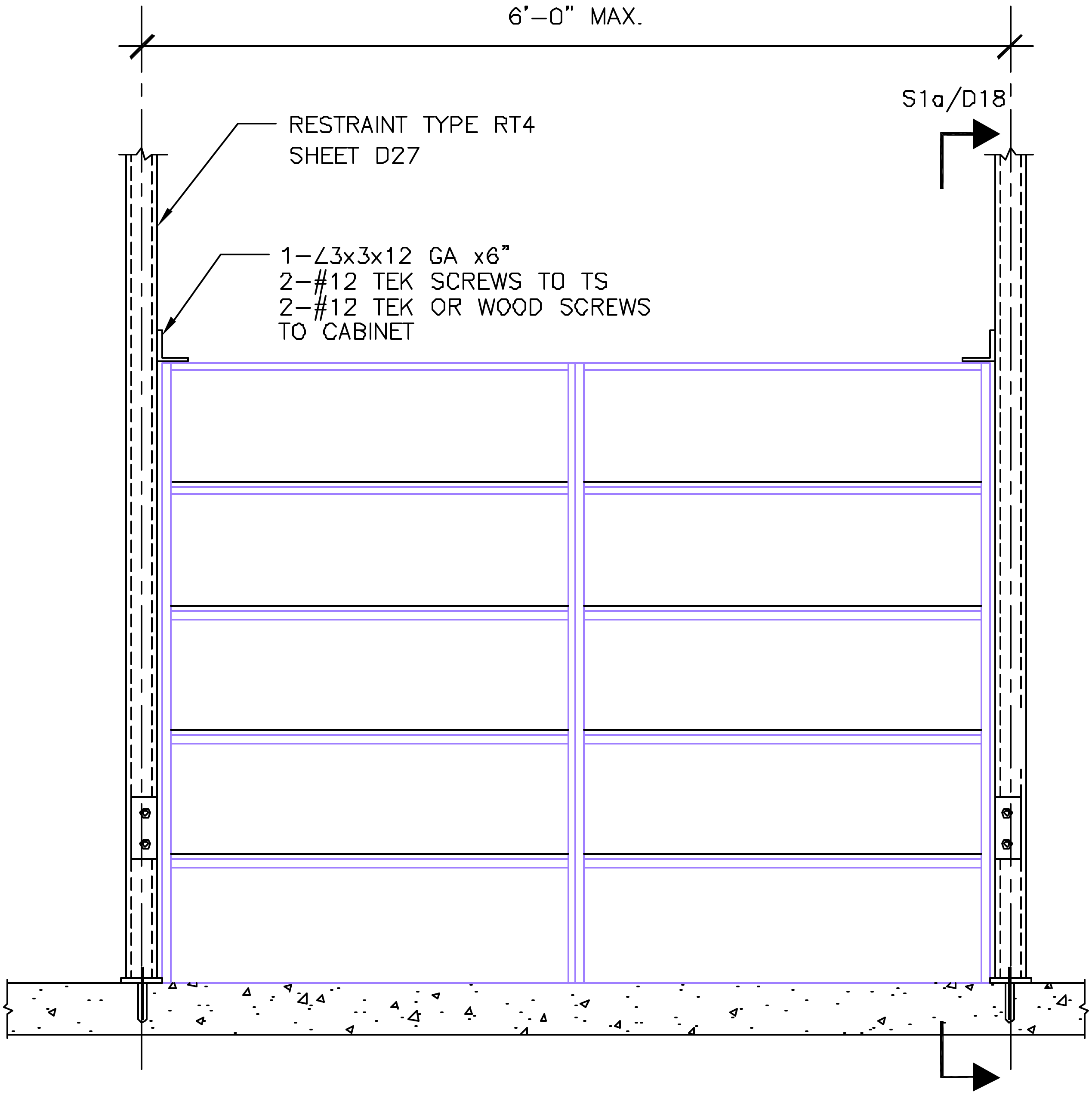
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **WHEELED RACKS**	SCALE: NO SCALE SHEET: **D15**



DETAIL H3c (ALTERNATIVE TO H3b)

WHEELED RACK RESTRAINT
(FREESTANDING)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **WHEELED RACKS**	SCALE: NO SCALE SHEET: **D16**

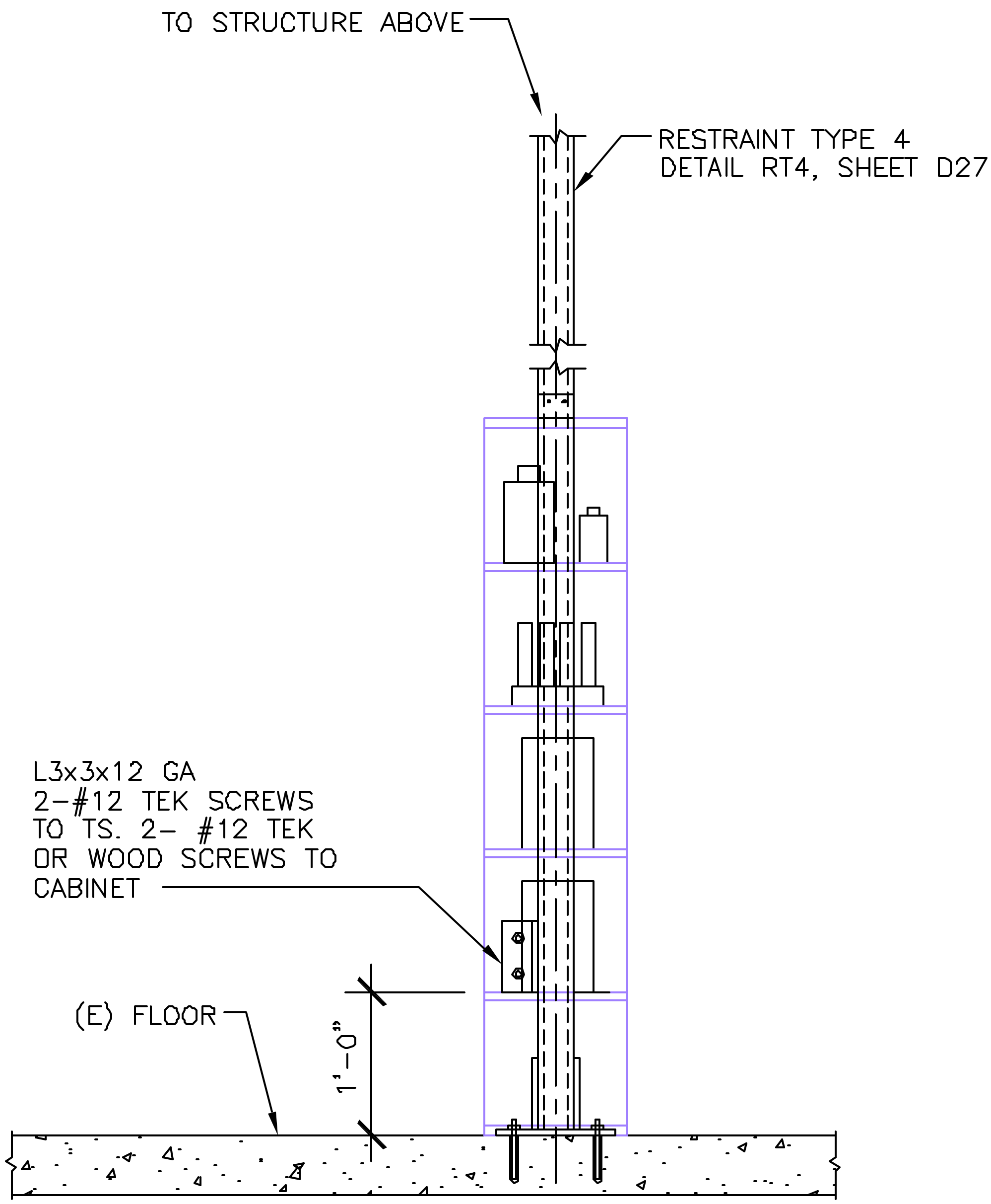


FREESTANDING BOOKSHELVES
FLOOR TO FLOOR RESTRAINTS

ELEVATION

DETAIL S1

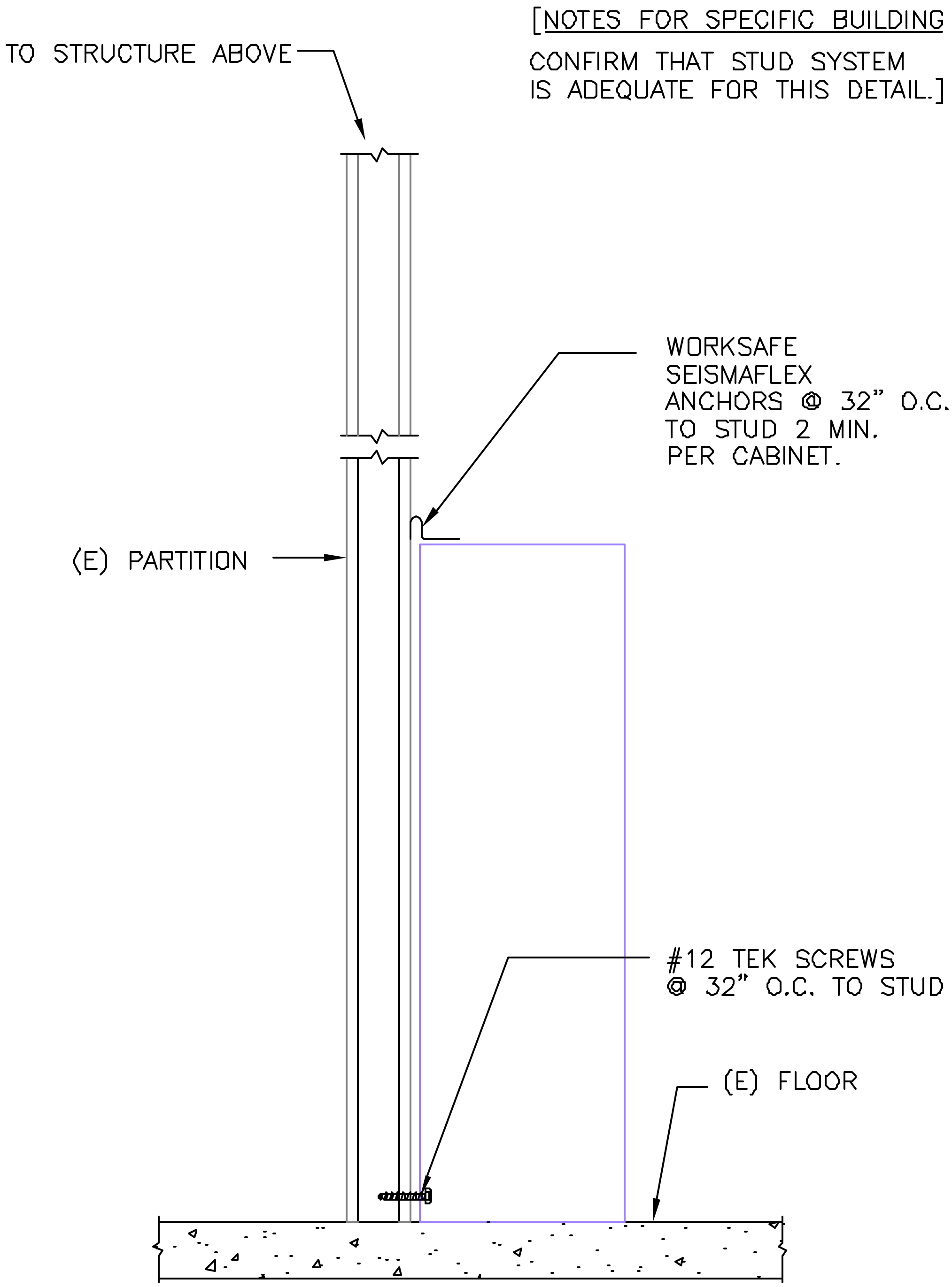
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **BOOKCASES**	SCALE: NO SCALE SHEET: **D17**



SECTION S1a

FREESTANDING BOOKCASES
FLOOR TO CEILING RESTRAINTS

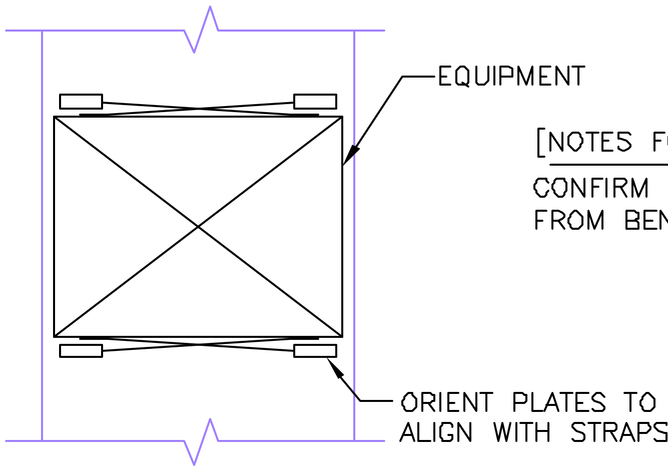
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: BOOKCASES	SCALE: NO SCALE
		SHEET: D18



DETAIL S2

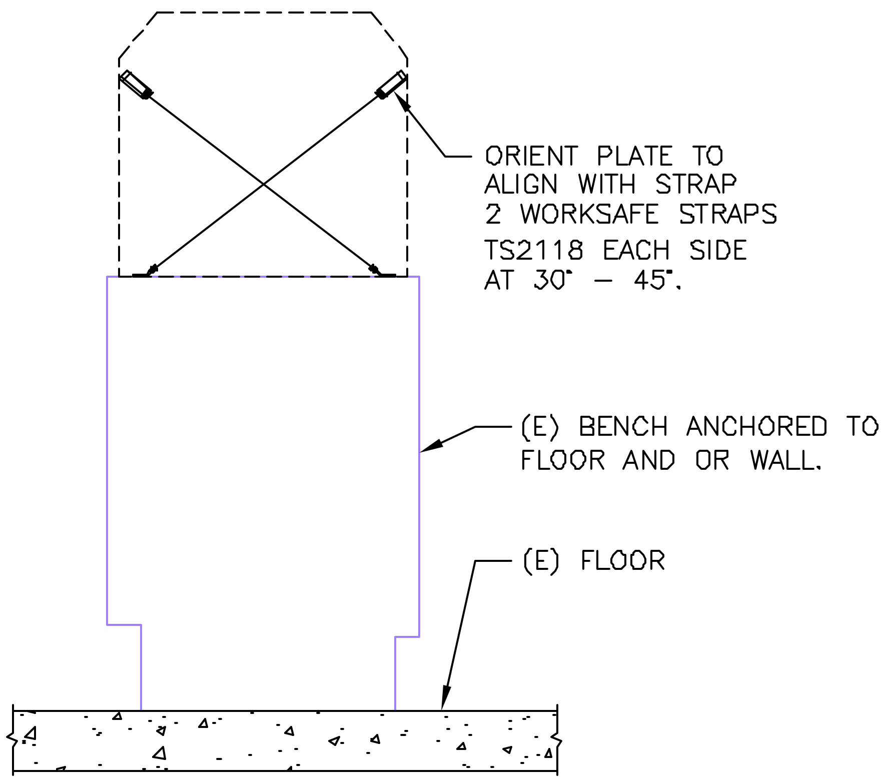
BOOKSHELVES/METAL CABINETS
ADJACENT TO WALLS

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **BOOKSHELVES CABINETS**	SCALE: NO SCALE SHEET: **D19**



[NOTES FOR SPECIFIC BUILDING
CONFIRM LIMITS ON WEIGHT, *
FROM BENCHTOP CONSTRUCTION]

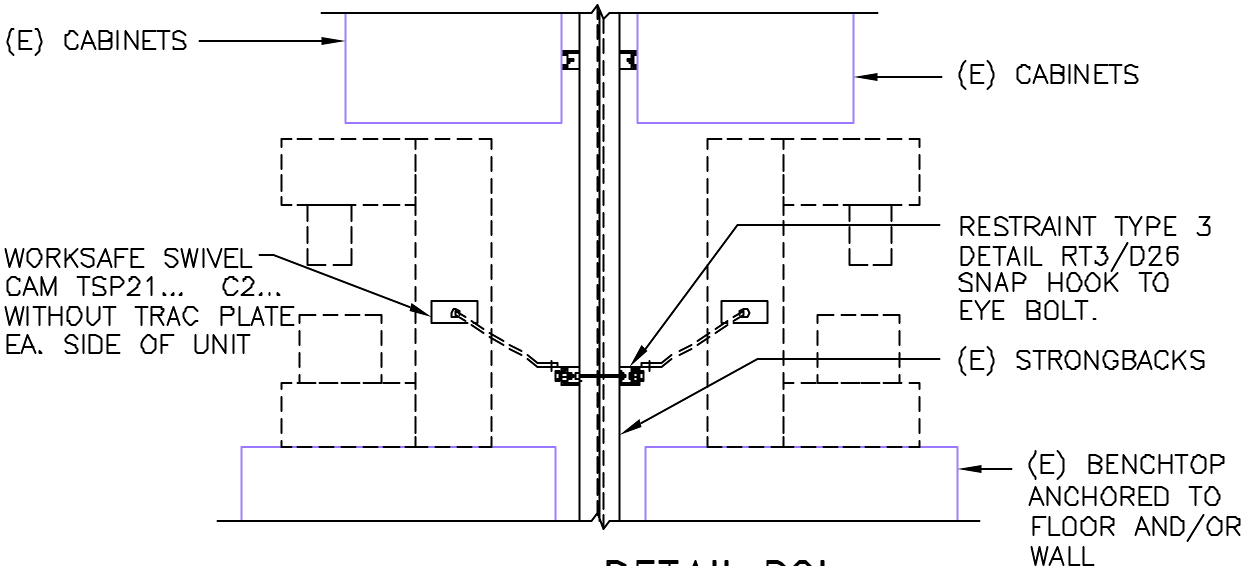
TOP VIEW



DETAIL B1

BENCHTOP HEAVY EQUIPMENT
(* LBS MAX.)

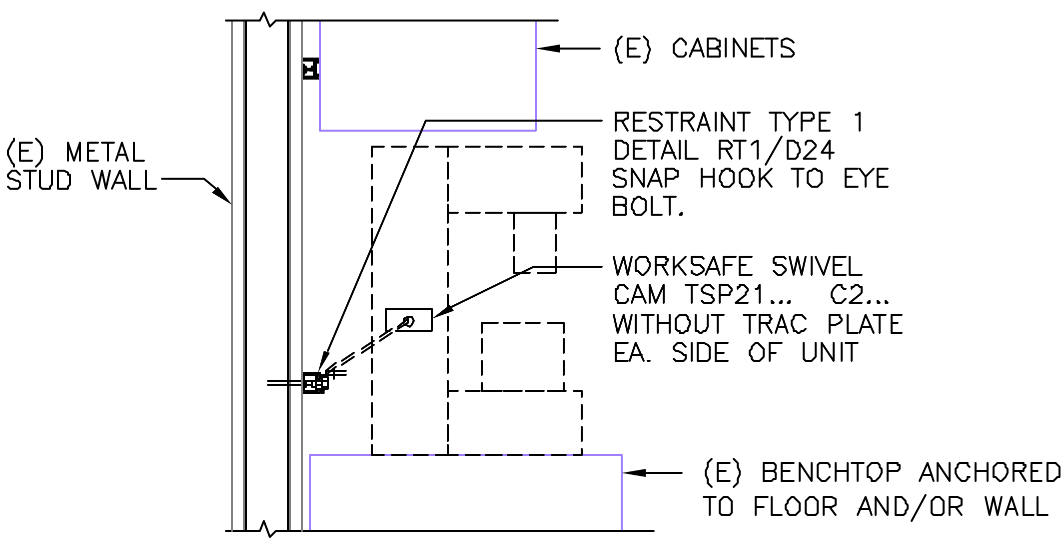
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D20**



DETAIL B2b

BENCHTOP HEAVY EQUIPMENT AT ISLAND
(* LBS MAX.)

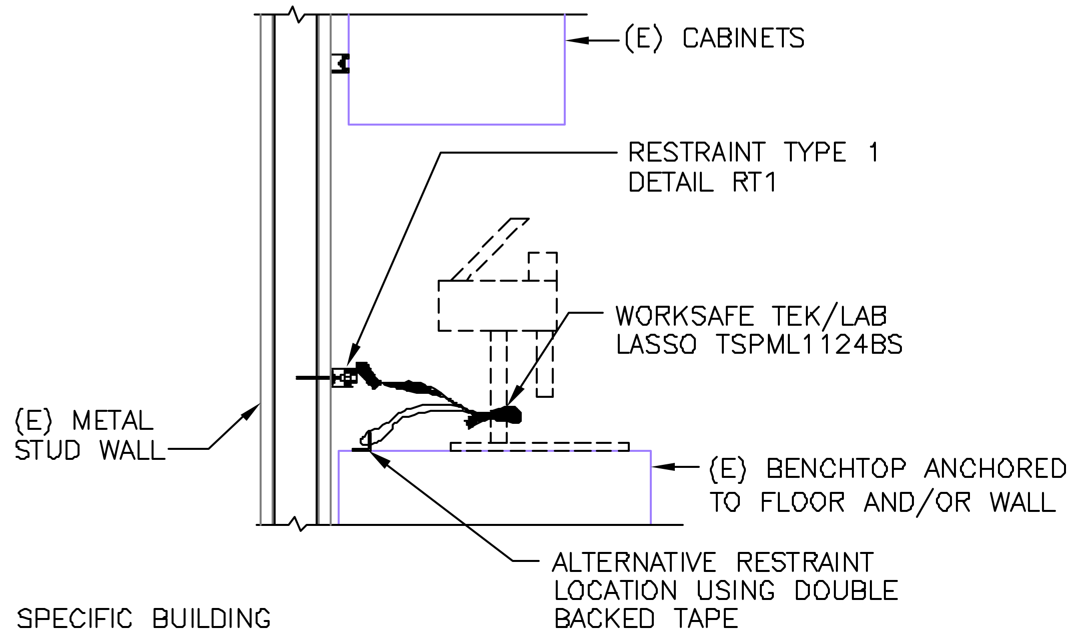
[NOTES FOR SPECIFIC BUILDING
DETERMINE LIMITING WEIGHT OR
LOCATIONS FOR THESE DETAILS.]



DETAIL B2a

BENCHTOP HEAVY EQUIPMENT AT ALL WALLS
(* LBS)

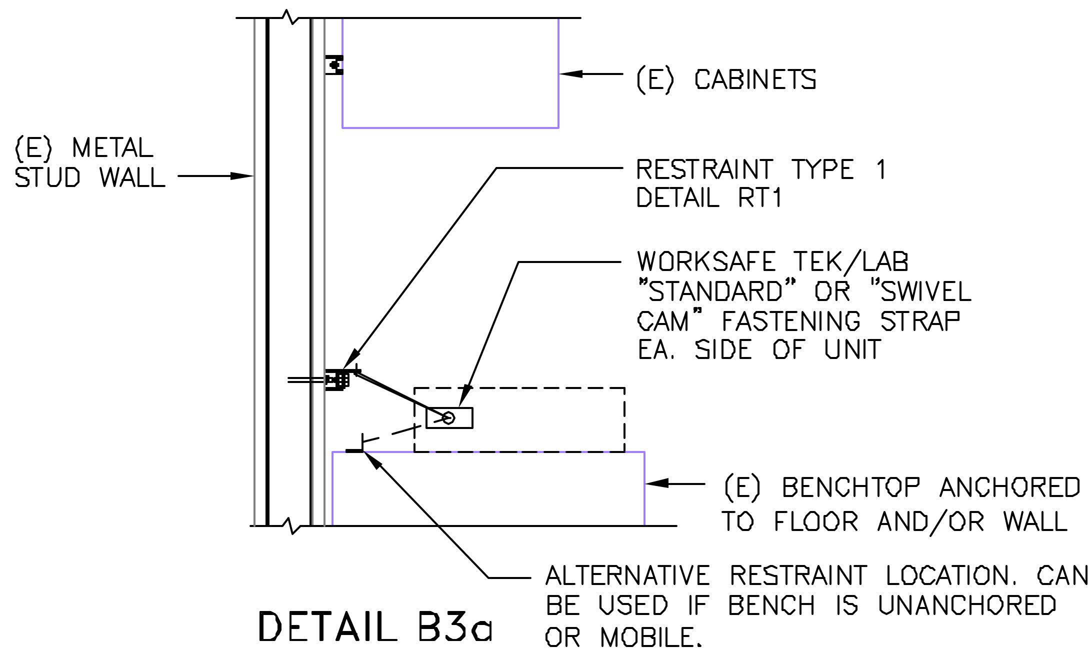
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D21**



[NOTES FOR SPECIFIC BUILDING
DETERMINE LIMITING WEIGHT OR
LOCATIONS FOR THESE DETAILS.]

DETAIL B3b

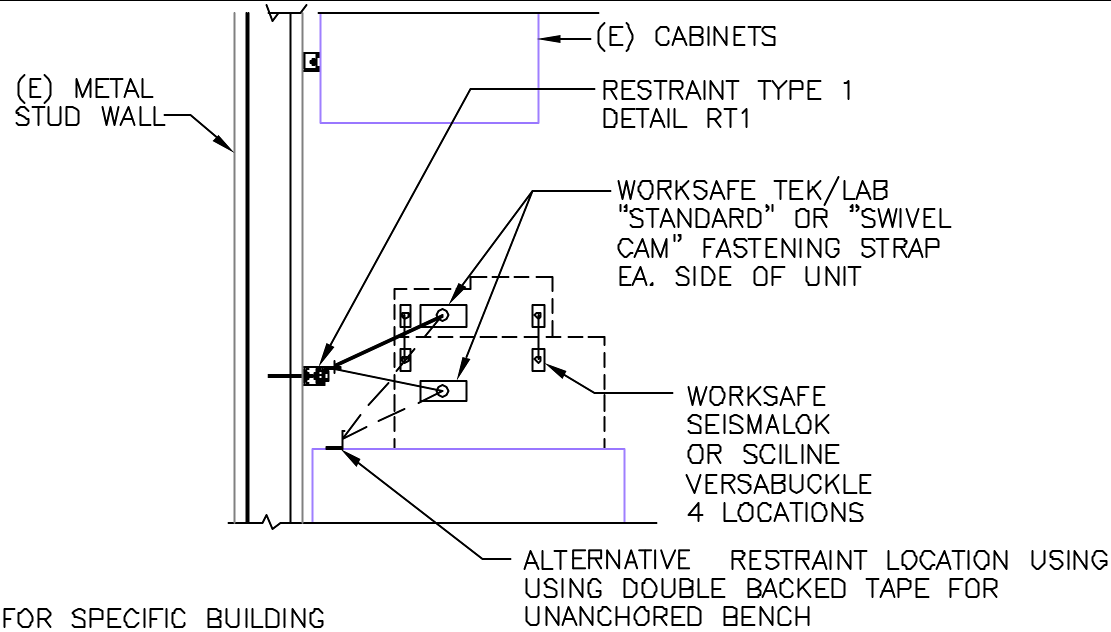
MICROSCOPES AT ALL WALLS
(* LBS)



DETAIL B3a

BENCHTOP EQUIPMENT
(*LBS MAX.)

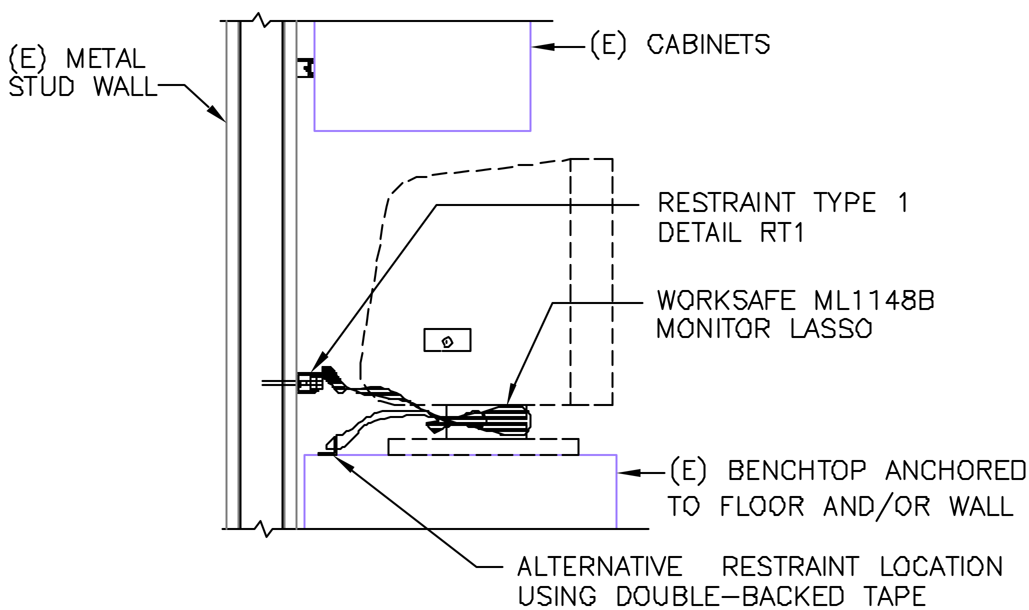
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D22**



[NOTES FOR SPECIFIC BUILDING
DETERMINE LIMITING WEIGHT OR LOCATIONS FOR THESE DETAILS.]

DETAIL B4

STACKED COMPONENTS
(* LBS)

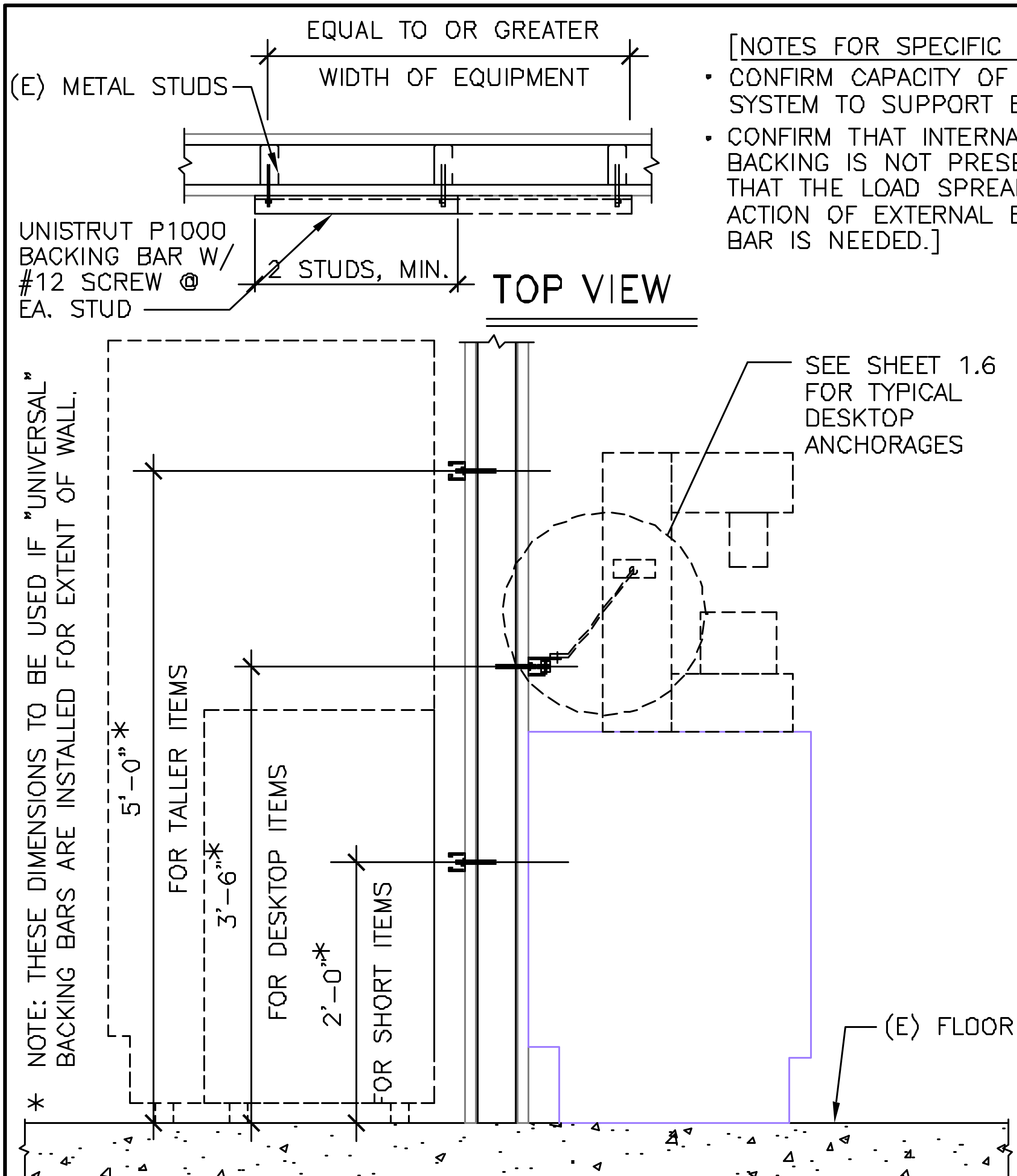


DETAIL B3c

COMPUTER MONITORS
AT ALL WALLS (* LBS)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D23**

[NOTES FOR SPECIFIC BUILDING
- CONFIRM CAPACITY OF STUD SYSTEM TO SUPPORT EQUIPMENT.
- CONFIRM THAT INTERNAL BACKING IS NOT PRESENT OR THAT THE LOAD SPREADING ACTION OF EXTERNAL BACKING BAR IS NEEDED.]

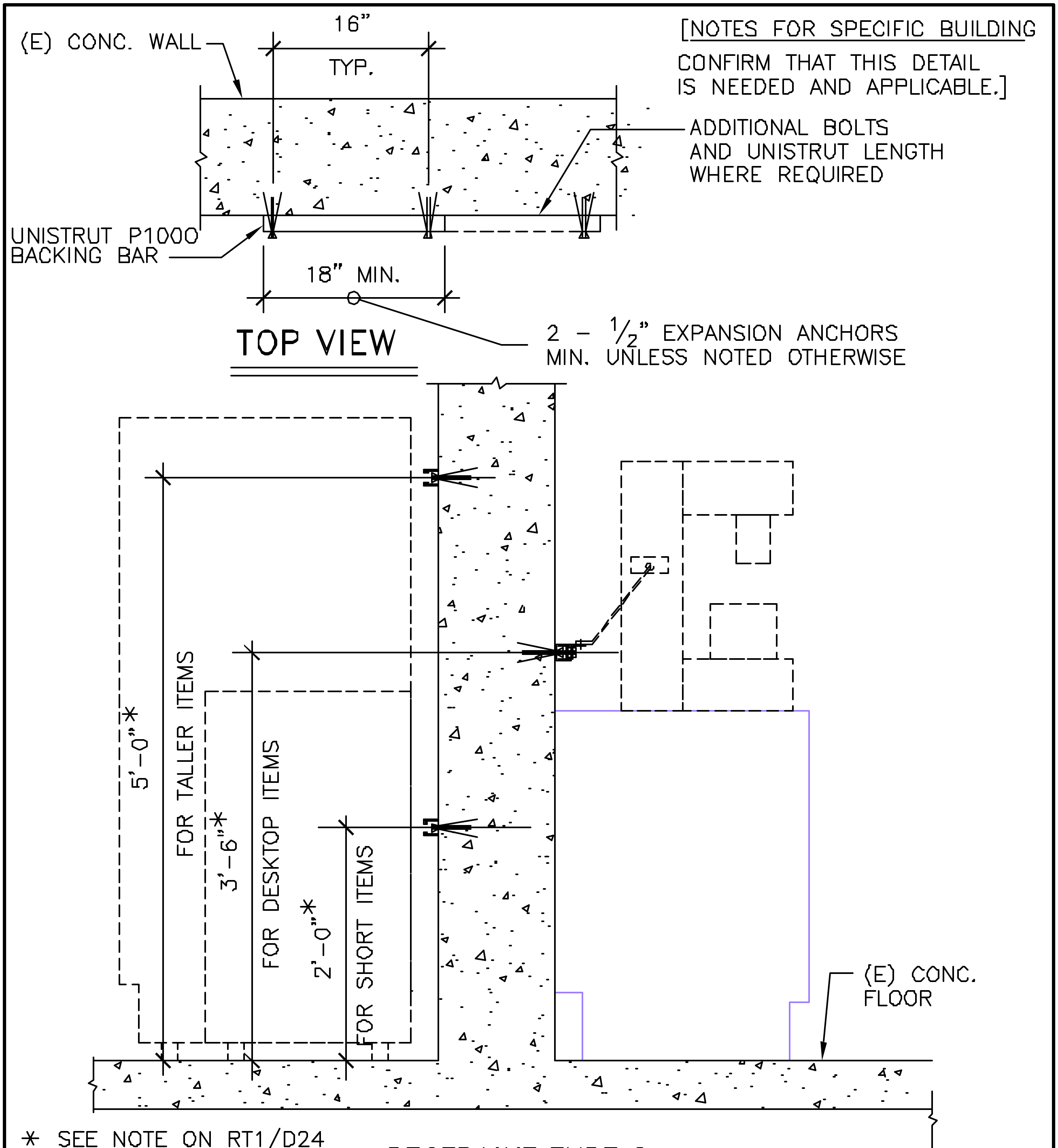


RESTRAINT TYPE 1

EXTERIOR BACKING BAR AT METAL STUD PARTITION WALLS THAT RUN TO FLOOR ABOVE WALLS. THOSE THAT STOP AT CEILING SHALL NOT BE USED FOR RESTRAINT WITHOUT DESIGN BY ENGINEER.

DETAIL RT1

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: TYPICAL RESTRAINT TYPES AT WALLS	SCALE: NO SCALE SHEET: D24



RESTRAINT TYPE 2

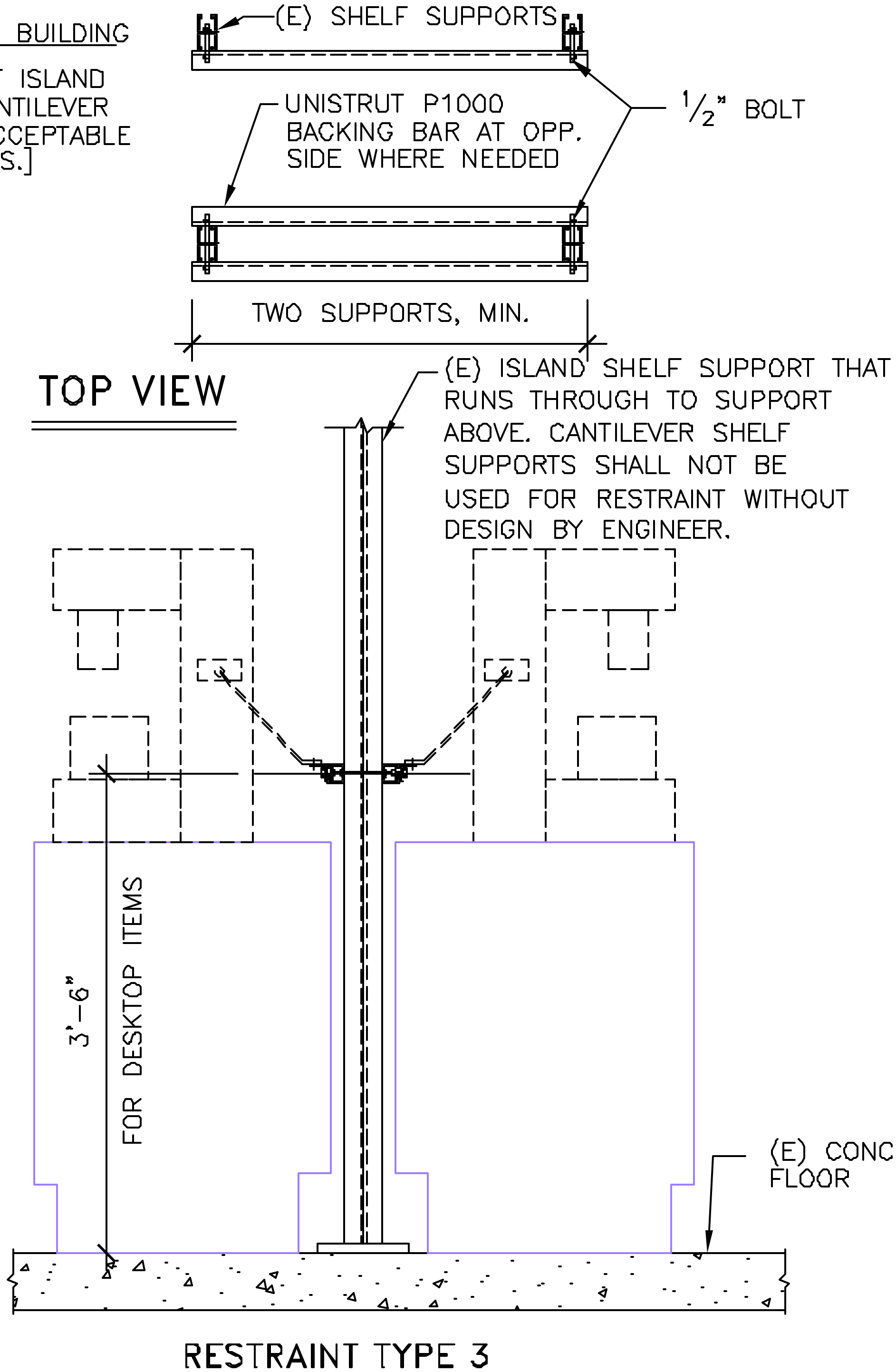
EXTERIOR BACKING BAR @ CONCRETE WALLS

DETAIL RT2

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: TYPICAL RESTRAINT TYPES AT WALLS	SCALE: NO SCALE SHEET: D25

[NOTES FOR SPECIFIC BUILDING

CONFIRM CAPACITY OF ISLAND SHELF SUPPORTS. CANTILEVER SUPPORTS MAY BE ACCEPTABLE FOR CERTAIN LOADINGS.]



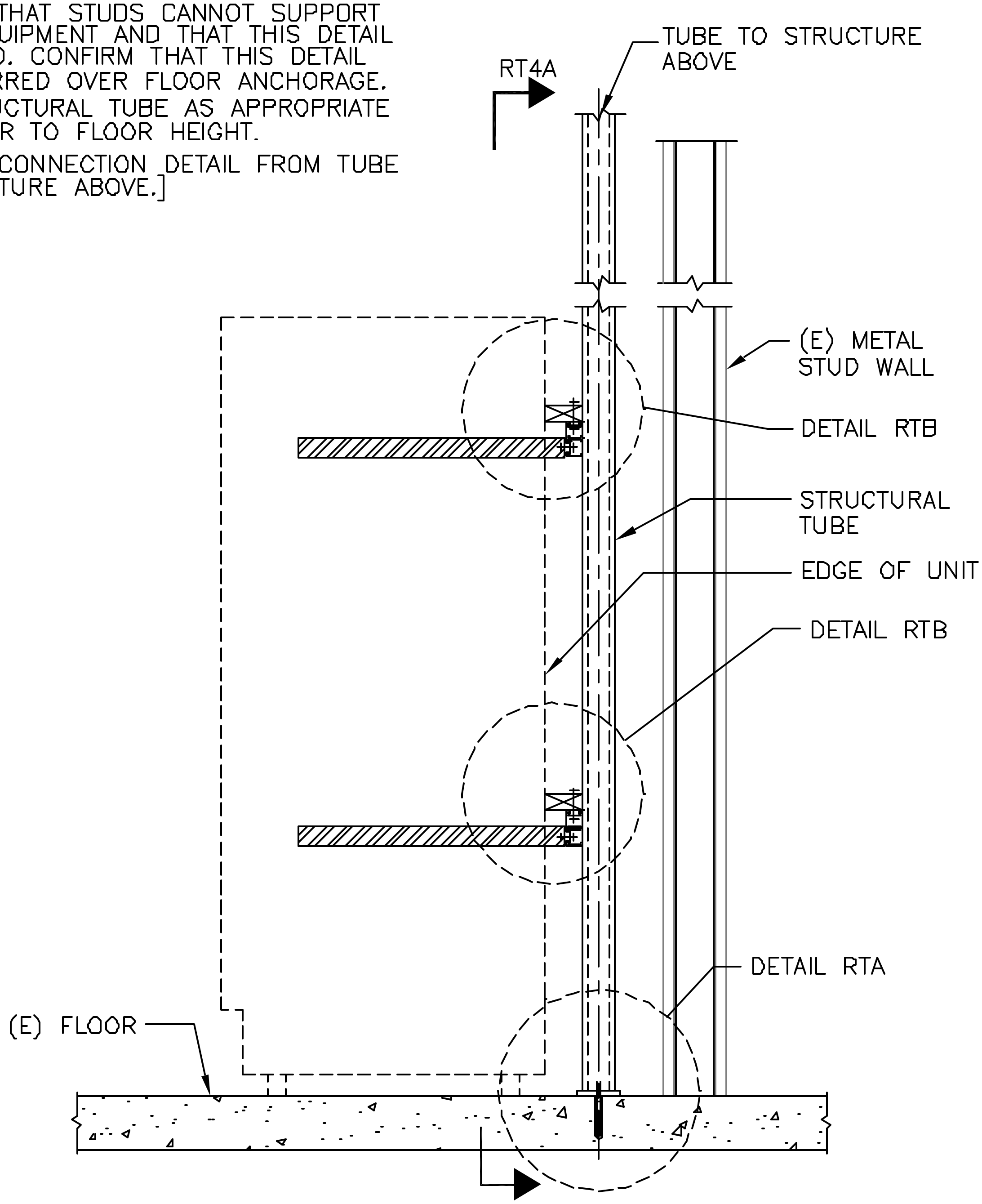
EXTERIOR BACKING BAR @ EXISTING CABINET SUPPORTS

DETAIL RT3

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL RESTRAINT TYPES AT WALLS**	SCALE: NO SCALE SHEET: **D26**

[NOTES FOR SPECIFIC BUILDING

- CONFIRM THAT STUDS CANNOT SUPPORT HEAVY EQUIPMENT AND THAT THIS DETAIL IS NEEDED. CONFIRM THAT THIS DETAIL IS PREFERRED OVER FLOOR ANCHORAGE. SIZE STRUCTURAL TUBE AS APPROPRIATE FOR FLOOR TO FLOOR HEIGHT.
- DEVELOP CONNECTION DETAIL FROM TUBE TO STRUCTURE ABOVE.]

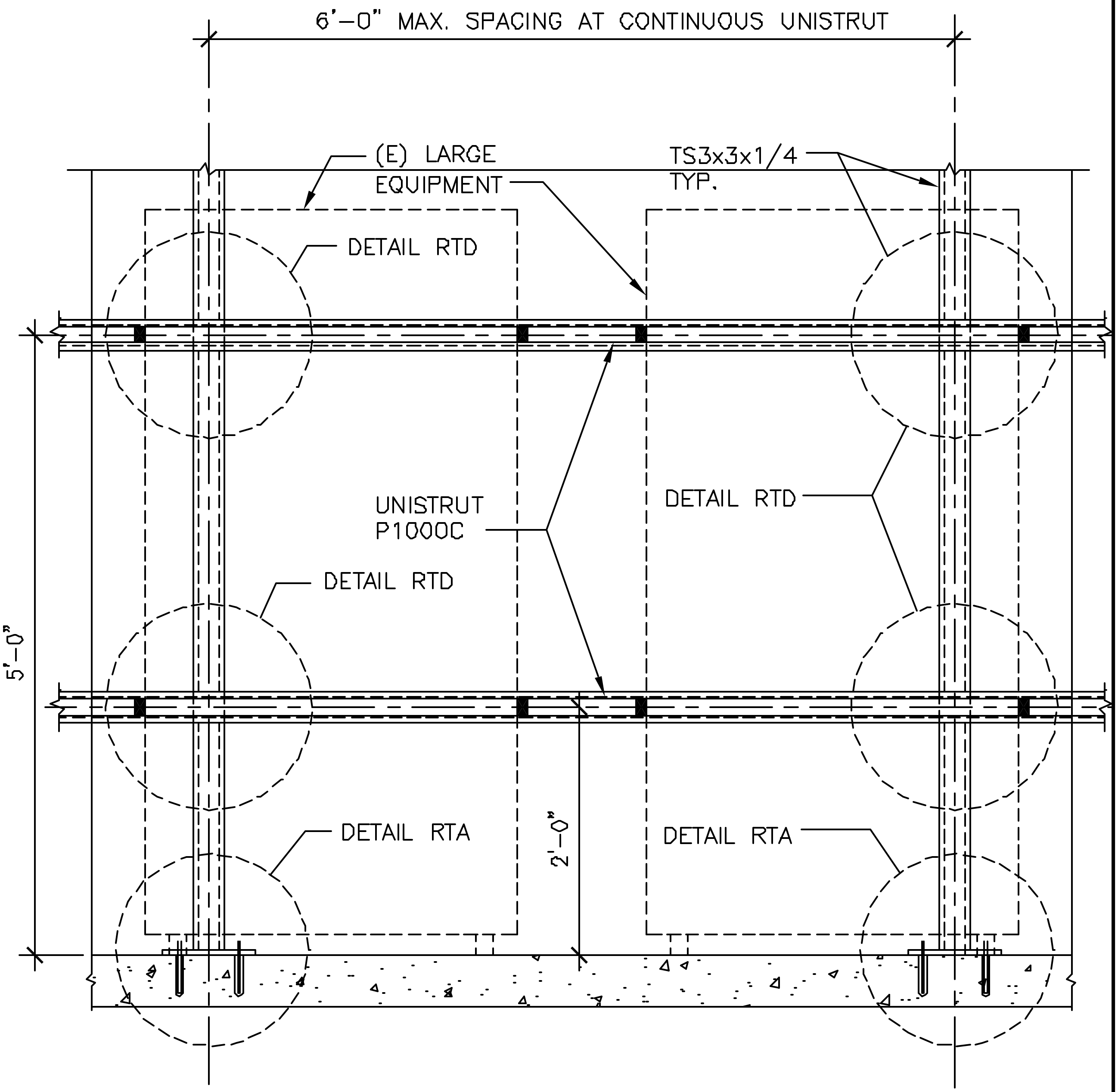


RESTRAINT TYPE 4

TYPICAL STRONGBACK DETAIL

DETAIL RT4

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL RESTRAINT TYPES AT WALLS**	SCALE: NO SCALE SHEET: **D27**



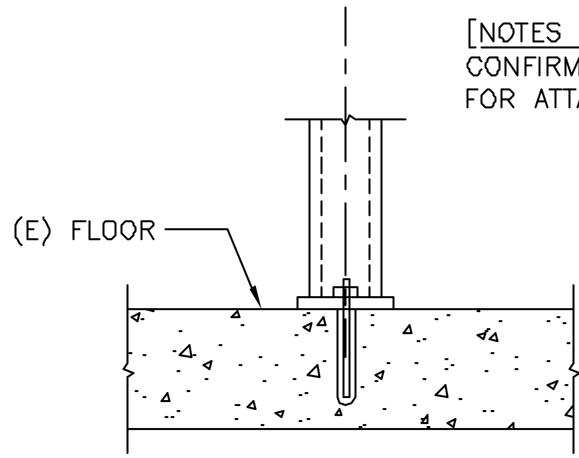
RESTRAINT TYPE 4

TYPICAL STRONGBACK DETAIL

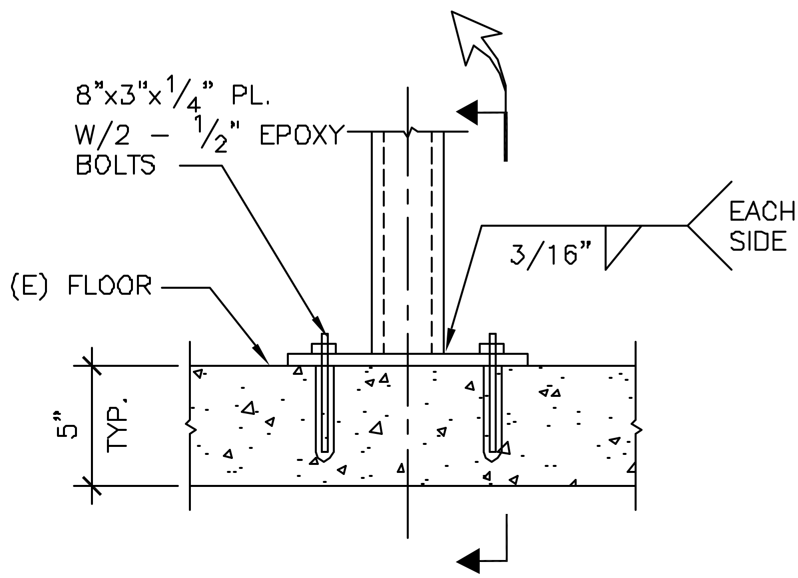
ELEVATION RT4a

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL RESTRAINT TYPES AT WALLS**	SCALE: NO SCALE SHEET: **D28**

[NOTES FOR SPECIFIC BUILDING
CONFIRM APPLICABILITY OF DETAIL
FOR ATTACHMENT TO FLOOR.]



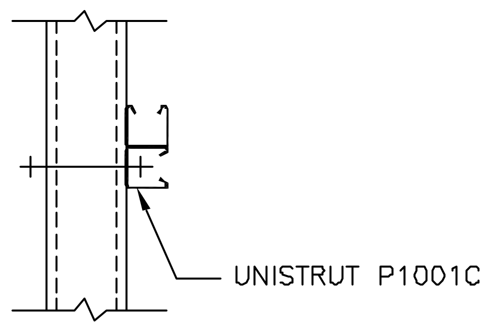
SECTION



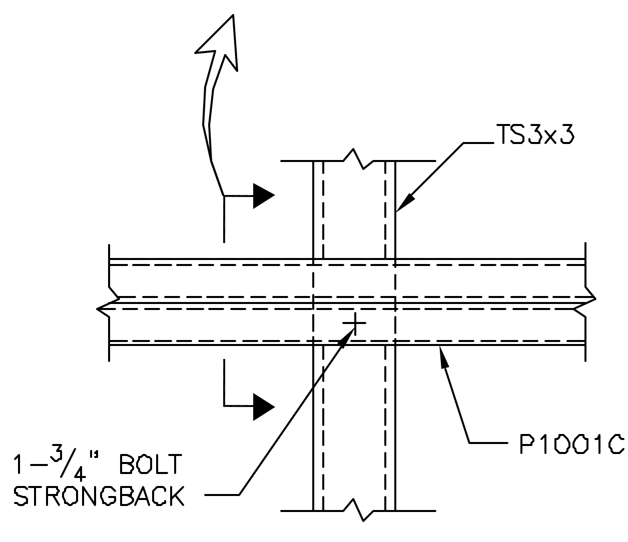
DETAIL RTA

STRONGBACK CONNECTION
TO FLOOR

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS FORMAT FOR SPECIFIC BUILDING	TITLE: **TYPICAL DETAILS**	SCALE: NO SCALE SHEET: **D29**



SECTION



DETAIL RTB

STRONGBACK CONNECTION
AT INTERMEDIATE SUPPORT

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: TYPICAL DETAILS	SCALE: NO SCALE SHEET: D30

Appendix A: Implementation Manual for the Seismic Protection of Laboratory Contents
Case Study Building 1

This appendix contains a fully developed implementation manual for Case Study Building 1, an existing concrete waffle slab and shear wall building built in the late 1980s.

Contents

List of Figures

List of Tables

1 Introduction

It is generally understood that earthquakes damage man-made objects by causing the ground to shake. More specifically, any one spot on the ground moves rather randomly in all directions as the waves generated by the fault rupture pass by, as is shown by the trace of movement in one spot for an actual earthquake in Figure 1. In general, the intensity of the motion, that is the tendency to cause damage, increases with the magnitude of the earthquake, the nearness of the site to the fault rupture, and the softness of the ground at the site. For more information on seismic ground motions, refer to US Geological Survey web site at **www.usgs.gov**.

Buildings respond to this shaking by swaying back and forth (in fact, in all directions, similar to the ground, but it is simpler to think about most buildings swaying in one or both of its major orthogonal directions). Commonly, the building's dynamic properties are sympathetic with the ground shaking, and the motion is amplified within the building, getting larger in floors higher in the building.

Earthquake damage in buildings is normally categorized as structural, nonstructural, or contents damage. Structural damage occurs when the sideways motion in the building is more than the columns, beams, braces, or structural walls can take without harm, usually indicated by concrete or masonry cracking and steel stretching or buckling. The nonstructural category refers to permanent or semi-permanent building components other than the structure such as cladding, partitions, ceilings, mechanical, plumbing, and electrical systems. Damage to these components can occur due to excessive movement between two adjacent floors (fracturing a partition that is connected to both), or by high accelerations that create large horizontal forces (breaking a pipe spanning between two adjacent supports or causing equipment to move off its base). Contents comprise everything else in the building, including furniture, non-building-related equipment (copy machines, autoclaves, refrigerators, computers, and microscopes), supplies (paper, glassware, chemicals, etc.), and work products (computer software and data, experiments). Contents are most typically damaged by forces created by building accelerations that cause the item to slide or tip over.

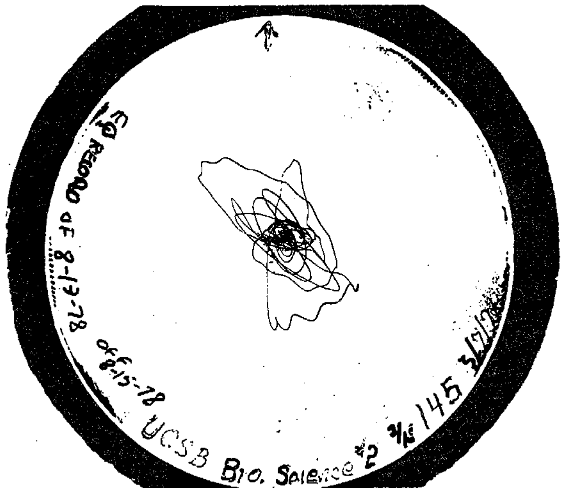


Fig. 1. Seismoscope Record from Biological Sciences II, UCSB

Examples of contents in laboratories include:

1. Tanks and cylinders such as gas cylinders, cryogenic containers, and liquid tanks;
2. Unique equipment and experimental setups;
3. Equipment not related to the building's mechanical, electrical, or plumbing systems such as refrigerators, freezers, dryers, dishwashers, and large incubators;
4. Storage elements such as drawers, bookshelves, cabinets, storage racks, and shelving units, and their contents; and
5. Benchtop items such as computers (and accessories), microscopes, mixers, microwaves, water baths, centrifuges, and small incubators.

Most regulations that control the design and construction of buildings contained in the local building code include requirements that minimize or control damage to the building's structural and nonstructural systems (although some parts of the U.S. in lower seismic zones do not require seismic design of nonstructural systems), but have no requirements for contents. This is probably due to the variability of contents and typically, the small effect of damage on public safety. However, 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 occupants and the general public.

At UC Berkeley, laboratories are 30 percent of the overall campus space. The value of their 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. These are the knowledge base of the university.

The potential loss of building operations is a serious issue for the university. However, the dollar value of the equipment, computers, and other contents in laboratories, the priceless nature of experiments in progress, the value of research supported annually, and the immeasurable value of the contribution to knowledge represented in university laboratories make them an obvious focus for mitigation of nonstructural hazards. (Comerio and Stallmeyer, 2001)

The seismic motion of the building will cause the contents to tend to slide or turn over depending on the ratio of height to base width and the friction between the base and support surface. The configuration of some items will cause them to rock on their base and the combination of rocking and sliding can result in the item “walking” some distance. Any of these responses can be damaging to the item or to nearby items—or occupants. Tipping over can cause direct damage to sensitive equipment, spilling of contents, or can lead to a secondary fall off a counter or shelf. Broken or spilled chemical containers can result in harmful releases or dangerous chemical combinations. Heavier items falling from a shelf will injure occupants. Sliding or walking of heavy equipment will also cause harm to occupants.

Conventionally, seismic protection is afforded contents by anchorage, bracing, or restraining, to prevent damaging movement. However, if damage is to be completely avoided, the characteristics of the item must be considered to ascertain appropriate protection measures. For example, rigidly anchoring equipment at its base may impart large accelerations into the mechanism, potentially resulting in internal damage. Similarly, anchoring a refrigerator or freezer to the floor will almost certainly cause the door to fly open and the contents to be emptied onto the floor. Adding a positive door latch will keep the door closed but may not prevent the contents from being thrown about inside the box and being damaged. In this case, close-fitting racks may also be needed to prevent damage. Appropriate seismic protection measures therefore depend on the physical characteristics of the item and its support, as well as the nature of acceptable performance in an earthquake. In some cases, the mobility needed for the function of small items coupled with their low cost and low potential hazard will result in the conclusion that seismic anchorage or bracing "is not worth it."

For items deemed extremely valuable due to their dollar worth or rarity, all sources of seismic damage must be considered. As mentioned above, some sensitive equipment may be internally damaged if merely anchored down. Experiments that require outside utilities need back-up provisions because it is likely that in large events, some utilities will be disrupted. Lastly, the total building environment should be considered. Concerns about the structural performance of the building may be obvious, but secondary hazards from failure of nonstructural systems must also be considered, ranging from lack of function of the mechanical systems to physical damage from falling ceilings or broken pipes.

This manual gives guidance for providing seismic protection for the contents expected to be common in Case Study Building 1 (CSB 1). Acceptable methods of anchoring to the floors, overhead structure, benchtops, and structural walls and partitions of CSB 1 are given, as well as limitations for their use. Some of the methods detailed herein can be installed directly by the user of the laboratory. Some will require the more skilled labor of experienced building or campus maintenance personnel. Some lab contents will be of such large weight or unusual configuration that anchorage details will require custom design by an engineer experienced in providing seismic protection.

2 Building and Site Description

2.1 BUILDING SITE AND OUTSIDE UTILITIES

The CSB 1 is located in the southwest quadrant of the UC Berkeley campus as shown in Figure 2. There are no known nonshaking seismic hazards at the site such as fault rupture, landslide, liquefaction, or earthquake-induced settlement. The soil is classified as Code Type C, typical for the UC Berkeley campus, and is not expected to produce abnormally large local amplification of ground motion. However, the site is located within 2 km of the very active Hayward fault, typical of the entire UC Berkeley campus. From proximity alone, the site is expected to experience very strong ground motions from moderate or large events on the Hayward fault. Building code coefficients for such sites imply that motions expected should be 1.3-1.5 times as intense as for sites 12 km or greater from the source fault. The site is also threatened by the San Andreas fault (30 km distant), Calaveras (20 km), Concord-Green Valley (22 km), Mt. Diablo thrust (16 km), Greenville (30 km), Rodgers Creek (32 km), and San Gregorio (36 km) faults. Ground motions at the site from a large event on these faults are also potentially damaging, but not to the extent of events occurring nearby on the Hayward fault.

Reliability of utilities serving the building to be available after an earthquake, as described in a recent campus seismic loss study [Comerio, 2000], is described below:

The campus steam distribution system, the main source for heat and hot water for central campus buildings, runs through two main tunnels, one built near the center of campus in 1904 and one along Campanile Road built in 1930. Additional elements of the steam system outside of CSB 1 were installed in the 1950s (additional steam piping) and 1980s (construction of the

Fig. 2. UC Berkeley Campus Map Showing Hayward Fault and CSB 1

Cogeneration Plant). Pipes in both main tunnels run through concrete ducts that are prone to leaks and breaks from ground movement. These ducts also carry other utilities such as data lines and electricity, which could be damaged in the event of a steam pipe leak.

The nearest electrical source to CSB 1 is Switching Station 1 located on the edge of Strawberry Creek. Switching Station 1, fed by the Grizzly Peak Substation and by the Cogeneration Plant, is the starting point for the campus distribution system. New switching stations (Hill Area Substation and Switching Station 5) will reduce the load on Switching Station 1, which will continue to serve CSB 1. Additional vulnerabilities are linked to transmission lines near the steam system and the effectiveness of the emergency generators.

CSB 1, as well as the entire UC Berkeley campus, is entirely dependent on East Bay Municipal Utility District's (EBMUD) water distribution and storage systems. Piping from EBMUD facilities consist of either older cast iron pipes (pre-1948) or newer, standardized PVC pipes. There is little or no redundancy or backup in the water supply system. Many of the older pipes have deteriorated and can break or leak even without ground motion. The most immediate threat from disruption of the water distribution system is the ability to fight fires. Beyond that, there is a possibility of contamination, disrupted steam generation, and disrupted water flow from seismic activity.

The campus sewer system feeds directly into the City of Berkeley's sewer system and from there to the EBMUD sewage facilities. Piping materials in the campus sewer system include cast iron, ductile iron, reinforced concrete, vitrified clay, and PVC. The oldest segments (vitrified clay) date back to the early 1900s. The current standard is PVC. Failure in the older, non-PVC sections of the system, whether near CSB 1 or not, would disrupt some or all parts of the campus, making the resumption of classes difficult. Laboratories in CSB 1, which rely on industrial waste disposal, could not restart either. Also, drinking water in CSB 1 could be contaminated.

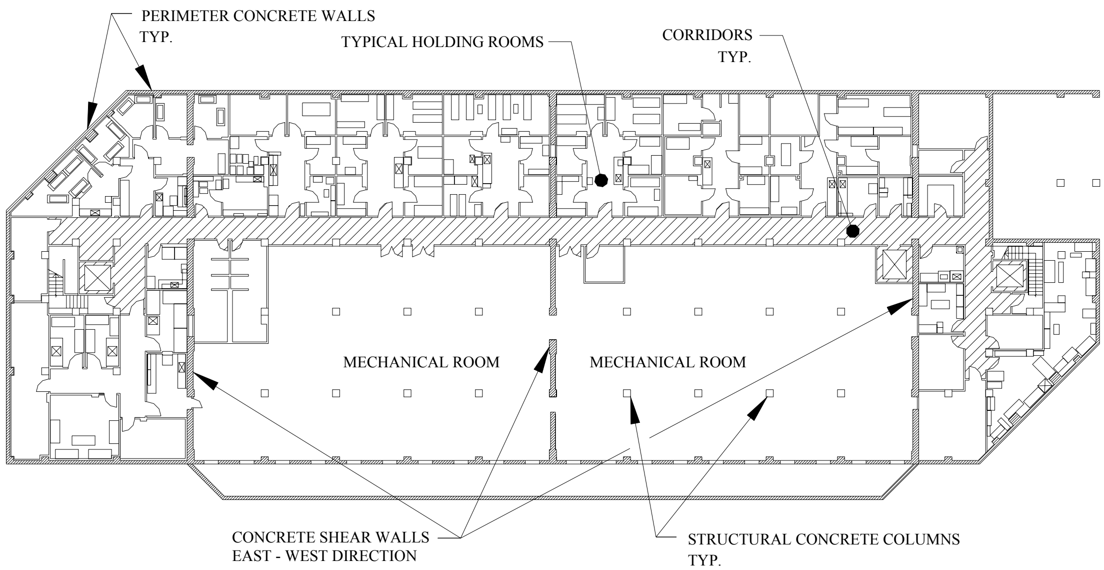
The natural gas supplied to the CSB 1 comes from PG&E transmission lines from the Milpitas terminal to the south. Most of the campus's natural gas is used by the Cogeneration Plant to produce electricity and steam, which could prompt interruptions in service to CSB 1 if any of the campus's 2-4 miles of steel gas piping is damaged during an earthquake. The fire risk from damaged pipes, regardless of their proximity to the CSB 1, should be considered as well. There are no easily accessible manual shutoffs on gas mains entering the campus.

Data and voice lines feeding CSB 1 generally share the same tunnels used for the steam system, where damage can occur from steam leaks. Plans are under way to relocate much of the communications network to a new conduit. The backbone for the network is located in the NE quadrant of the campus, connecting with another hub before feeding the CSB 1. In addition to data line connectivity, all communications systems rely on full electrical power. Internet services enter the campus at two locations – on the north and south sides – although beyond that there is little redundancy. Steam conduits used to hold additional electrical, voice, and data lines are at full capacity.

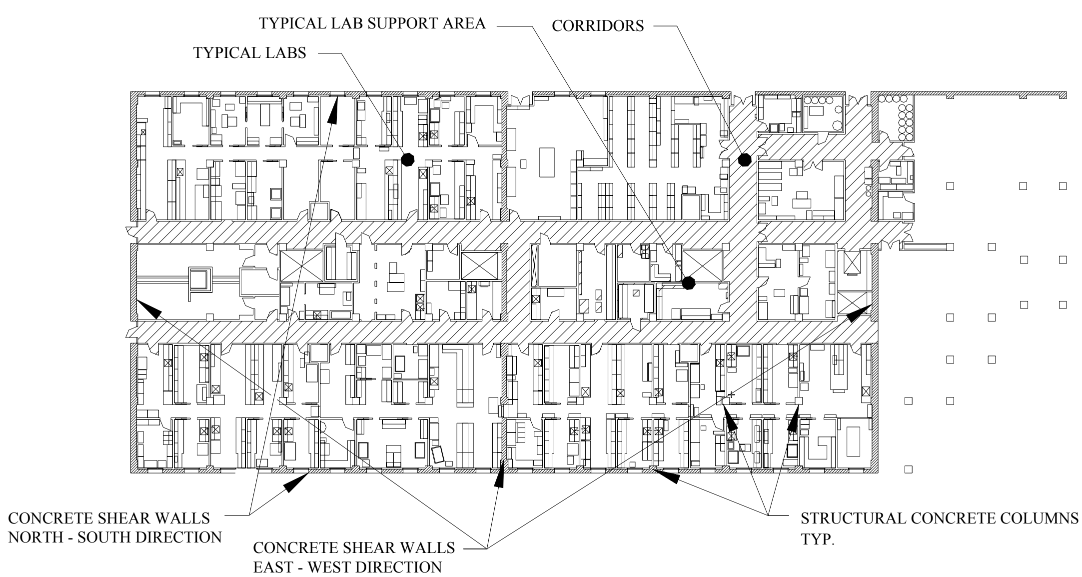
2.2 BUILDING CHARACTERISTICS

The building was completed in 1988, intended to provide high technology research laboratories for organismal biology. The building is essentially rectangular in plan and is nominally 100 feet wide and 300 feet long, and 6 stories (plus a basement) high. See Figure 3. The floors consists of a two-way concrete joist system, 24½" in depth (called a “waffle slab”) spanning 20'-0" in the longitudinal direction and 22'-10" in the transverse direction to square concrete columns. Waffle slab construction allows floors to span to columns without deeper beams or girders. A solid concrete floor slab 4½" deep spans between joist to compete the floor system. See Figure 4.

The lateral force (seismic) -- resisting system consists of discrete 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 3. 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.

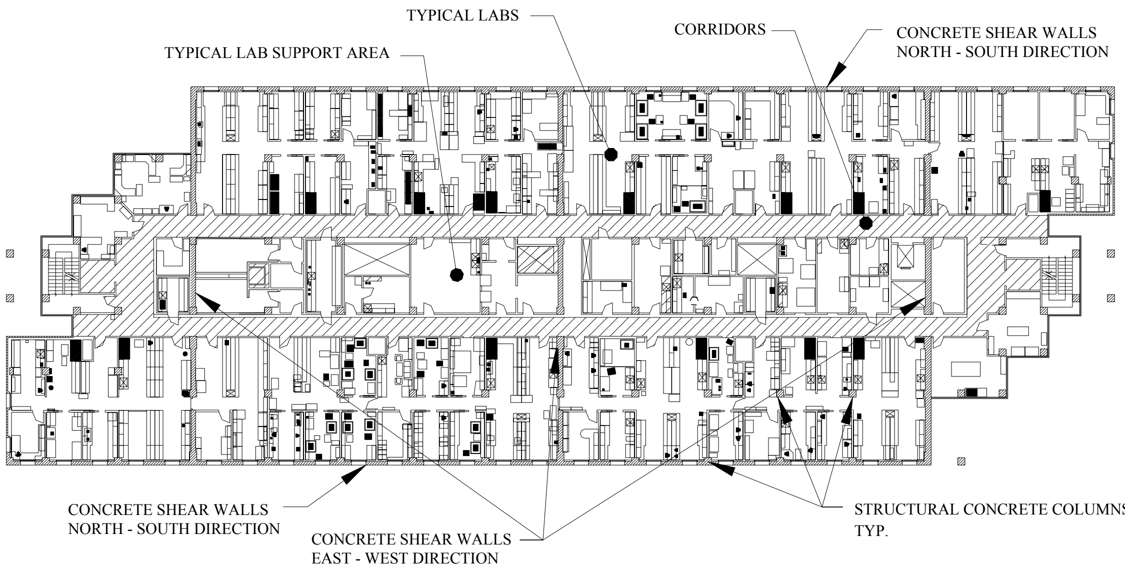


a. Basement Plan

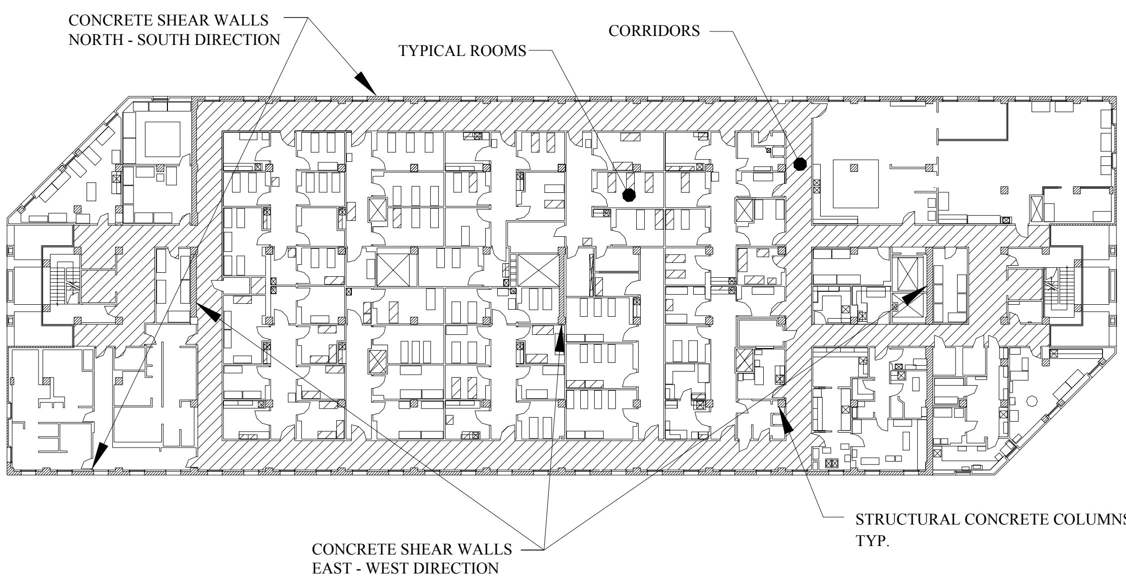


b. 1st Floor Plan

Fig. 3. CSB 1 Floor Plans



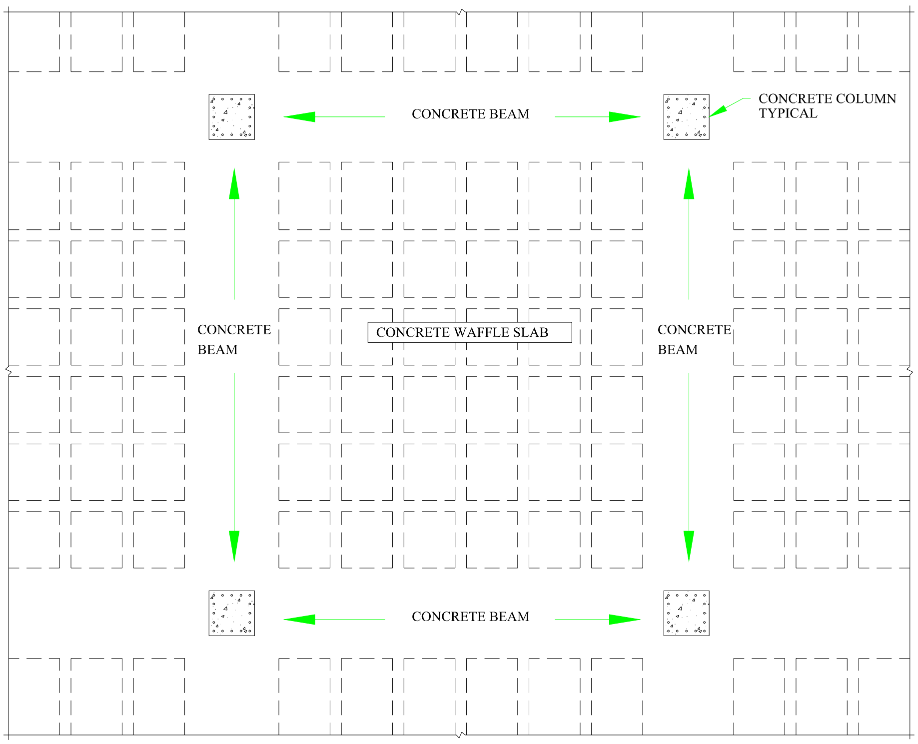
c. 2nd through 5th Floors Plan – Typical



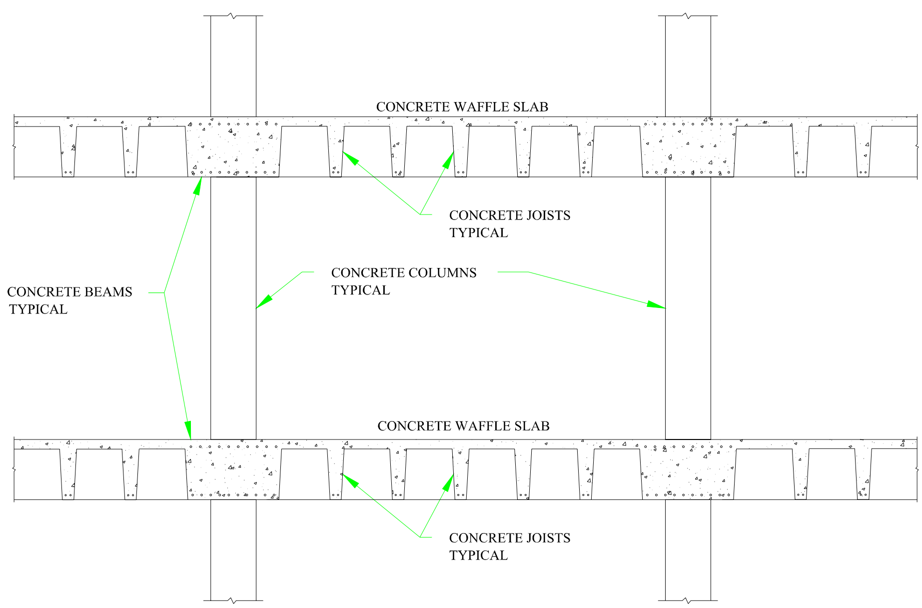
d. 6th Floor Plan

Fig. 3. CSB 1 Floor Plan (continued)

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 hung-ceilings, and the corridors have a metal-grid hanging ceiling to cover mechanical equipment. Floors are either vinyl tile or exposed concrete.



TYPICAL FRAMING PLAN



TYPICAL FRAMING SECTION

Fig. 4. Typical Plan and Section of Concrete Waffle Slab in CSB 1

2.3 EXPECTED SEISMIC PERFORMANCE

Structural seismic performance is expected to be better than average on campus. A rating system used in a recent campus-wide seismic evaluation [UCB, 1997] has assigned expected performance based on a scale developed by SEAOC for Vision 2000 [SEAOC, 1996] as shown in Table 1. The ratings were assigned to each building for three different levels of shaking: occasional shaking, having a 50% chance of being exceeded in 50 years (or on average, occurring once every 72 years); rare shaking, having a 10% chance of being exceeded in 50 years (or on average, occurring once every 425 years); very rare shaking, having a 2% chance of being exceeded in 50 years (or on average, occurring once every 2475 years). The very rare shaking is also sometimes characterized as resulting from the "maximum credible event" and is normally used only in that context. The expected structural performances of CSB 1 are shown in the top line of Table 2.

Performance of nonstructural building systems, evaluated for the Comerio economic loss study [Comerio, 2000] based on walk-through observations, is also shown in Table 2. The categories of "Architectural finish" and "MEP" refer to the partitions, ceilings, mechanical, electrical, and plumbing systems of the building. "Contents" is in the same contents as used here, but was judged solely from observation of the level of intensities of fragile contents and restraint mechanisms. The "Water Damage" index was also set from observation of the pressure water systems in the building.

A more thorough walk-through performed in association with producing this manual indicated a level of anchorage and bracing of nonstructural systems more complete than average for this vintage of building, confirming the previously expected low damage levels at least for the occasional shaking. However, in general, the seismic bracing installed for the larger pipe systems is judged relatively ineffective, leading to more expected damage to those systems and a chance of greater damage in the "Water Damage" category. The building walk-through also indicated that the emergency generator housed in a separate small building near the Southeast corner of the building was apparently installed after the building was complete and was not provided adequate seismic protection. Until retrofitted, power from this generator should not be counted on after moderate to strong shaking.

Table 1. Damage States and Performance Level Thresholds

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

Table 2. Expected Performance for Life Sciences Building Addition

Earthquake Scenario		Occasional	Rare	Very Rare
Structural Damage Index (1)		8	7	6
Nonstructural Damage Index (1)	Architectural finish	8	6	5
	MEP	7	5	3
	Contents	6	4	3
	Water Damage	6	4	2

(1) Damage index from Table 1.

2.4 SEISMIC DESIGN REQUIREMENTS

Building codes like the Uniform Building Code [ICBO, 1997] contain requirements for anchoring many architectural and building service system components to the structure for seismic forces. The applicability of these anchoring requirements to contents is vague and the boundary between nonstructural building components and contents is blurred. For example, no components that could be classified as contents are listed in the code other than storage racks and floor-supported cabinets over six feet in height. Traditionally, items classified as contents are installed by the owner or user after construction is complete and there is a little jurisdictional control. However, because of the similarity of the classes, code anchoring requirements for nonstructural components can be directly applied to contents when such anchorage is deemed appropriate.

For nonstructural components, codes require anchorage to sustain specified lateral forces measured as a percentage of element weight. This proportion of weight is sometimes referenced in terms of the acceleration of gravity, *g* (e.g., 0.5g meaning 50% of component weight), but is more accurately simply written directly as 0.5 Weight (or 0.5W). The magnitude of the code loading for nonstructural components, termed F_p in most codes, is dependent on the location of the building relative to potential source faults, site soils conditions, and the height of the component within the building. Also in the formula for F_p, as shown in Table 3, is an importance factor, I_p, intended to give additional reliability for anchorage of important equipment or other components. Additional factors include a_p, a measure of dynamic amplification of seismic forces created by flexibility of the component, and R_p, a measure of ductility or toughness of the connection. Maximum and minimum loadings are also specified that override the results from the formula. Although for most components in this manual a_p will be 1.0, and R_p will be either 1.5 or 3.0, this formula should be applied by an engineer knowledgeable in seismic design, and is given here for general information only. Applying these rules to the CSB 1 yields the basic percentages of weight at each level, prior to modification by a_p and R_p, shown in the first column of Table 3. The second column shows the force as a percentage of weight that is required by the code formula for design.

The NEHRP Provisions (BSSC, 2001), a national source document for future codes, contains a method of determining appropriate design forces for nonstructural elements based on dynamic analysis of the building. In this case, a_i is determined directly from a time history dynamic analysis and can be substituted for the code values at each floor. This kind of analysis was performed on CSB 1 as part of the PEER test bed studies and then values are shown in column 3 of Table 3. When using building-specific formula in the NEHRP recommendations, the design forces shown in Table 3 are obtained.

The design forces in column 4 in Table 3 were used to develop the details recommended in this manual for the CSB 1. It is also recommended that these values be used for future custom design of restraint in the building, adjusted for appropriate values of a_p and R_p.

Table 3. Design Forces for Components and Contents in CSB 1 Using R_p = 1.5

Floor	a_i per UBC %g[1]	Design Force per UBC, %W[2]	a_i from non-linear analysis, %g	Design Force from analysis, %W[2]
Roof	240	160	99	65
7	200	133	71	50
6	180	120	67	45
5	160	106	70	45
4	130	86	70	45
3	110	74	68	45
2	82	56	61	42
Ground	.6	42	56	42
Basement	.6	45	NA	42

Notes

1. $a_i = C_a\left(1+\frac{3h_x}{h_r}\right)$ or as derived from dynamic analysis

2. Design Force percentage of Weight = $\frac{a_i a_p}{R_p / I_p}$ a_p =1; I_p =1; R_p = 1.5.

Min = 0.7 x Ca = .7 x .6 = 0.42

3 Seismic Anchorage in the Lab Environment

Most seismic protection of contents consists of restraint against sliding or tipping during the building motion induced by an earthquake. This restraint is obtained by attaching the item to a stable building component that itself is strong enough to resist the shaking and provide anchorage. Anchorage details must be conservatively designed and be reliable because it is likely that they will be in place for months or years and be fully tested only once -- by the earthquake. This section describes types of anchorage often used for restraint of contents and caveats for their use. This section also describes building components in CSB 1 that can be used for anchorage, including floors, ceilings and overhead structures, walls, and built-in furniture.

Section 5 contains specific details for anchorage of various contents and limitations on their use for CSB 1.

3.1 ANCHOR TYPES

3.1.1 Concrete

Anchorage to concrete slabs is achieved by drilling a hole and inserting one of a variety of bolts made for this purpose. Mechanical-type drilled-in anchors expand against the sides of the hole to provide a tight and secure fit (Figure 5). Many of these types of anchors are sensitive to installation procedure to achieve their rated value. Care must be taken to drill the right diameter and depth of hole and to tighten the nut in accordance with the manufacturer's instructions. Chemical anchors are installed by filling a narrow annulus around the bolt with specially formulated epoxy (Figure 6). The epoxies are normally two-part mixes that must be combined immediately before installation. Systems are available that require hand mixing, that automatically mix the two parts in special caulking guns, and that place the two chemicals in a cartridge that is placed in the hole, broken, and mixed in place. The rated value of chemical anchors is also sensitive to installation procedure and the type of drill used and cleaning of the hole must be strictly in accordance with the manufacturer's instructions.

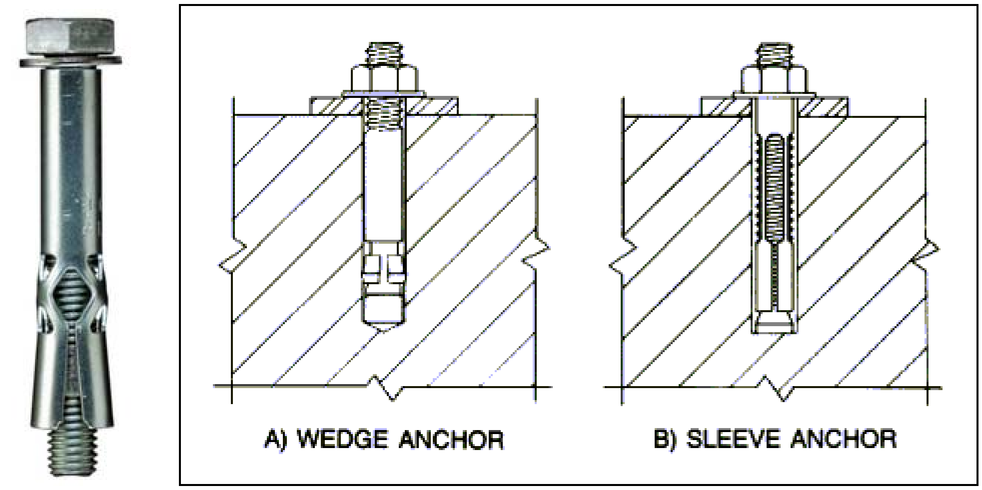


Fig. 5. Typical Expansion Anchors

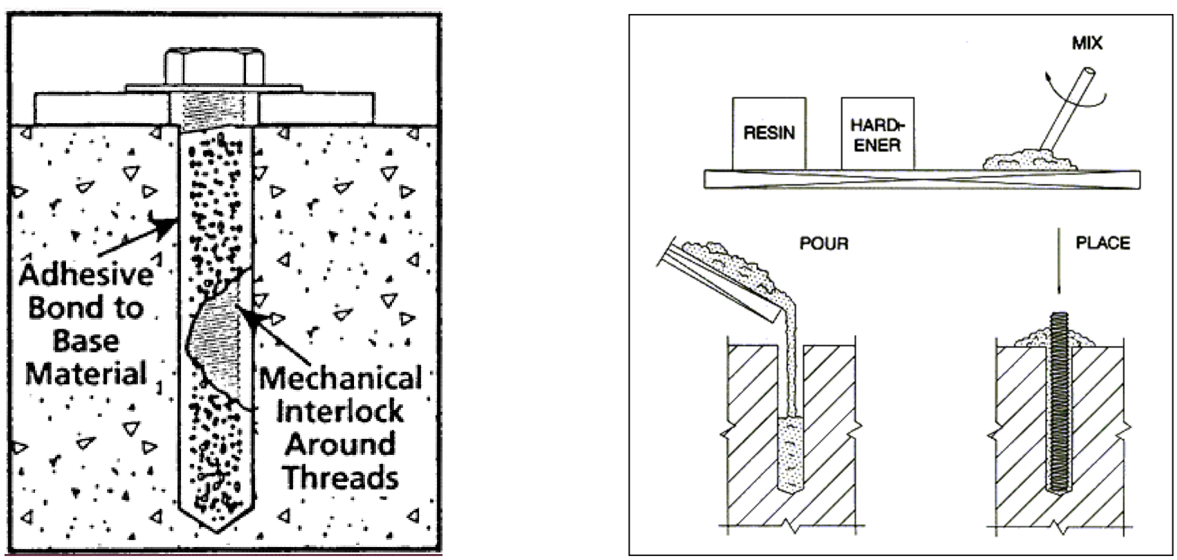


Fig. 6. Typical Chemical Anchors

3.1.2 Metal

Items are connected to sheet metal or steel with bolts, sheet metal screws, or welding. Welding requires a high level of expertise, and cumbersome equipment, and is not normally used for seismic anchorage of contents. Use of bolts requires pre-placed holes of the correct size in the items to be connected. Sheet metal screws can be installed through predrilled holes of the correct size, or, more conveniently and more reliably, can be "self-drilling." (See Figure 7.) When using self-drilling sheet metal screws, it is important to use the correct type and size for the application in accordance with manufacturers instructions.

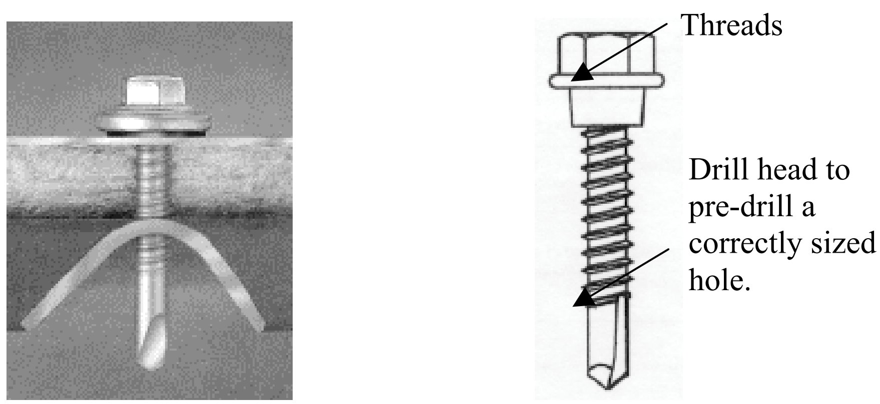


Fig. 7. Typical Self-Drilling Sheet Metal Screws

3.1.3 Wood

Wood screws are normally used to connect seismic anchorage to wood because of their high tensile load capacity and their removability. Larger wood screws may also need a pre-drilled hole to facilitate installation and to prevent splitting.

3.1.4 Adhesives

A wide variety of adhesives are available for wood, metal, and plastics, and even concrete, including glue, epoxy, and double-backed tape. Considerations for use of these products as attachments of seismic restraint are discussed below.

Nondestructive removability: In most circumstances of restraining contents, it will be desirable to remove the restraint with a limited amount of damage to surfaces of the item as well as the restraining building element. Many adhesive products will permanently damage surfaces. Instant industrial adhesives based on cyanocrylate, for example, provide extremely high strength, but are difficult to work with and are difficult to remove without damage or use of powerful solvents.

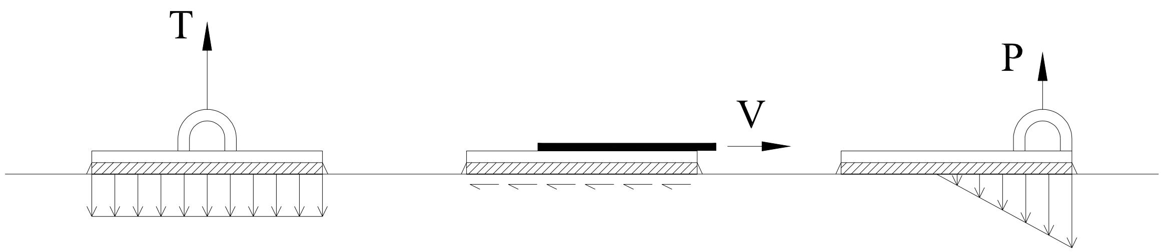
Resistance to environmental effects: The strength of some adhesives degrade, notably epoxies, when exposed to sunlight or certain chemicals, or with aging. The characteristics of the adhesive should be investigated although the information may be difficult to obtain from manufacturers.

Sensitivity to installation and overall reliability: Most adhesives are sensitive to installation procedures and the manufacturer's recommendations must be strictly followed. For example, when raised computer floors came into use, the small pipe- or tube-columns used for support were installed by gluing the column's steel base plate to the structural floor. Although in the ideal case these connections were very strong, their installation conditions varied widely, and ultimately the adhesive connection was judged unreliable to resist seismic forces, and building codes now require bolted connections.

Industrial double-backed tape (VHB™ by 3M®) is often used in commercial seismic restraints for contents because of its convenience and potential strength. Other than cleaning of surfaces, no installation instructions are normally given. However, 3M recommends applying a pressure of 15 pounds per square inch of area to gain full contact and adhesion. For light countertop devices that consist of small plates with double-backed tape, this pressure (about 35 pounds for a 1.5 inch square plate may automatically be applied by a user. However, a 2x3 inch plate would require 90 pounds of pressure, unlikely to be applied without specific instructions, particularly on a vertical surface.

Strength ratings: For nonindustrial adhesives test results are seldom available to determine reliable strengths in different circumstances of use. Although each and every seismic restraint need not be designed, the range of expected seismic loadings are known and should be considered if pre-designed restraints are not used.

However, the load "rating" of the adhesive must be carefully examined. For example, a common use of adhesives is attaching flat plate elements or angles to a benchtop, cabinet wall, or to a flat surface of the component itself. Such an installation is shown in Figure 8. Loading *T*, pure tension, shown in Figure 9a, assumes the load is applied either to the exact center of the plate, or uniformly across the plate (which is seldom the case). Double-backed tapes commonly used for seismic restraints will hold 100 pounds per square inch (psi) of contact surface in such a loading case. Figure 9b shows a similar pure loading case in shear, where the load, *V*, is applied almost in line with the adhesive (practically impossible to achieve), and tests have shown that the tape will also hold 100 psi for this loading case. Figure 9c shows the more common case in actual applications, where the load is applied to the edge of the plate, tending to "peel" the plate from the substrate. Loading capability of the tape for this case is considerably smaller, as little as 20 psi of contact area average. Loading similar to the *T* case, but at an angle to the plate, or the *V* case, where the load may be located an inch or more above the surface of the adhesive, can also cause significant reductions to the 100 psi rating of the tape. Similarly, this tape is not all intended for constant loading (a hanging weight for instance), and the load capacity drops to less than 5 pounds per square inch in that situation. Details suggested in this manual using these kinds of adhesives take these characteristics in account.



100 pounds per square inch in pure tension.

100 pounds per square inch in pure shear.

As little as 20 pounds per square inch average in peeling.

(a) (b) (c)

Fig. 8. Adhesive Installation and Loading

3.1.5 Various Connectors for Gypsum Wall Board or Plaster

Nonstructural walls in buildings, often called “partitions,” are most often made up of steel or wood vertical elements (studs) spaced at one to two feet apart and covered with ½" to 1" of gypsum wall board or plaster. There are many fasteners manufactured to attach light loads to these surfaces such as plastic plugs that expand when a screw is inserted, or “mollybolts” and “butterfly” anchors that open up to create a threaded nut on the inside face of the wall. These anchors are intended for pictures, light shelving, or other decorative items, are dependent on the integrity of the gypsum board or plaster for their strength, and, in general, should not be used for seismic anchorage. However, plaster surfaces, depending on the thickness of plaster and the style of lath, can be quite strong, and can be suitable for seismic anchorage for smaller loads. In instances where such uses are unavoidable and backing plates are not available, a simple testing program can establish reliable tension loads for various styles of anchors. A safety factor of 3 against pullout, established by test, should be used against the design seismic loadings previously suggested.

3.2 COMPONENT ANCHORAGE LOCATIONS IN CSB 1

Typical conditions in labs in CSB 1 are shown in Figure 9. There are typically no ceilings in the lab area and the concrete structure of the floor above is exposed. The laboratory utilities run exposed overhead, supported on trapezes. The trapeze structures do not necessarily have any excess loading capacity and should not be used to support or brace lab contents. If such a use is required, an engineer should establish adequacy of the support. The floors are generally protected against fluid spills by vinyl tiles or coating. Walls are either concrete (see Figure 3 for locations) or steel stud and gypsum board. The typical built-in lab benches and cabinets are wood, attached to vertical unistrut posts running from floor to structure above. These posts are designed to support the over-bench shelving or cabinets and their contents, and should not be used to support additional equipment or to provide seismic restraint for anything but incidental benchtop equipment or small, floor-mounted residential-type refrigerators. The typical office area is shown in Figure 10.

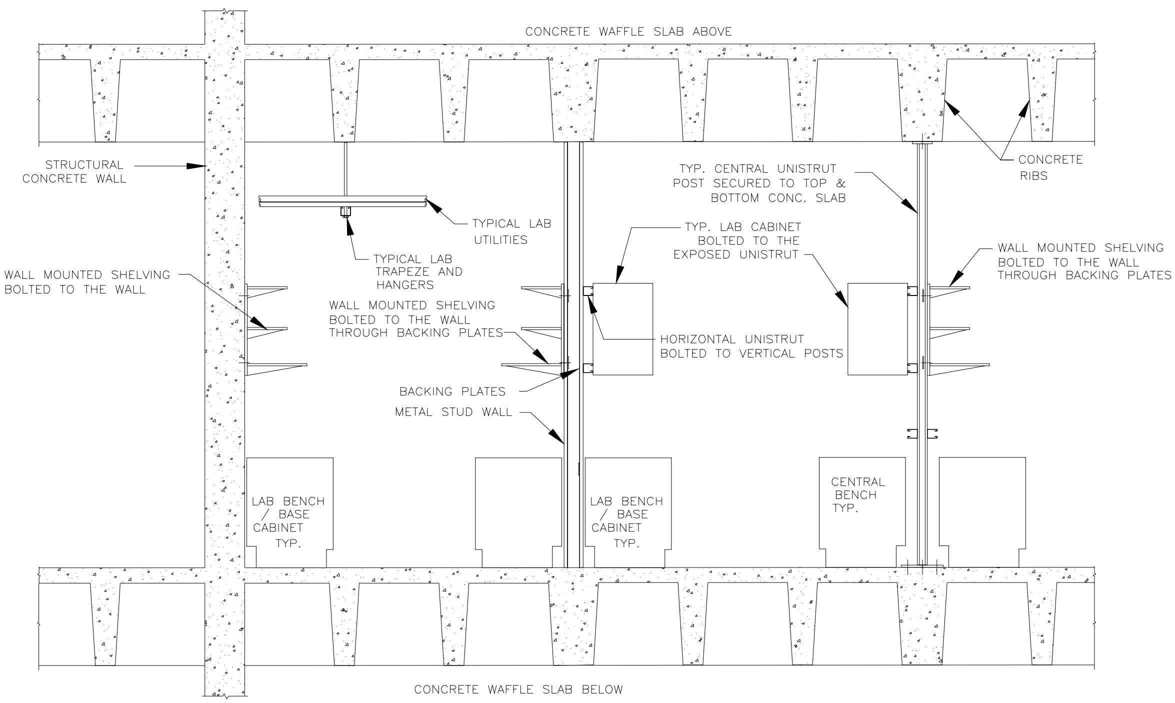


Fig. 9. Typical Lab Conditions

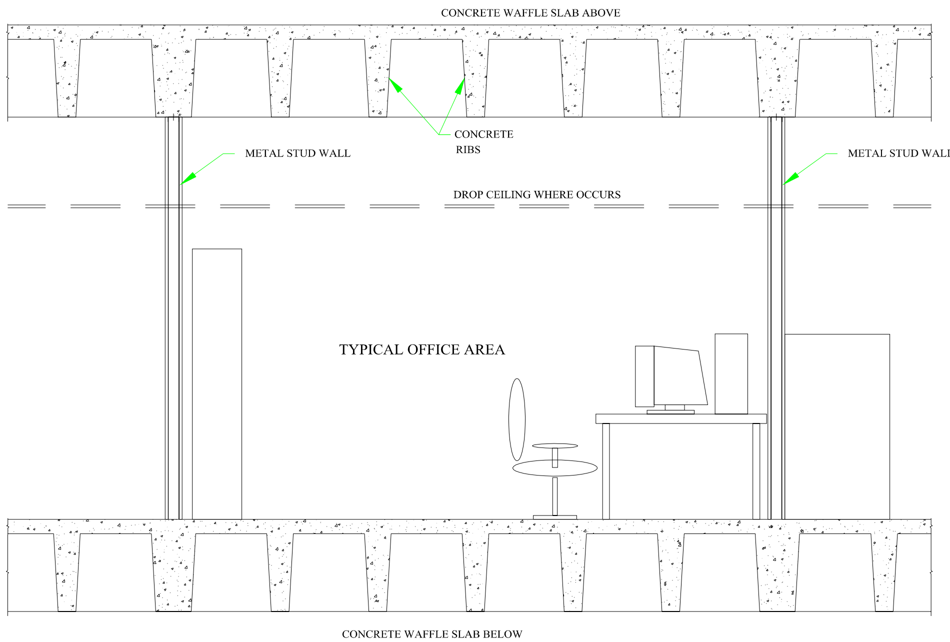


Fig. 10. Typical Office Conditions

3.2.1 Anchorage to Floors

Floors throughout the building are concrete waffle slabs, except in the basement, which has a 6" thick slab-on-grade. The waffle slabs were previously described and the concrete slab is 4½" thick, except directly over one of the deeper rib joists. Care should be taken to not drill through the slabs, so the maximum depth of hole in the waffle slab is 3" and in the basement slab, 4". Many drilling systems used for installation of mechanical and chemical anchors will easily cut through reinforcing steel embedded in concrete. Magnetic bar detectors can be used to find bars located close to the surface that could possibly be cut. Main reinforcing steel is located directly over rib joists at a depth of 2" and these bars should not be cut. Smaller bars are also located in the slab areas and they should also be avoided if possible; however, these bars can be cut if it is difficult or impossible to relocate a hole. Current requirements for laboratory floors include resistance to moisture or chemical penetration that could easily be compromised by drilled-in seismic anchors. A completed installation of a mechanical anchor will certainly break a surface seal and could lead to a penetrable floor as well as corrosion of the anchor inside the hole. Chemical anchors are less likely to cause these problems, but the acceptability of any anchorage into laboratory floors should be checked with the appropriate building staff.

3.2.2 Anchors to Overhead Structure

Anchors may be placed in the concrete surfaces of the undersides of the waffle slabs. Anchors should not be placed on the bottom of ribs as main reinforcing runs 1½" from the surface. Anchors may be placed into the sides of joists (above the bottom reinforcing) or to the bottom surface of the slab. See Figure 11. Chemical anchors should not be used in a configuration that will put them in constant tension (e.g., hanging an item from the slab soffit) because epoxy under constant loading will creep.

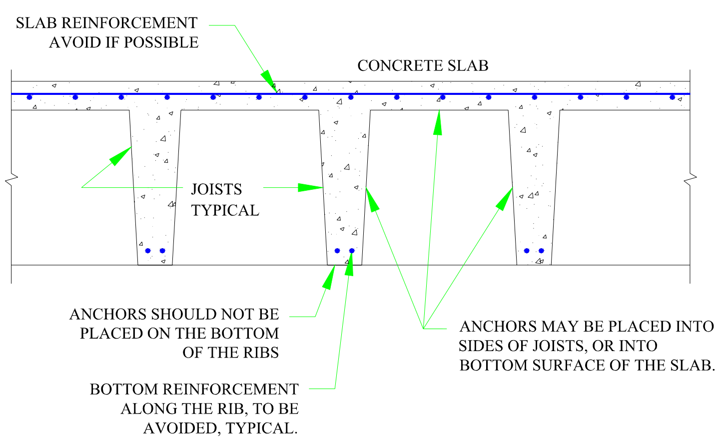


Fig. 11. Anchors to Overhead Structure

In general, anchors should be avoided to suspended ceilings. There are two types of suspended ceilings in CSB 1. Some office areas contain suspended ceilings of gypsum board or gypsum lath and plaster which are supported by light-gauge metal angles attached to the main runners that carry the ceiling finish. The other type of suspended ceiling used in CSB 1 is the metal ceiling panels used in corridors to cover mechanical and electrical piping above.

In general, it is recommended to not attach anything to the mechanical, electrical, or piping utilities in the building. However, pipe trapezes may be used to support light loads (of less than 20 lbs).

3.2.3 Anchors to Concrete Walls or Columns

Concrete columns and walls are located in CSB 1 as noted on the plans in Figure 3. The main concern with installation of drilled-in anchors on vertical concrete surfaces is cutting of reinforcing bars. Vertical bars in columns or at the edges of openings should never be cut [Figure 12]. Other reinforcing steel in CSB 1 walls is similar to slab steel: it should be avoided, but could be cut if other options are not available.

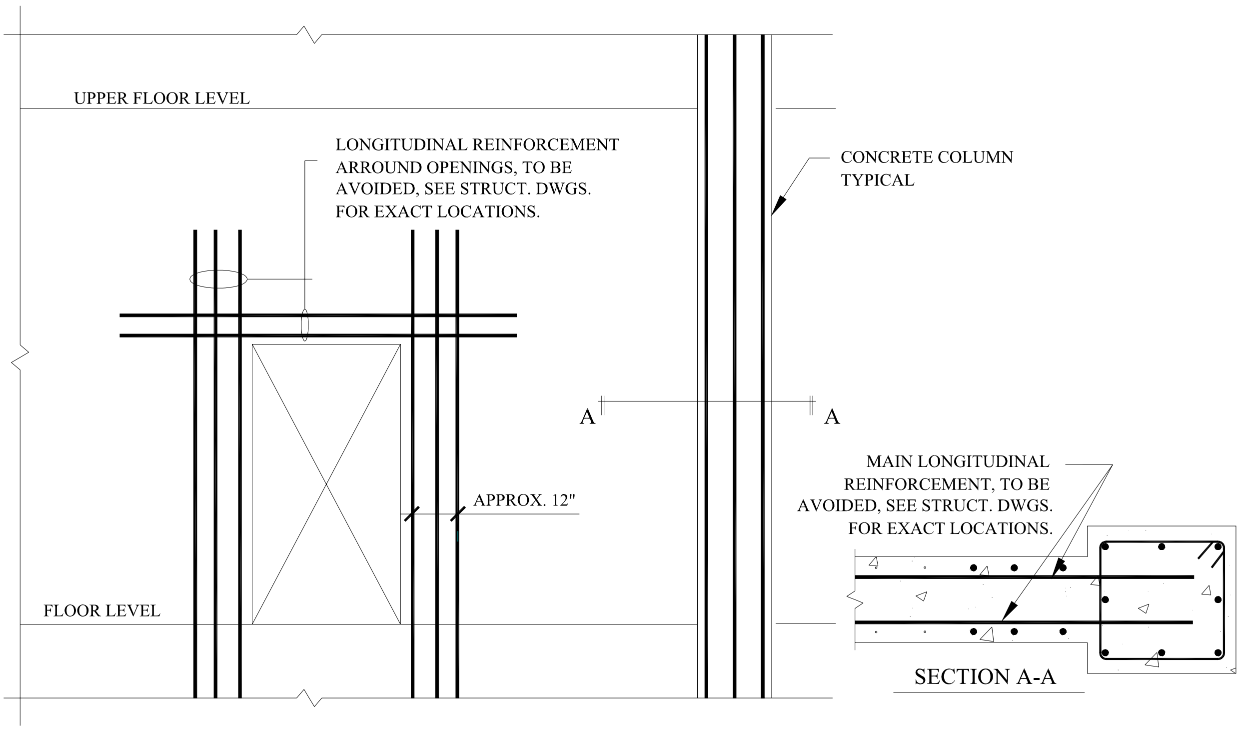


Fig. 12. Anchor to Concrete Walls or Columns

3.2.4 Anchors to Non-Concrete Walls

Nonstructural walls in this building are steel stud partitions consisting of 3 5/8" deep, 20 gauge studs spaced at 16" on center spanning vertically 11'-6" between the floors and the bottom plane of the waffle slab above. Continuous channel-shaped steel tracks support the studs top and bottom. The studs are positively attached to the floor track with screws and are only laterally restrained at the top track to allow for differential movement between floors. A single top track, assumed to be 16 gauge, runs continuously at the bottom of the waffle, sometimes aligned with a joist rib and sometimes running across ribs. For sound control or fire protection, the space between waffle ribs is filled with gypsum board directly above partitions, attached only to a track placed at the perimeter.

Connections to steel stud walls must be attached either directly to a stud or through a backing bar. Connection to the studs is limited by location and surface area. Normal backing bars are steel plates or channels installed at the time of original construction under the gypsum board spanning between studs. The only internal backing bars installed in this building during construction were located at known anchorage locations such as built-in cabinetry or shelving. Backing bars also can be installed when construction is complete, but wall finishes must be locally removed and replaced in a significant area of wall. When anchoring contents in locations with no internal backing bars, it is more common to add an external backing bar on the surface of the wall consisting of a unistrut element extending across three or more studs and attached directly to them with self-tapping screws. The elements of a steel stud wall are shown in Fig. 13.

It is difficult to anchor most floor supported to the floor because it is not designed for such anchorage (exceptions include some tanks and other equipment that have legs and mounting holes suitable for bolting to the floor). The attachment itself may damage the equipment and anchorage loads during an earthquake can damage the frame, the mechanisms, or the contents. The partitions in laboratories are conveniently located to provide restraint not only for floor-mounted equipment and moveable tables and racks, but also for heavier bench and table mounted equipment. However, the top track detail used in this building limits the use of partitions as a source of seismic restraint. These limits are indicated in the seismic anchorage details recommended for the building in Section 5. In general, the limits are set by the top track detail. However, the top track can be reinforced by angles installed on each side of the wall in the plane of the top track, and, in combination with installation of exterior, continuous backing bars, the walls can be made to provide restraint for most large upright, floor mounted equipment found in labs. If equipment exceeds the weight limits given for the retrofitted wall, or as an alternative to retrofit, new vertically-spanning structural elements, called strongbacks, can be installed.

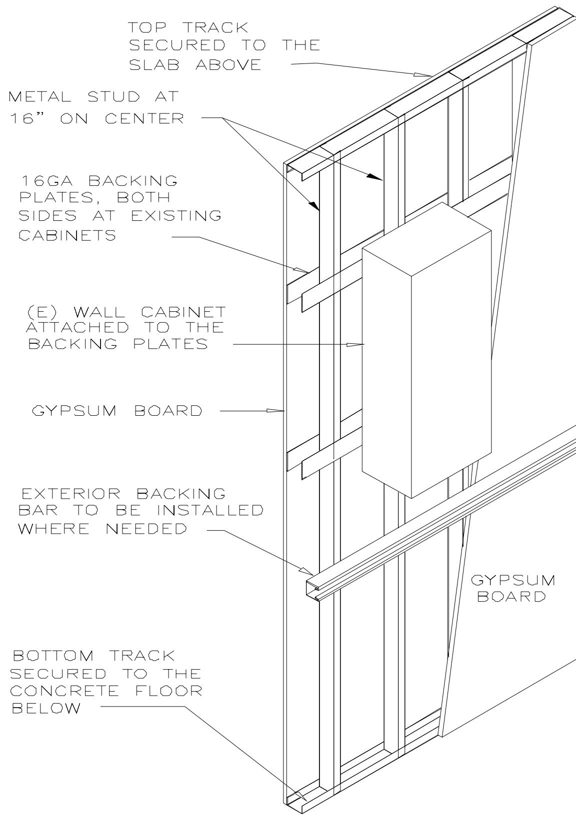


Fig. 13. Typical Metal Stud Wall

3.2.5 Anchors to Built-In (Anchored) Lab Furniture

A common component of a typical laboratory is the island bench. It consists of two rows of freestanding back-to-back benches, often with shelving above them supported by central steel posts or strongbacks. A strongback is a steel tube or other structural element running from the floor below to the structural floor above to provide lateral support of furniture or contents. See Figure 15. These benches and their supporting strongbacks can be used to restrain light- and medium-weight equipment on the benchtops or nearby as shown in the details in Section 5.

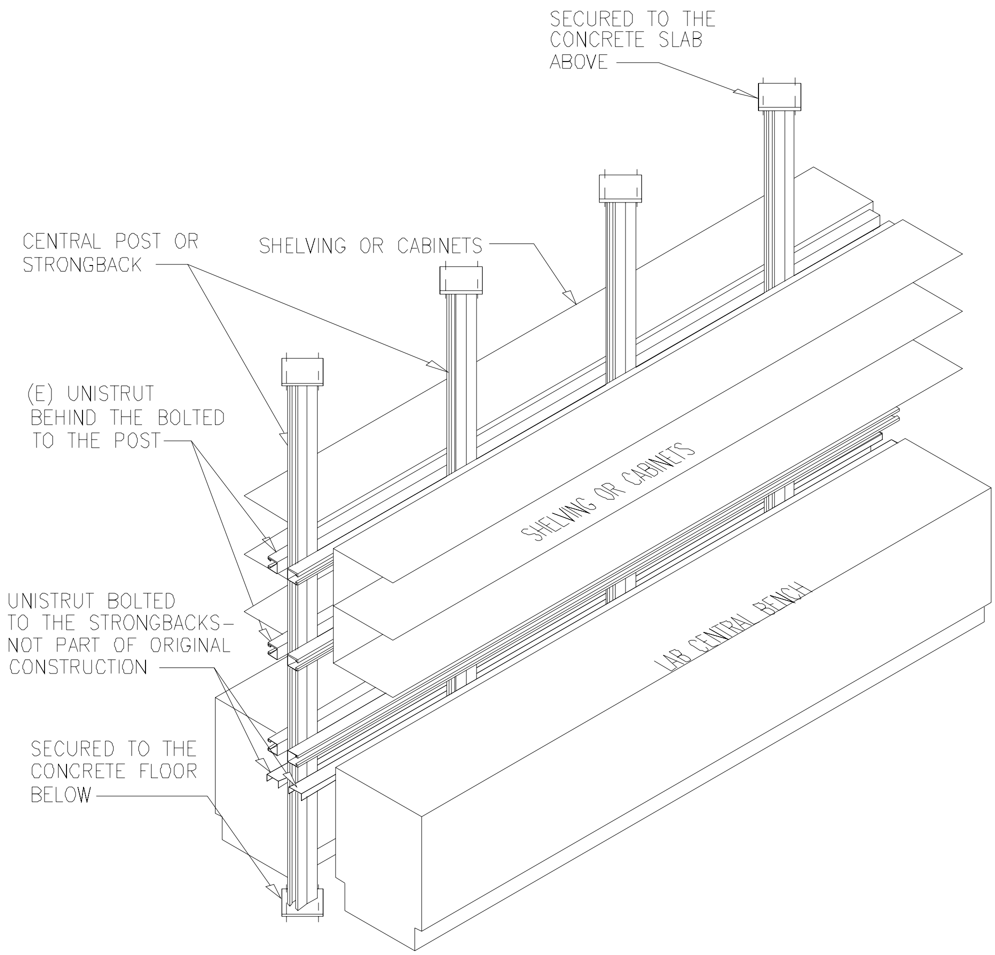


Fig. 14. Typical Lab Island Bench and Shelf System

In the CSB 1's island workbenches, Unistrut P1001's at 48" on center are typically used. Benches are bolted to both of the Unistruts and to the concrete floor below. Cabinets are typically supported by a pair of Unistruts running horizontally along the length of the bench and bolted to the vertical posts. Another horizontal Unistrut may be installed about 6" higher than the bench and bolted to the central posts. This Unistrut may be used to support several light items as shown in Section 5.

Where lab benches, cabinets, or bookshelves are located next to a wall, they are typically anchored to the concrete floor below, the wall behind, or both. Original lab furniture in CSB 1 may be considered anchored. Anchorage of furniture that has been moved or installed as part of a remodel must be verified.

Freestanding tables, cabinets, files, or shelves may be considered as possible candidates to restrain other light objects. However, the element itself must be secured before any such restraint can be considered effective.

4 Guidelines for Providing Seismic Protection

Examples of items that are considered user-supplied contents are given in the Introduction. Protection of these items against damage caused by earthquake shaking, even though such shaking may be rare, may be desirable to avoid the following types of losses:

- Life safety of occupants: Life safety can be threatened by heavy objects falling or tipping directly onto occupants, or by sliding or tipping into a position that blocks egress from a work area. Life safety risks can also be created in a laboratory by release of hazardous materials, either directly by broken containment, or by two or more released materials combining to create a hazardous substance.
- Protection of data, other results of experiments, or ongoing experiments: Data or other results of experiments may be one of a kind, difficult to "backup," or take years to replace. Ongoing experiments may represent investment of enormous time and/or resources. Even if protected from direct physical damage due to shaking, interruption of certain utilities or supplies could damage or ruin future results.
- Protection of valuable or hard-to-get equipment: Specialized equipment in labs often represents a large investment that should be protected, or may be difficult or time consuming to replace, or both.

The obvious response to the threat of damage from earthquakes is to provide restraint for all contents in the laboratory environment. The two primary reasons why this may not always be necessary or appropriate are cost and the potential effects of seismic restraint on the function of the element or the lab as a whole. Costs of providing seismic protection to the complete contents of typical labs could cost as much as $20 per square foot. Restraining a portable benchtop instrument with a quick-release system to facilitate changes in location may affect efficiency and is likely to not always be implemented by staff. Providing a docking station for wheeled equipment may take up space and inhibit movement in the room. In addition, in areas of lower seismicity, serious damage is far less likely and only the highest priority items may warrant protection.

It is therefore prudent to prioritize contents with respect to their potential to cause losses in the three categories discussed above. It is possible to develop evaluation systems that will result in a single priority rating for each element based on concerns for all three types of losses, but such systems are complex and require many qualitative judgments.

Rather than complex evaluation systems that combine the potential for each type of loss, it is suggested that a simple linear system be used that considers the risk presented by each element in each category in turn. It is recommended that *Life Safety* issues be considered first, then *Importance*, and *Dollar Value* third, although any order could be used. Any element that is judged high priority in the first category need not be considered for the second and third categories, and so on.

Considerable judgment will be required by the users to place the contents of their lab into one or more priority levels, but the systematic approach suggested will greatly assist the process. Some users may conclude that all the contents of their lab should be provided with seismic restraint. Studies of five labs at UC Berkeley concluded that the cost of providing complete seismic restraint ranged between $10 and $16 per square foot of lab. It is recommended that $15 per square foot be used for a budget figure. Based on subsets of priorities developed from consideration of potential losses discussed above, costs of providing seismic restraint can be estimated as a proportion of this $15 per square foot figure (e.g., if approximately 50% of all items will be restrained, assume it will cost $7.50 per square foot). The costs of providing various levels of seismic restraint must be weighed against the potential damage and loss to arrive at an appropriate scope of work for each situation.

Additional guidance for setting priorities within each category follows.

4.1 LIFE SAFETY

"Life Safety" is a well-known phrase dealing in general with the health and welfare of people. In earthquake engineering, an acceptable state of life safety is somewhat undefined but is normally interpreted as the prevention of deaths—and possibly life-threatening injuries—but certainly not prevention of all injuries. In other words, considering the rarity of seismic events, providing an injury-free environment is not considered cost-beneficial—if possible at all. There is little data from which a direct relationship can be made between seismic restraint of laboratory contents and seismic protection intended by the building code with respect to life safety. The guidelines in Table 4 are aimed at prevention of serious injury as opposed to life-threatening injury, although the distinction may be subtle. Being struck by a 20-pound object falling from 5 feet or more from the floor clearly could cause a death, but is more likely to cause a serious injury. The limit of 20 pounds and the height of 5 feet are both arbitrary limits and are taken from the State of California's code governing hospital construction. Similarly, the size and weight of unrestrained floor-mounted equipment that could become dangerous during earthquake shaking are unknown. 400 pounds is often, but the source and validity of this weight is questionable. 200 pounds is suggested in this manual. Lastly, building codes and other standards sometimes consider a permanent connection to utility systems (gas, water, and power) as a trigger for seismic protection, presumably due to the potential secondary hazard from breaking such a connection. The guidelines in Table 4 therefore should be considered judgmental and are given for general guidance.

There is virtually no guidance available for limits on the sliding of large and heavy objects. Sliding, presumably with considerable friction between the device and the floor, is differentiated from rolling, such as the case with a heavy, wheeled cart or tank. Once set in motion from impact with a wall or lab bench, the wheeled device has little to slow it down and could become a dangerous projectile. On the other hand, friction at the base of the nonwheeled object will quickly slow and stop the movement and additional movement will come only from additional seismic floor motions. If overturning is unlikely and prevention of sliding is not required to prevent breakage of connected utilities, the level of risk to life safety is unknown, but probably small. The device could pin an occupant against a wall or other fixed object, causing crushing injuries, or could gradually slide into a position to block an exit. These events are unlikely but possible. The benefits of restraint of such elements must be weighed against the "costs," including the cost of providing the restraint itself, a potential disruption of operations, and a potential increased damage to the contents of the device due to transfer and possible amplification of floor motion from the anchorage.

Any items that are determined to present a *Life Safety* risk, and will be restrained for that reason, can be set aside from evaluation for *Importance* or *Dollar Value*.

Table 4. Life Safety Risk Levels

<table>
<tr><th>Of Concern</th><th>Intermediate Concern</th><th>Low Concern</th></tr>
<tr>
<td>
Potential spill of hazardous substance or chemical combination into hazardous substance
Item weighing 20 lbs or more stored or mounted 5 ft or more above floor
Countertop equipment permanently connected (hard wired or plumbed) to building or laboratory utility systems
Freestanding storage racks, or cabinets over 5 ft tall
Floor mounted equipment weighing more than 200 lbs., over 5 ft tall, or with width less than 2/3 of height.
Wheeled equipment, tanks, or racks normally weighing over 200 lbs (including contents):
when over 5 ft tall or with width less than 2/3 of the height
Other items judged by users to be dangerous to occupants in earthquake shaking
</td>
<td>
Countertop items weighing 50 lbs or more
Unrestrained storage cabinets or racks less than 5 ft tall and with width less than 2/3 of height
Wheeled equipment, tanks, or racks normally weighing over 200 lbs (including contents):
When less than 5 ft and with width greater than 2/3 of height (could be tethered when not in use)
Items on wheels weighing less than 200 lbs
</td>
<td>
All items not fitting, or similar to, other categories
</td>
</tr>
</table>

4.2 IMPORTANCE

Importance in a lab environment is not always proportional to size and weight. The importance of an item with respect to its value as data, results of experiments, or in saving, protecting, or maintaining data, other results of experiments, or ongoing experiments can be judged only in each lab. Importance can be assigned in any number of priorities, but complexity of the rating system is directly proportional to the number of categories. One lab decided that this rating could be simplified into only two characterizations: “important” or “not important.” Assuming that important items will be seismically protected, these items can be set aside from evaluation for *Life Safety* or *Dollar Value.* See Table 5 for suggestions of parameters to determine relative importance.

4.3 DOLLAR VALUE

Similar to *Importance*, the threshold for concern about dollar losses from damaged equipment or other items in the laboratory can be set only by the individual lab or institution. The time that replacement would take should also be considered, although this issue may also be considered under *Importance*. Since many fairly common computers, microscopes, and similar equipment are valued at $5000 or less, this figure could be used to describe the lowest priority category (assuming *Importance* is judged independently). An upper value, for example, of $100,000 or $250,000, to which the highest priority is assigned, should also be set. Setting such high and low figures creates three categories to prioritize seismic protection.

Table 5. Importance Measures for Equipment and Materials in the Laboratory

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)

5 Recommended Anchorage Details

This section describes detailed anchorage and restraint that will apply to most contents of CSB 1 labs. Lab users can install some of the restraint details, but some details will require installation by experienced trades-persons that are part of the building staff, the university staff, or are employed by private contractors. Very specialized lab equipment or experimental setups may be heavier, larger, or of a configuration that does not fit into the categories covered. Seismic restraint for these items must be custom-designed by a civil or structural engineer experienced in earthquake engineering.

Contrary to anchorage of most mechanical and electric building systems equipment, it is not generally recommended to restrain owner-furnished contents by bolting to the floor. Exceptions include tanks with mounting legs, certain cylinder restraint products that are designed with plates and bolt holes for floor mounting, and the base connection of strongbacks. Most floor-supported equipment is mounted on wheels, leveling legs, or a framework not designed to anchor the weight of the equipment for earthquake loads. Unless the manufacturer certifies the base of such equipment for such anchorage, it is recommended to provide restraint from existing partitions or to install steel strongbacks. In addition, it is desirable to minimize drilling holes into the floor structure which compromises the moisture proofness of the floor, may form a trip hazard, and will be hard to satisfactorily repair when no longer needed.

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. 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. The details shown for this equipment in CSB 1 uses a commercially available strap attached to the equipment by stud bolts on a plate adhered to the surface with double-backed 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 designs are not available, or require load testing. An alternative to this detail is shown in Figure 16. The restraint provided by overhead "hangers" will prevent overturning or excessive sliding and will probably reduce shock transmission. The cost of the sizable strongbacks and overhead beam must be weighed against the cost of installation of the smaller strongbacks required for the commercial device. In addition, the system requires engineered design for the specific location in which it will be implemented.

Loading limitations or other limitations of use are given for the recommended details. For equipment that falls outside the load or configuration limitations shown, engineered design is necessary for seismic restraint.

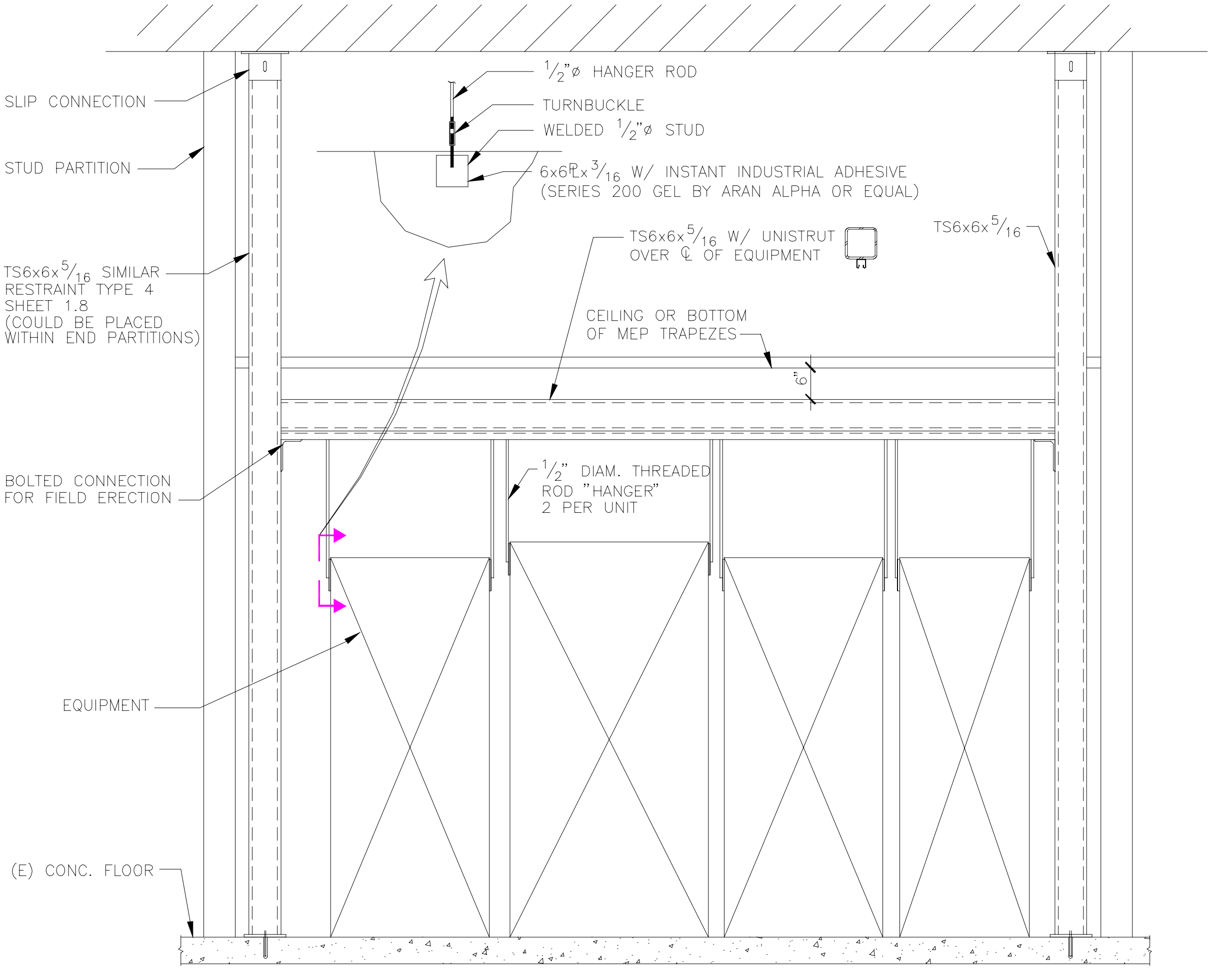


Fig. 15. Alternative Equipment Restraint System at Equipment Halls
(Requires Engineering Design)

General Notes

1. Source of Material:

   A. The structure and configuration of the existing building is based on construction drawings, dated 14 November 1985.

   B. "Typical" contents of labs on CSB1 was collected by Professor Mary Comerio and Research Assistants and was completed in the fall of 2002.

   C. Typical seismic restraint details were developed by Rutherford & Chekene, Consulting Engineers.

2. Intent of Basic Restraint: The details shown are intended to prevent excessive movement of the various elements during strong earthquake motion. This restraint is expected to protect occupants from serious injury and significantly reduce the incidence of functional damage to the component.

   A. Protection of Functionality: In addition to the Basic Restraint, continued functionality of restrained components following an earthquake is primarily dependent on the susceptibility of the component to damage from shocks transmitted through the restraint or, for smaller benchtop equipment, from potential overturning. Functionality may also depend on continued utility services such as water, electricity, or gases that are not addressed by these details.

   B. Protection of Contents: In addition to the Basic Restraint, the contents of shelving, racks, refrigerator/freezers, incubators, etc., must be protected from falling from storage location.

      1) Shelving: Typical shelving is provided with perimeter lips approximately 1 1/2" high. For sensitive contents, or for contents with heights of 3" or more, lips of one half the height of the contents should be installed. For further protection, protective racks or trays separating individual contents should be installed on shelves.

      2) Refrigerator/Freezer: These components should be provided with a positive door latch. For further protection, protective trays separating individual contents should be used on interior storage racks.

3. Materials, Fabrication, and Installation:

   A. Prefabricated restraint devices: Devices noted "Worksafe" are references to Worksafe Industries products. Alternative manufacturers of similar products shall certify equality of load capacity.

   B. Slotted channels: Devices noted "Unistrut" are references to Unistrut Corporation products. Alternative manufacturers of identical products are available.

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **NOTES**	SCALE: NO SCALE SHEET: **D1**

C. Fabricated Steel components (structural steel tubes and connectors): Fabrications shall comply with the Code of Standard Practice for Steel Buildings and Bridges.

1) Materials:

i Steel Plates, Shapes, and Bars: ASTM A 36

ii Steel Tubing: ASTM A 500

iii Steel Pipe: ASTM A53

2) Fabrication:

i All welders shall have passed AWS (AWS D 1.1, Structural Welding Code) qualification tests for the welding processes involved and, if pertinent, have undergone recertification.

ii Shear and punch metals cleanly and accurately. Remove burrs.

iii Ease exposed edges to a radius of approximately 1/32 inch.

iv Shop Primer: Fast-curing, lead- and chromate-free, universal modified-alkyd primer complying with performance requirements in FS TT-P 664; selected for good resistance to normal atmospheric corrosion and ability to provide a sound foundation for field-applied topcoats.

D. Fasteners:

1) Bolts and Nuts: Regular hexagon-head bolts, ASTM A 307, Grade A, with hex nuts, ASTM A 563.

2) Self-drilling screws for metal-to-metal or wood-to-metal: ITW Buildex TEK Screws or equal.

3) Lag Bolts: ASME B18.2.1

4) Wood Screws: Flat head, carbon steel, ASME B 18.22.1

5) Expansion Anchors to Concrete: Anchors with current ICBO/ICC-ES approval for use under conditions called for (diameter, embedment, through metal deck, etc.). Install in strict conformance with approval requirements and manufacturer's recommendations. Twenty-five percent of anchors shall be torque tested in accordance with approval requirements.

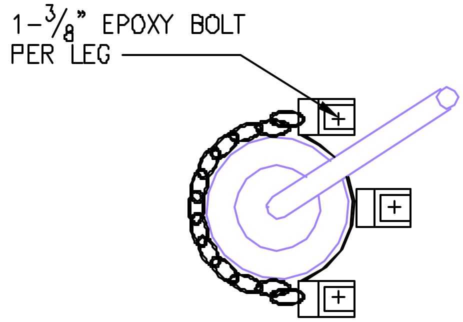
6) Epoxy Anchors: Anchors with current ICBO/ICC-ES approval for use under conditions called for. Select to minimize chemical off-gassing. Confirm with occupants that use is acceptable prior to installation. Do not use in overhead configuration. Install in strict conformance with approval requirements and manufacturer's recommendations.

7) Adhesive double-backed tape: 3M® UHB™ (does not gain full strength for 72 hours)

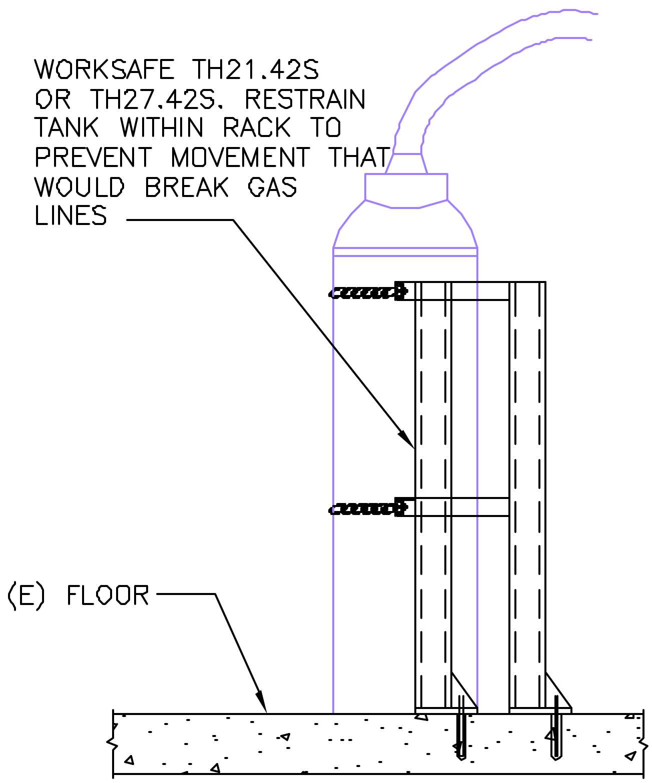
i For use on plates less than or equal to 4 square inches: Clean surfaces with isopropyl alcohol/water or heptane. Remove protective sheet immediately before applying. Apply with as much pressure as possible and hold to allow full contact and adhesion.

ii For use on plates greater than 4 squre inches: Plate shall have one pad factory applied. An identical pad shall be field applied to the target surface. After cleaning the surface, the field pad shall be applied incrementally while applying pressure with a metal or wood squeegee slightly wider than the pad. The entire surface will then be rolled with a 1" wide wood roller with firm pressure. The strap plate shall then be applied with as much pressure on the two pads as possible applied with a roller over the strap plate.

E. Exterior backing bars: Slotted channel members as called for in details, directly connected to the flanges of three metal studs minimum. The end of the slotted channel shall be extended 1" minimum and 6" maximum beyond the centerline of the outside stud. Exterior backing bars may be installed over 4 or more studs to provide a wall attachment location for various equipment. Stud locations shall be determined with a metal detector or probing. Connection of backing bars for use with seismic details shown here to gypsum board, plaster, or other wall surface material is not permitted without design by Engineer.



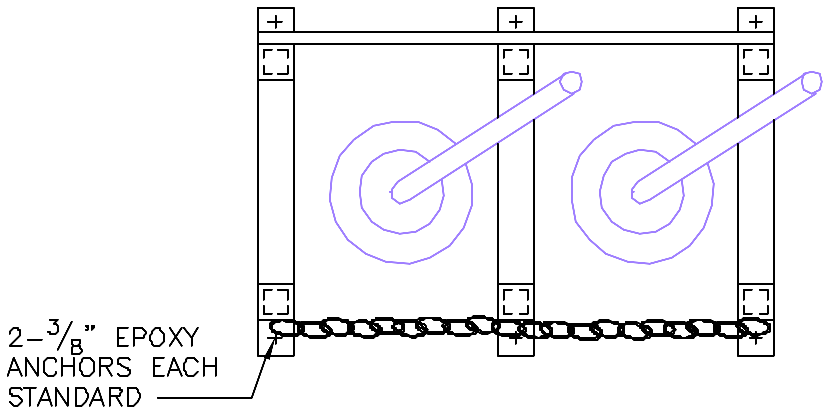
TOP VIEW



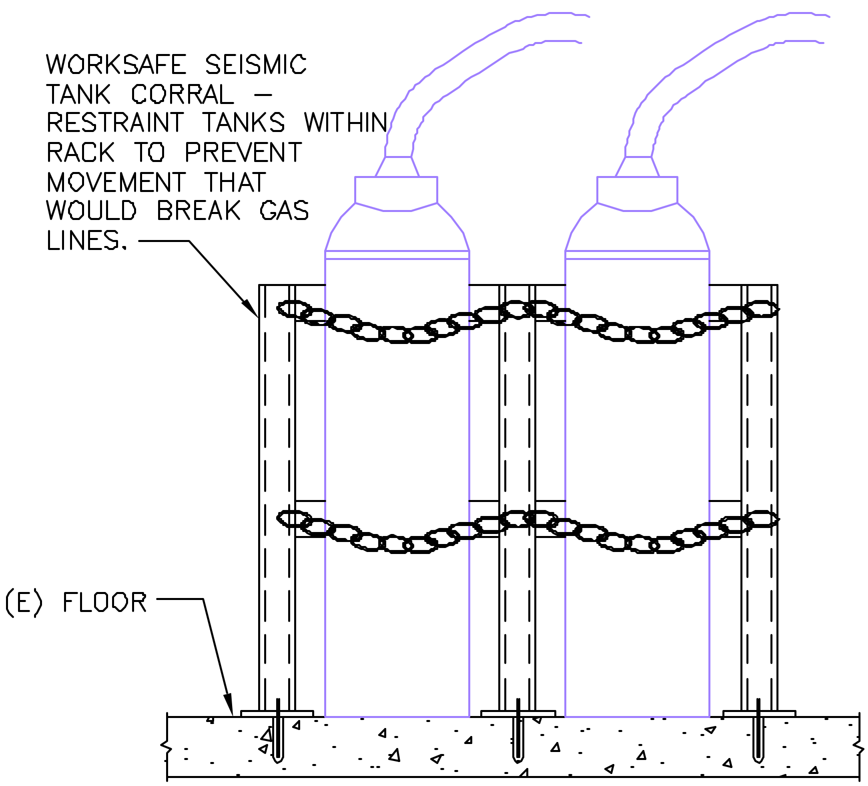
DETAIL T1

GAS CYLINDER RESTRAINT
(FREESTANDING – SINGLE CYLINDER)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D4**



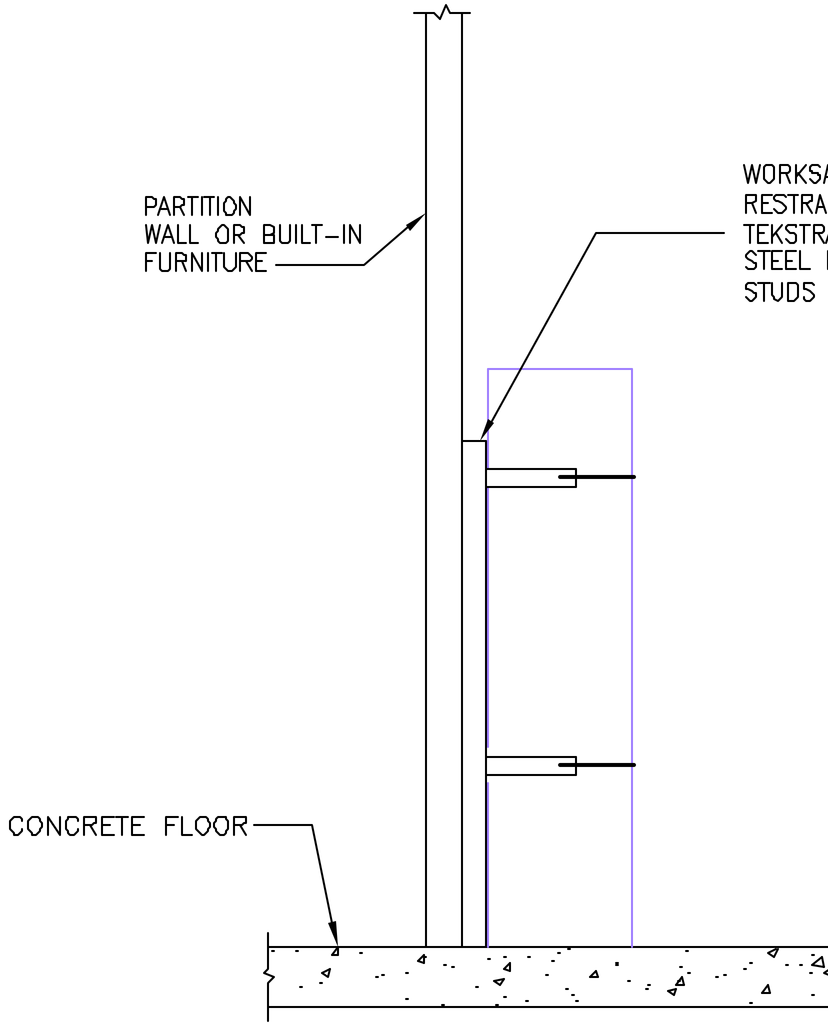
TOP VIEW



DETAIL T2

GAS CYLINDER CORRAL
(FREESTANDING - MULTIPLE CYLINDERS)

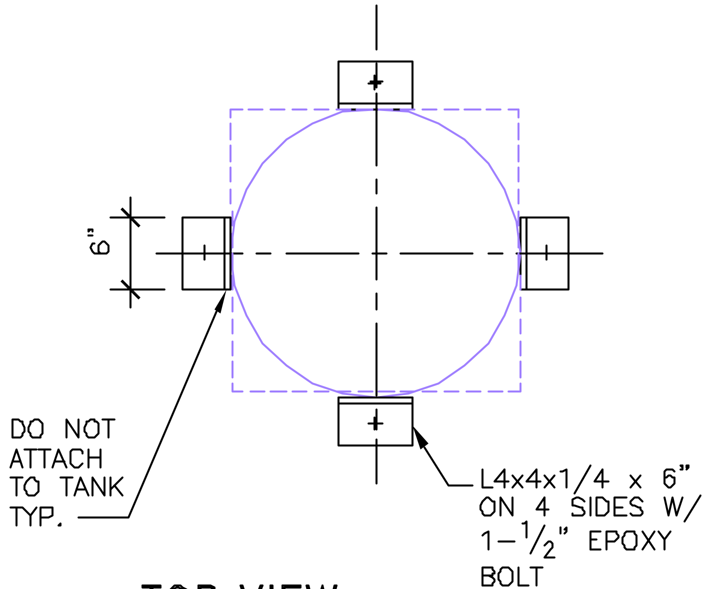
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE **D5**



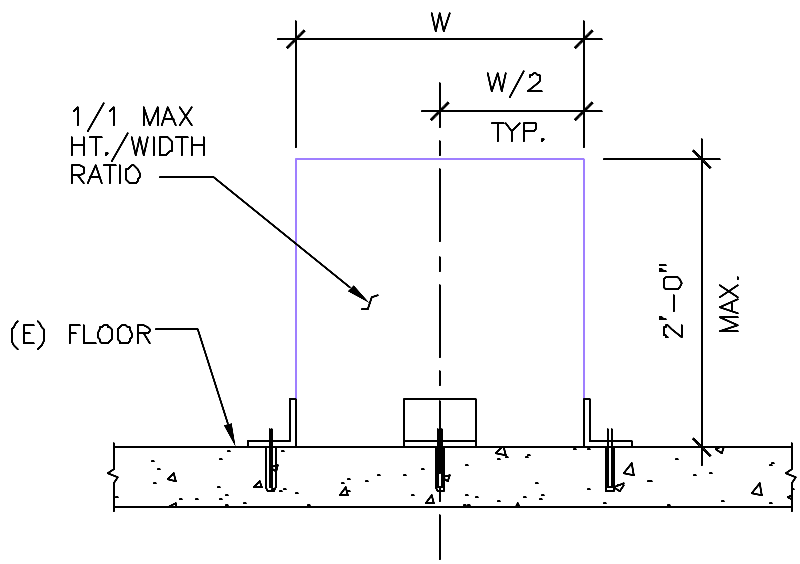
INDIVIDUAL TANKS
10–12" DIAMETER

DETAIL T3

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: TYPICAL TANK RESTRAINTS	SCALE: NO SCALE D6



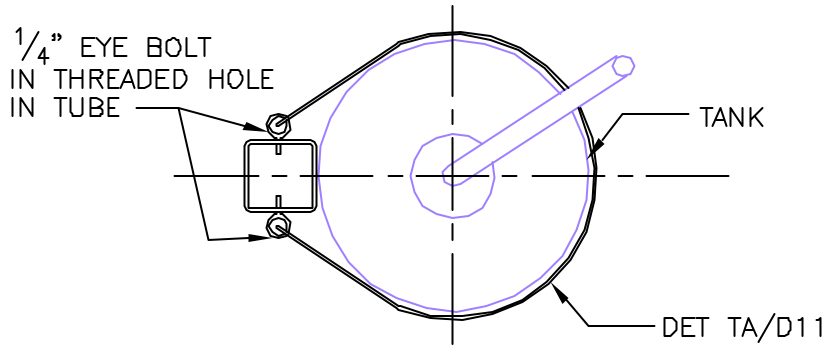
TOP VIEW



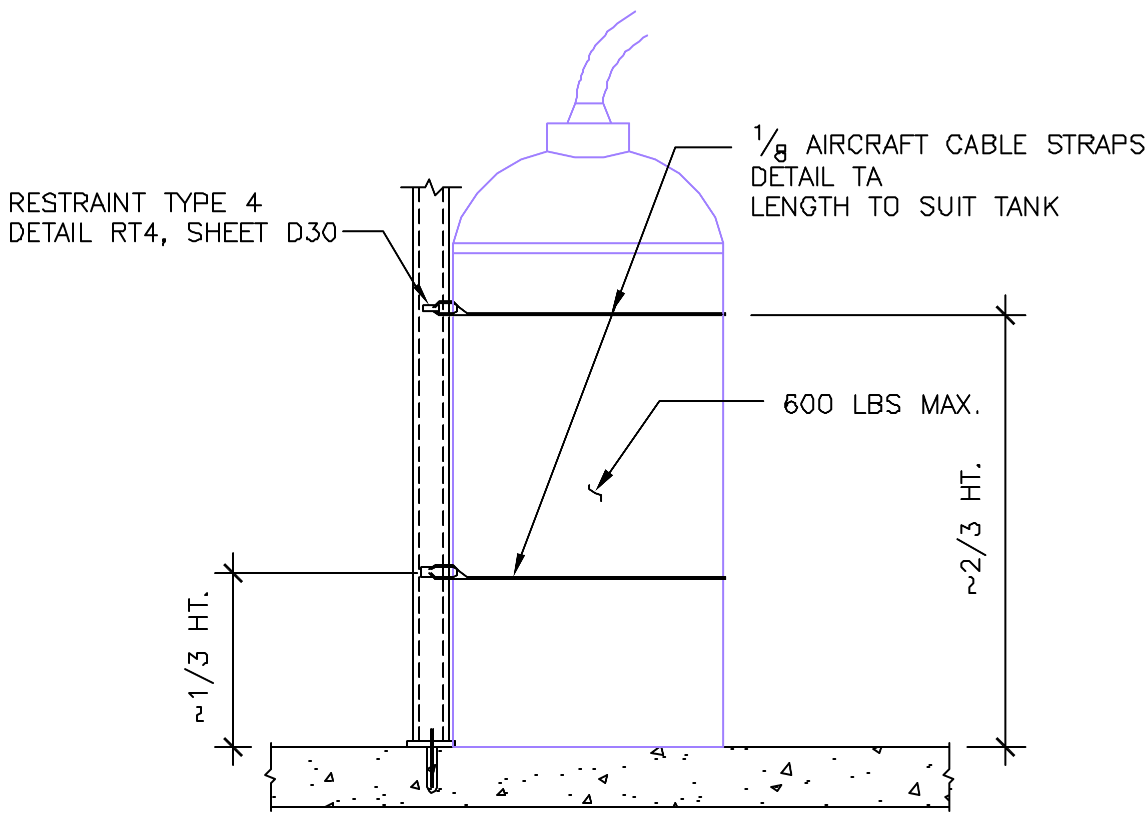
DETAIL T4

LOW PROFILE TANK RESTRAINT (FREESTANDING)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D7**



TOP VIEW

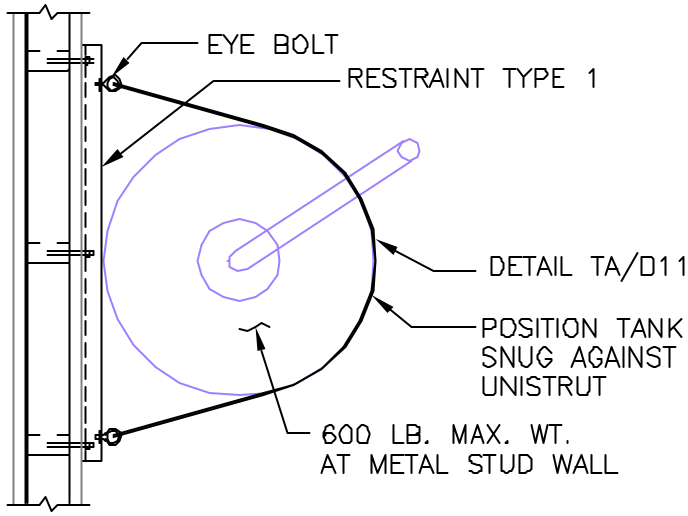


NOTE: IF TANK HAS BUILT–IN BASE OR LEGS, IT CAN BE BOLTED TO FLOOR W/ 3 MIN. 1/2" EPOXY BOLTS.

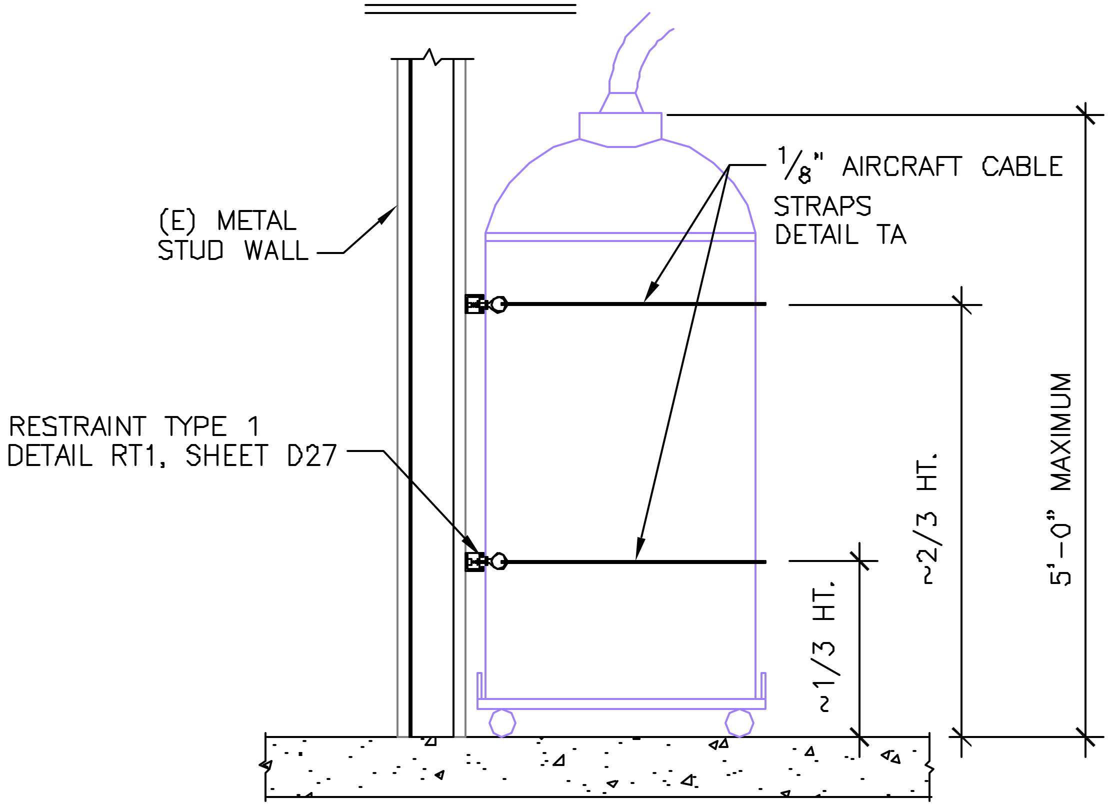
DETAIL T5

LARGE TANK RESTRAINT
(FREESTANDING)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D8**



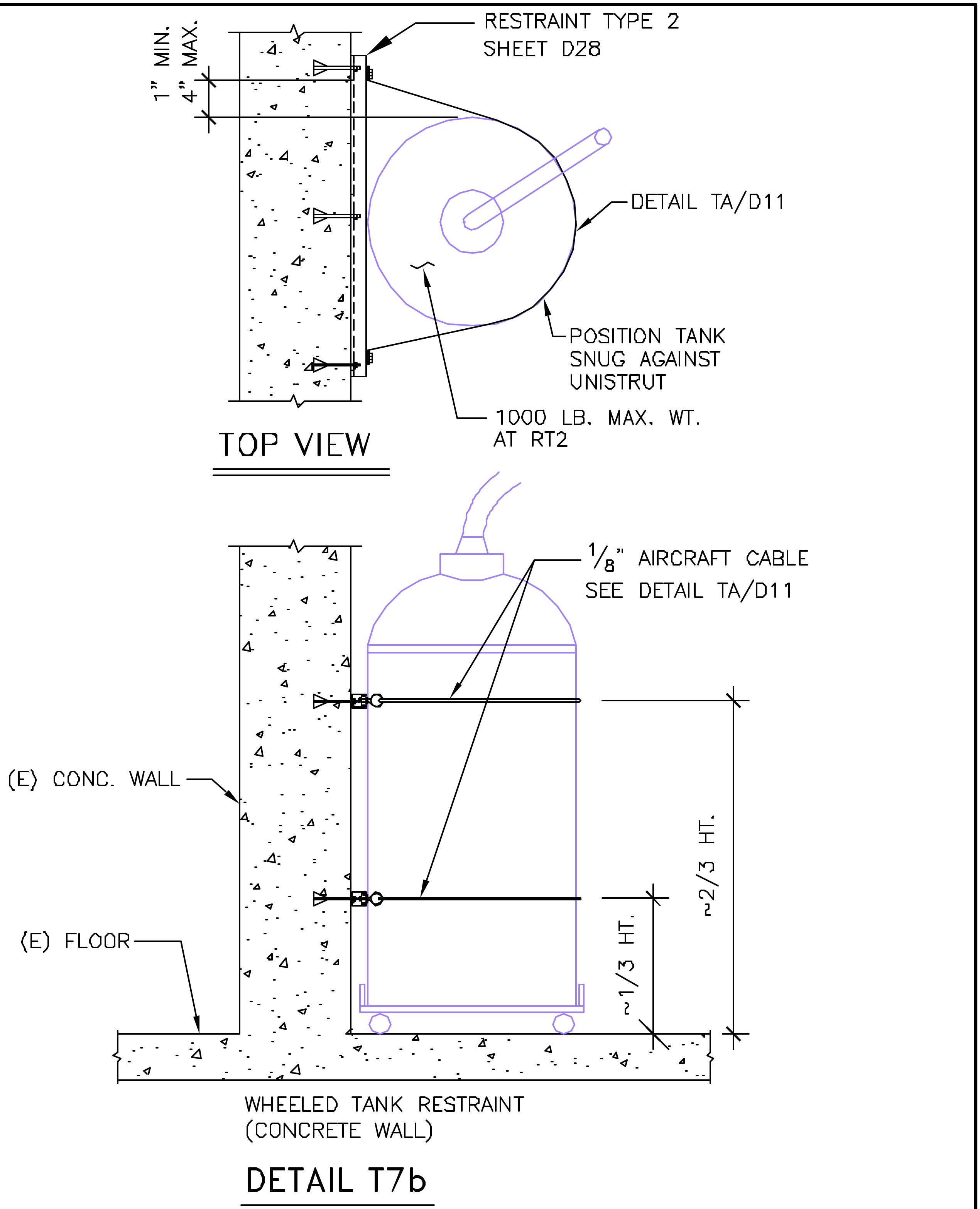
TOP VIEW



WHEELED TANK RESTRAINT (METAL STUD WALL)

DETAIL T7a

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D9**

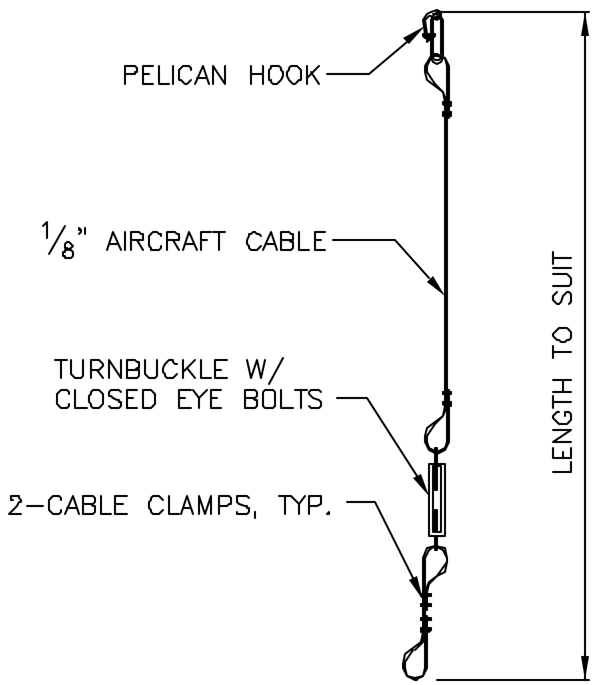


IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1

TITLE: **TYPICAL TANK RESTRAINTS**

SCALE: NO SCALE

SHEET: **D10**

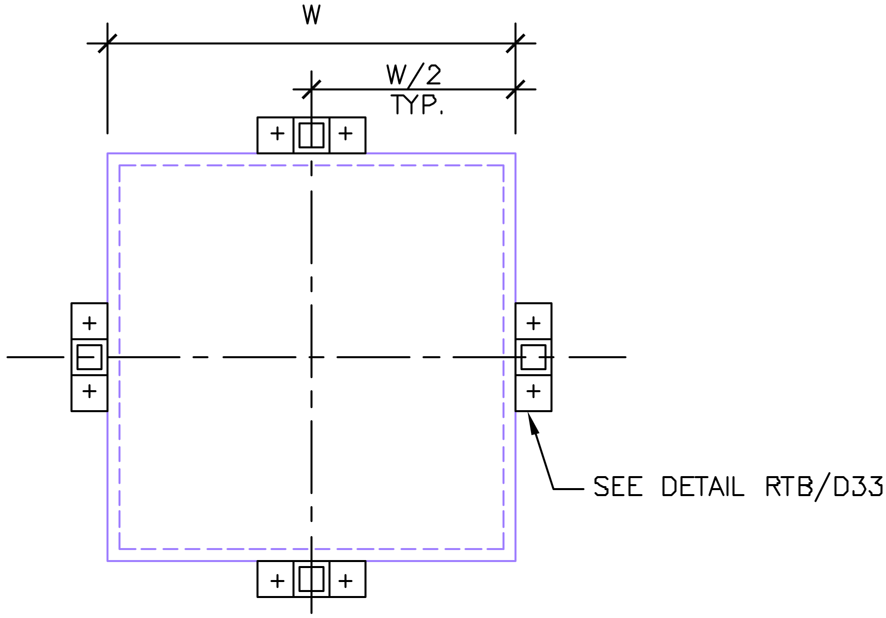


NOTE: IF LENGTH IS MADE SUCH THAT CABLE IS TIGHT WHEN PELICAN HOOK IS ENGAGED, TURNBUCKLE CAN BE ELIMINATED

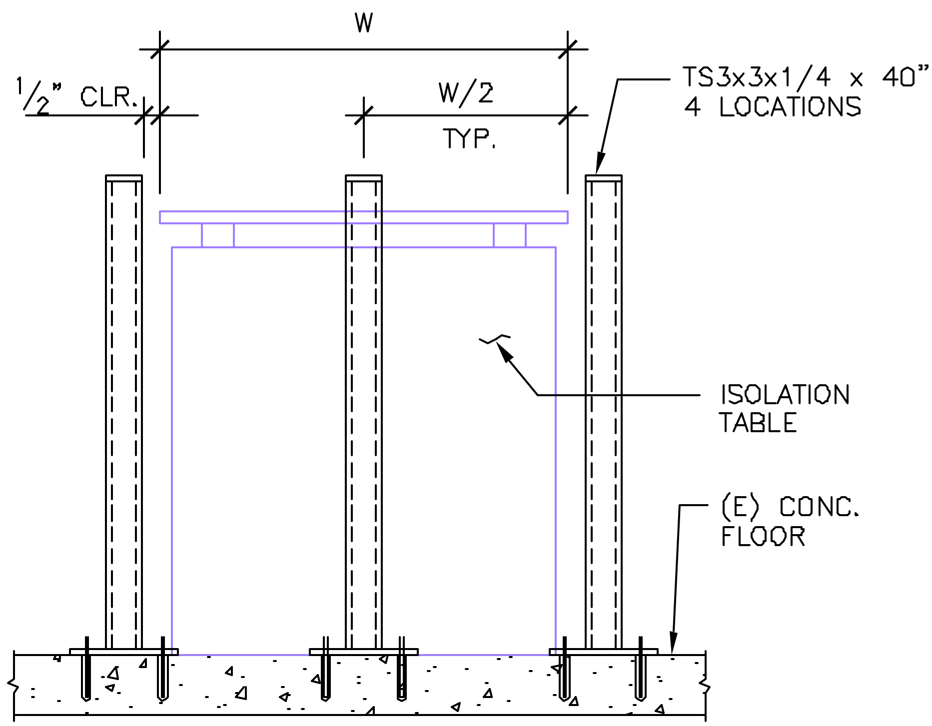
AIRCRAFT CABLE STRAP

DETAIL TA

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: TYPICAL TANK RESTRAINTS	SCALE: NO SCALE SHEET: D11



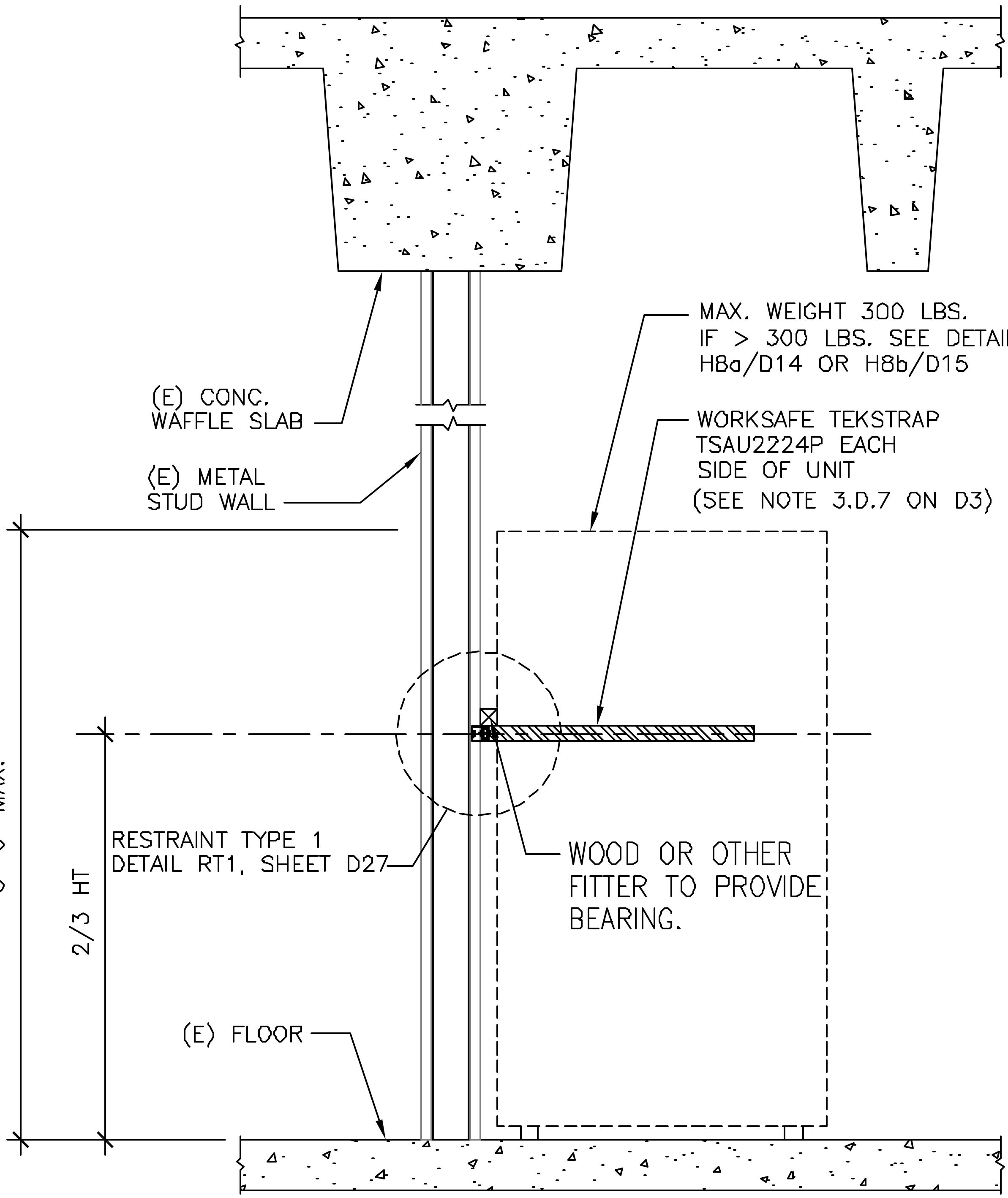
TOP VIEW



DETAIL U1

VIBRATION ISOLATED TABLE RESTRAINT
(FREESTANDING)

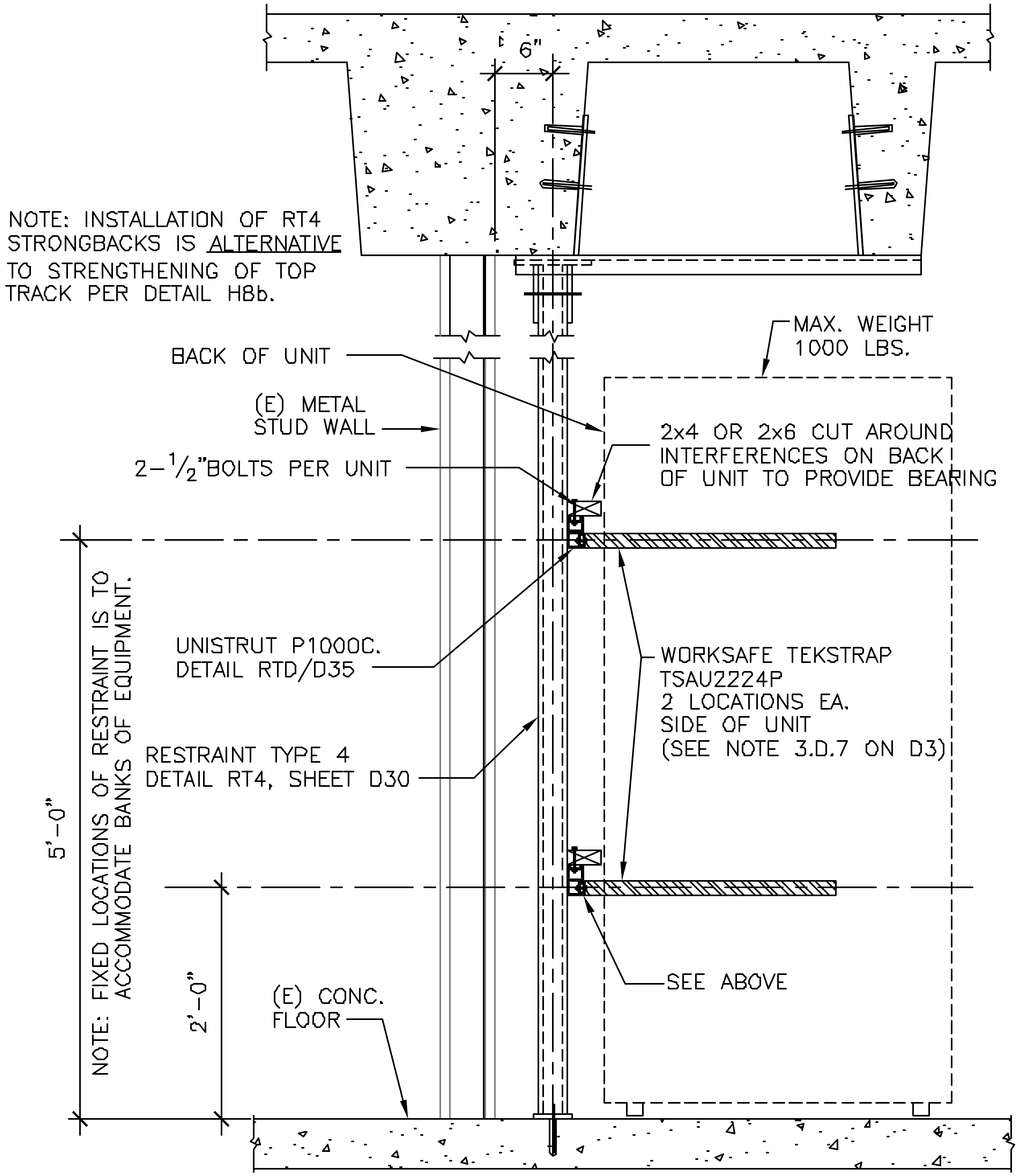
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **MISCELLANEOUS EQUIPMENT**	SCALE: NO SCALE SHEET: **D12**



DETAIL H7

RESIDENTIAL STYLE REFRIGERATOR

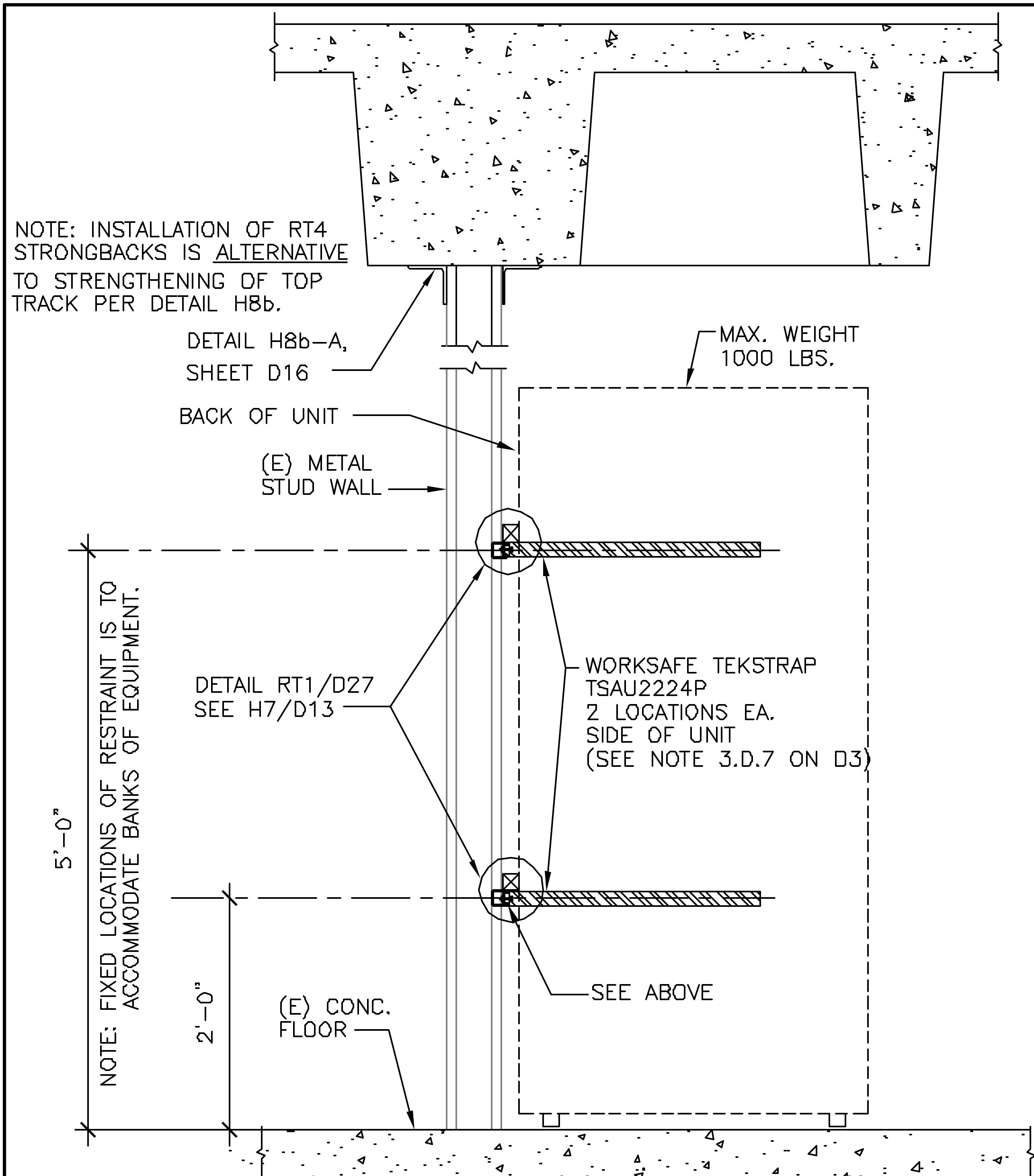
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL LARGE EQUIPMENT RESTRAINTS**	SCALE: NO SCALE SHEET: **D13**



DETAIL H8a

LARGE REFRIGERATOR/FREEZER/INCUBATORS

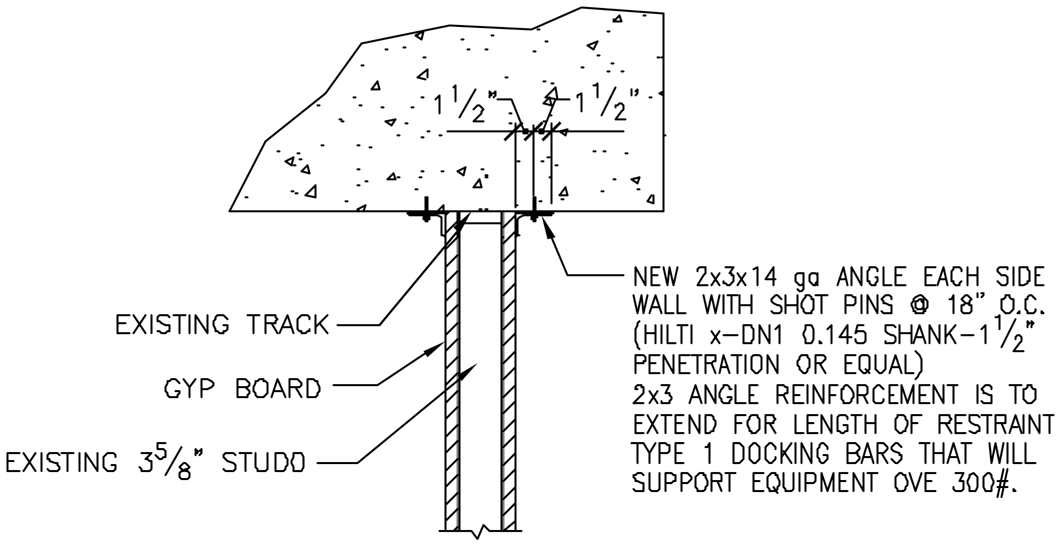
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **ALTERNATIVE FOR TYPICAL LARGE EQUIPMENT RESTRAINTS**	SCALE: NO SCALE SHEET: **D14**



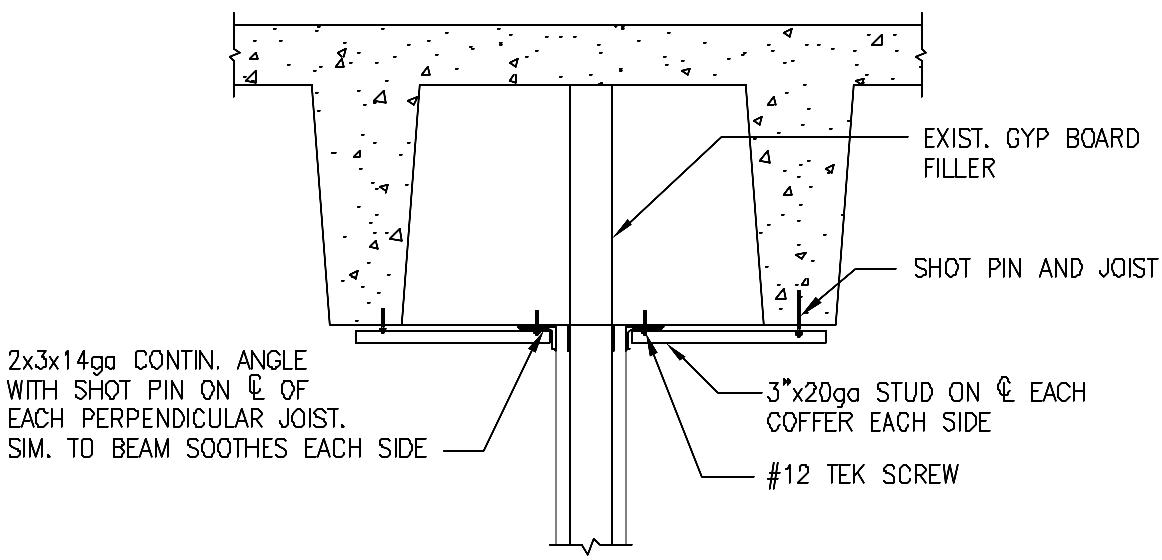
DETAIL H8b

LARGE REFRIGERATOR/FREEZER/INCUBATORS

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **ALTERNATIVE FOR TYPICAL LARGE EQUIPMENT RESTRAINTS**	SCALE: NO SCALE SHEET: **D15**



AT BEAM SOFFITS

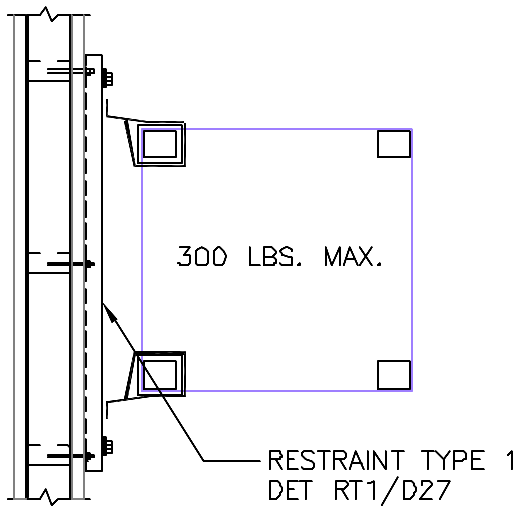


AT WAFFLE SLAB

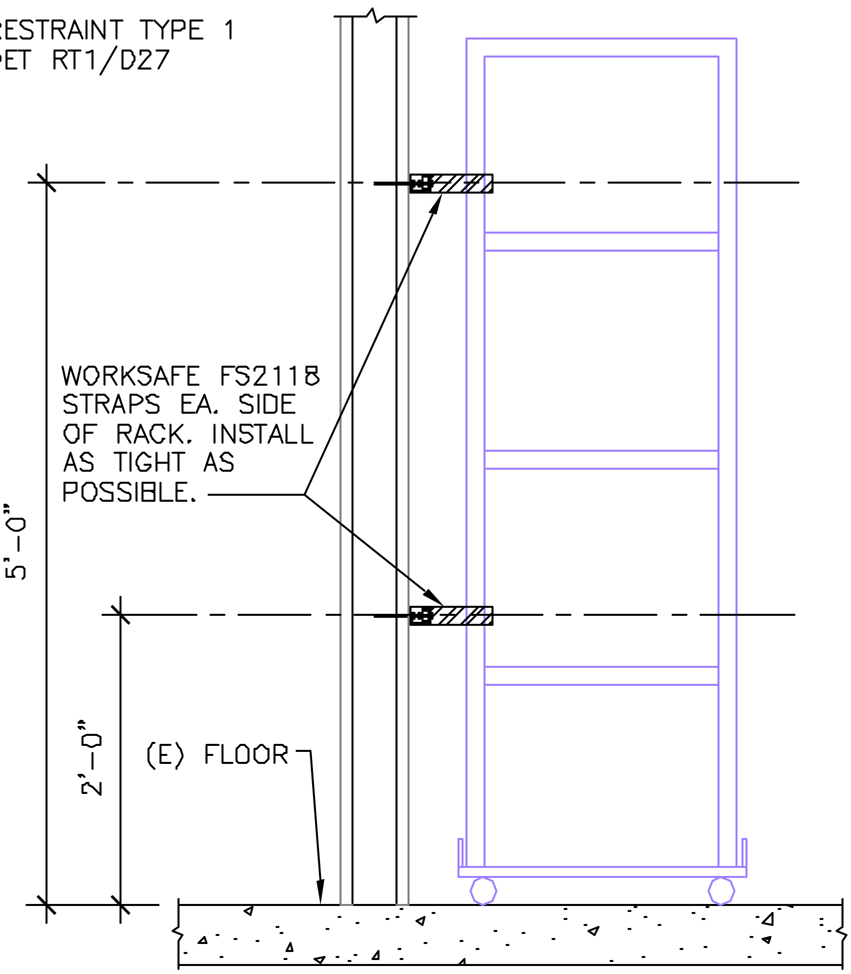
DETAIL H8b–A

LARGE REFRIGERATOR/FREEZER/INCUBATORS

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **PARTITION STRENGTHENING FOR LARGE EQUIPMENT**	SCALE: NO SCALE SHEET: **D16**



TOP VIEW



DETAIL H9a

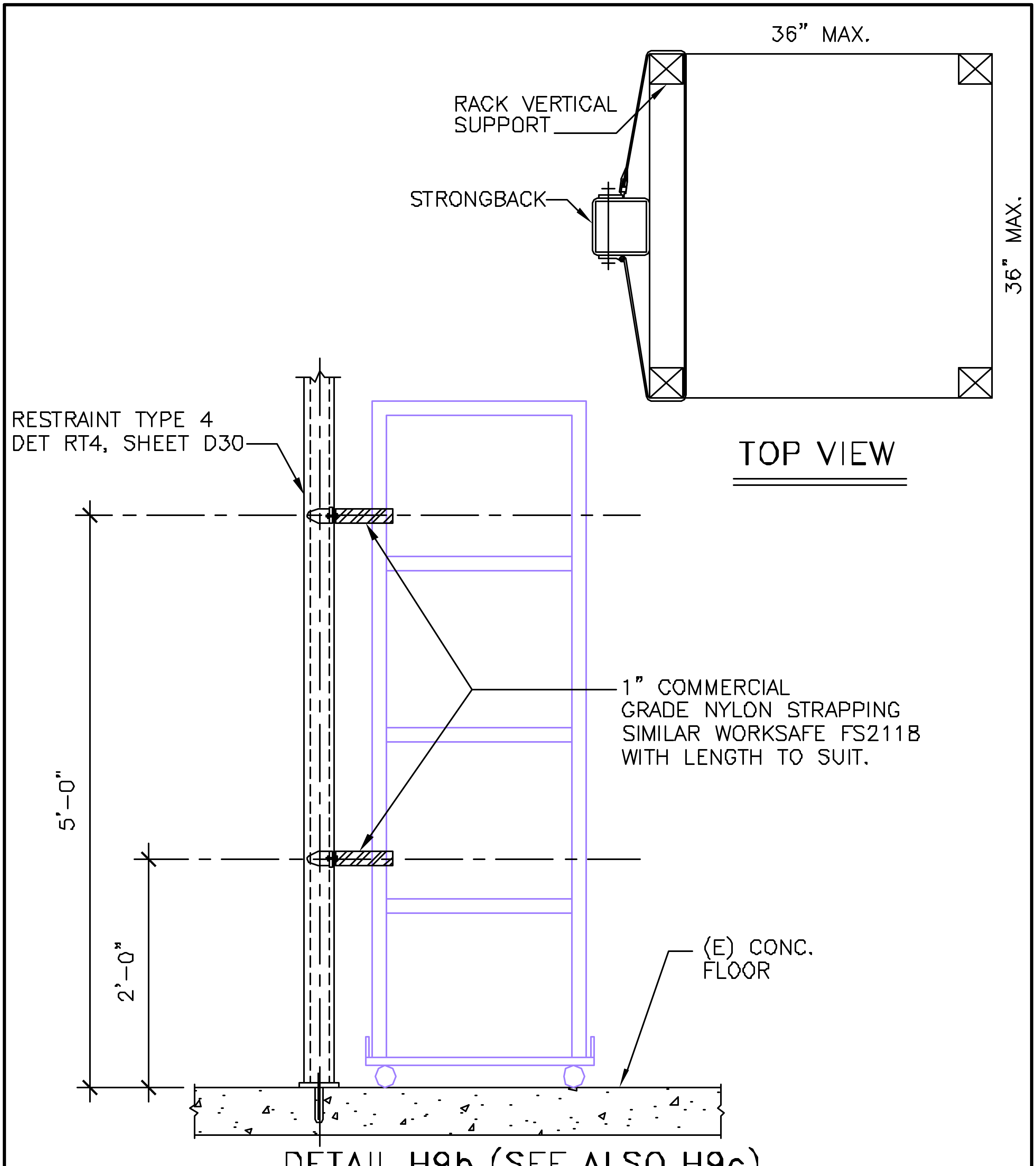
WHEELED RACK RESTRAINT
(ADJACENT TO WALL)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1

TITLE: **WHEELED RACKS**

SCALE: NO SCALE

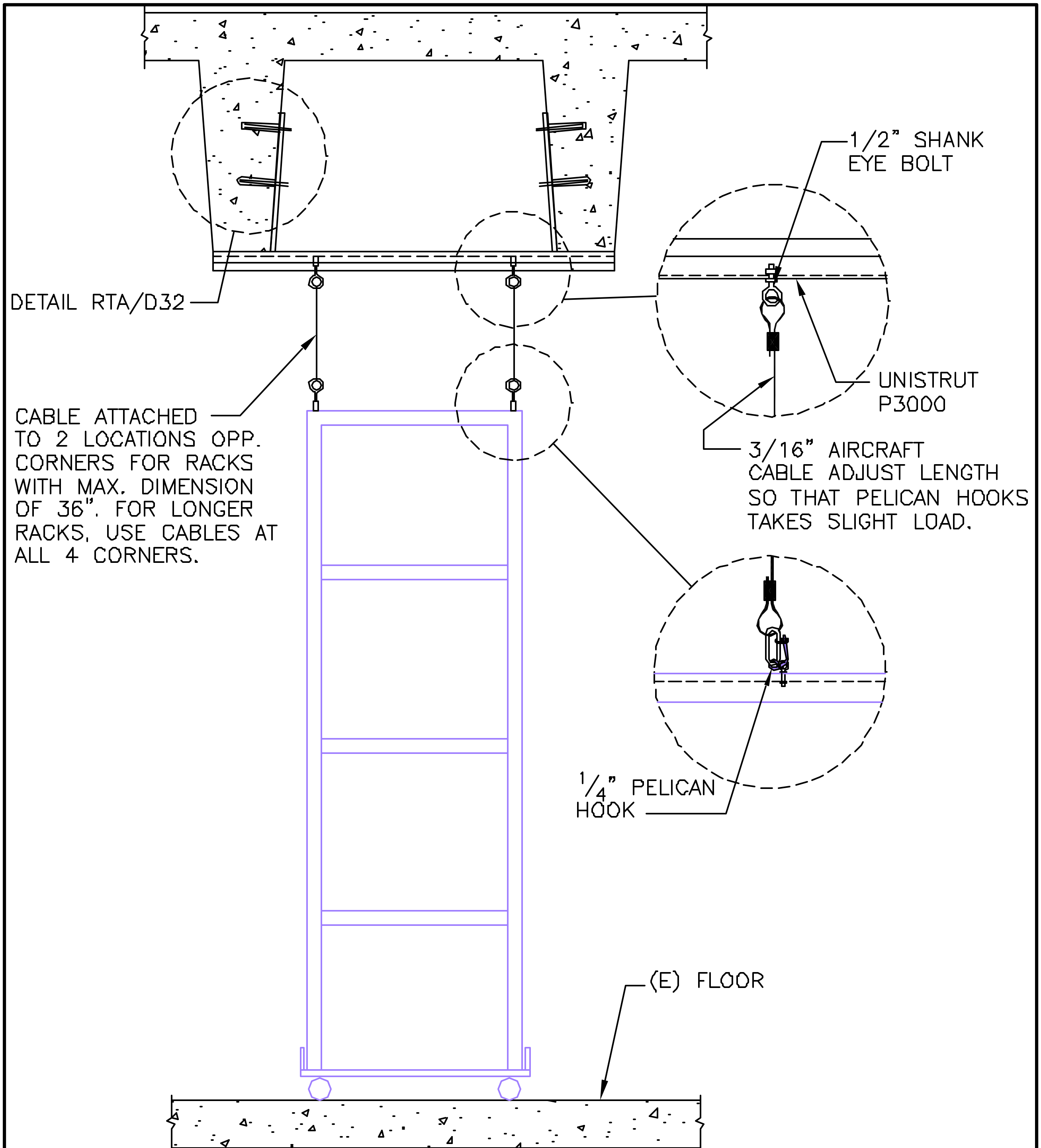
SHEET: **D17**



DETAIL H9b (SEE ALSO H9c)

WHEELED RACK RESTRAINT (FREESTANDING)

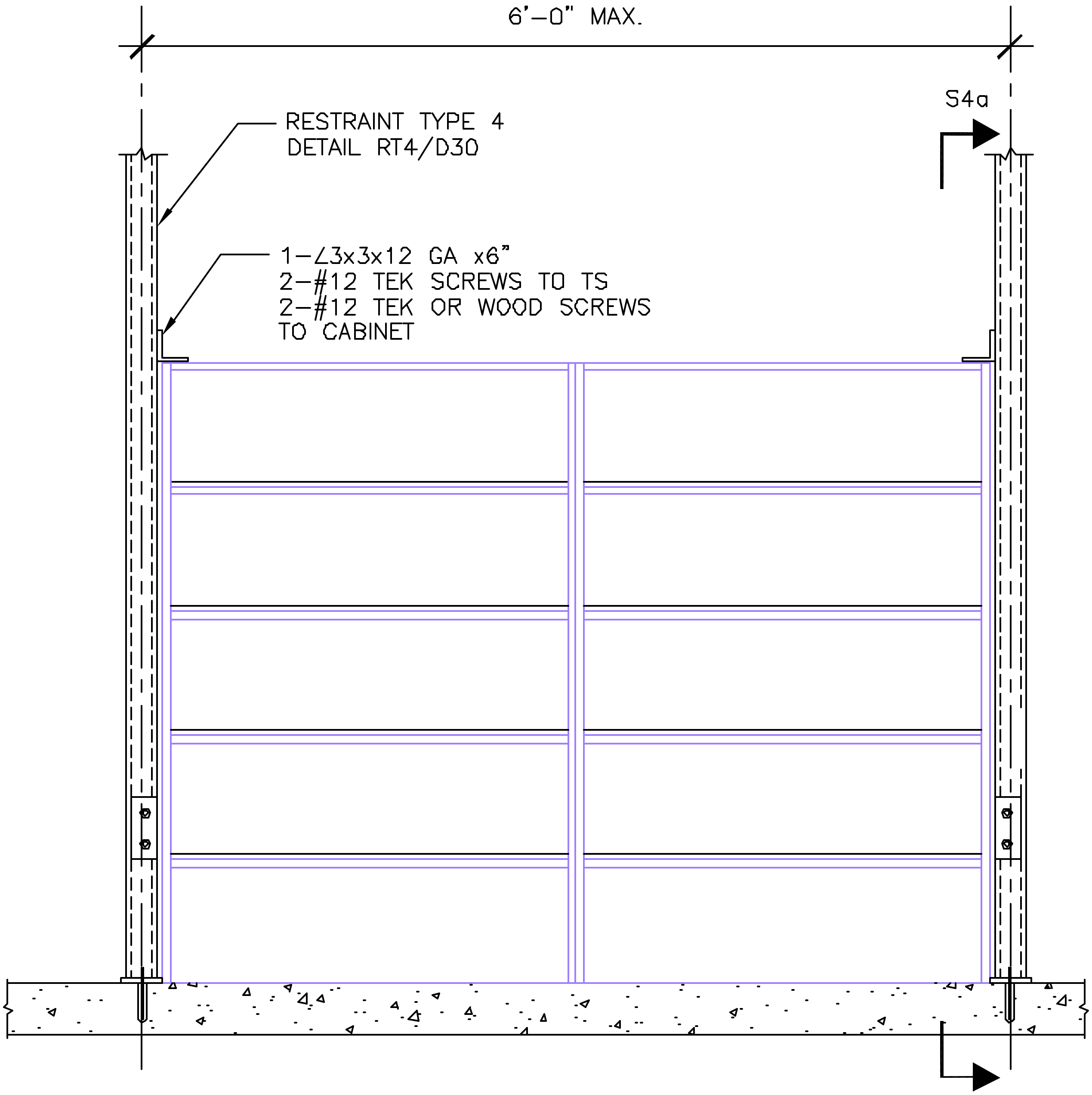
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: WHEELED RACKS	SCALE: NO SCALE SHEET: D18



DETAIL H9c (ALTERNATIVE TO H9b)

WHEELED RACK RESTRAINT
(FREESTANDING)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **WHEELED RACKS**	SCALE: NO SCALE SHEET: **D19**

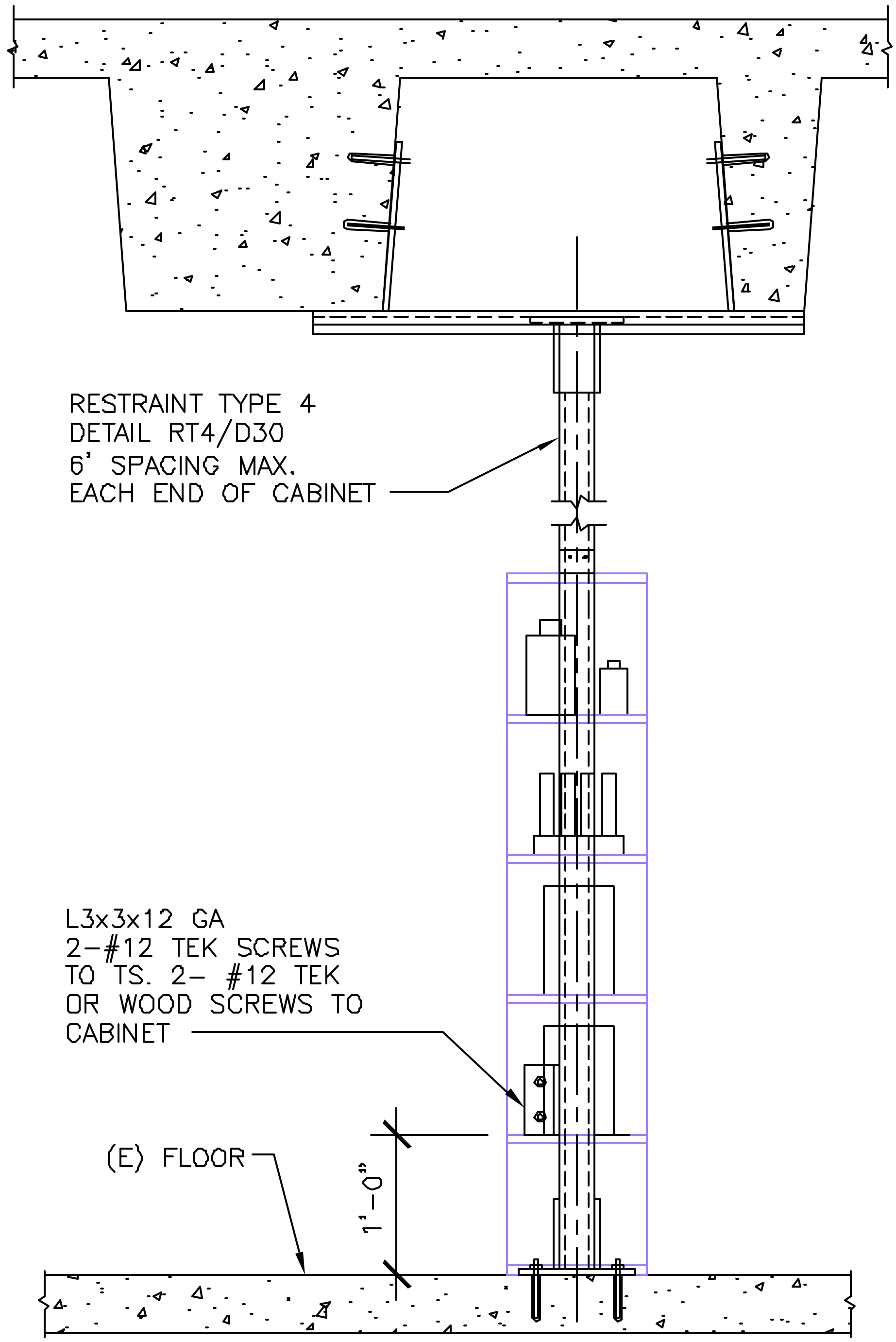


FREESTANDING BOOKSHELVES
FLOOR TO FLOOR RESTRAINTS

ELEVATION

DETAIL S4

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: FREESTANDING BOOKCASES	SCALE: NO SCALE SHEET: D20



SECTION S4a

FREESTANDING BOOKCASES
FLOOR TO CEILING RESTRAINTS

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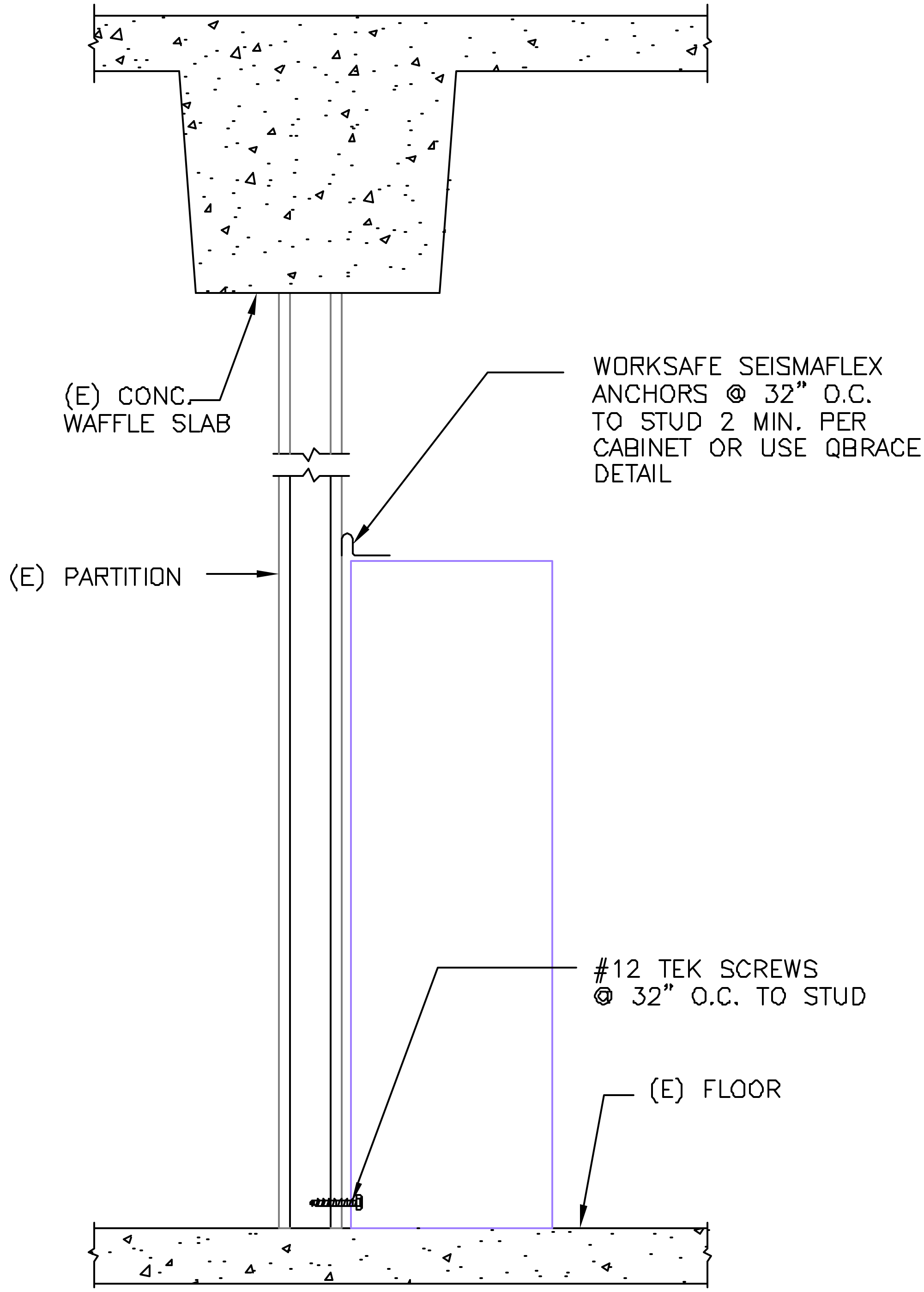
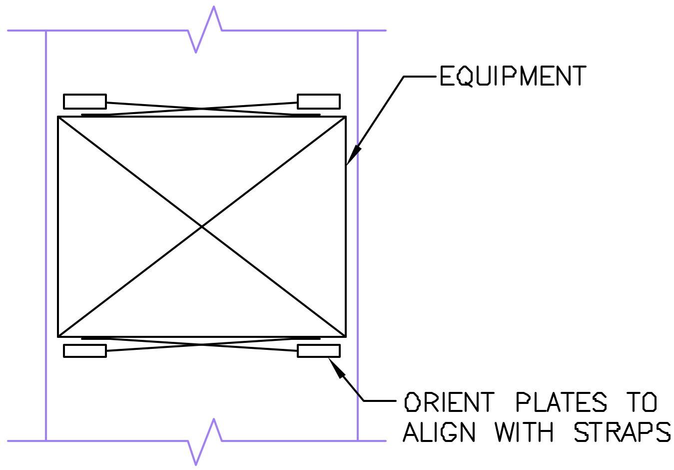


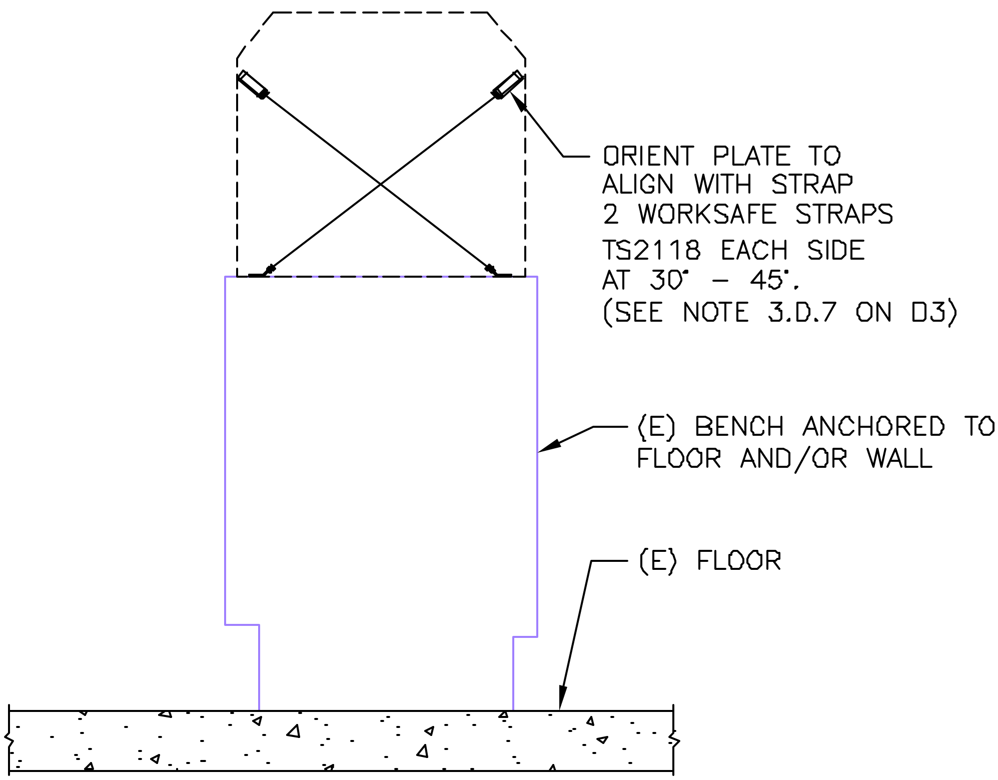
DETAIL S6

BOOKSHELVES/METAL CABINETS
ADJACENT TO WALLS

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **BOOKSHELVES CABINETS**	SCALE: NO SCALE
		SHEET: **D22**



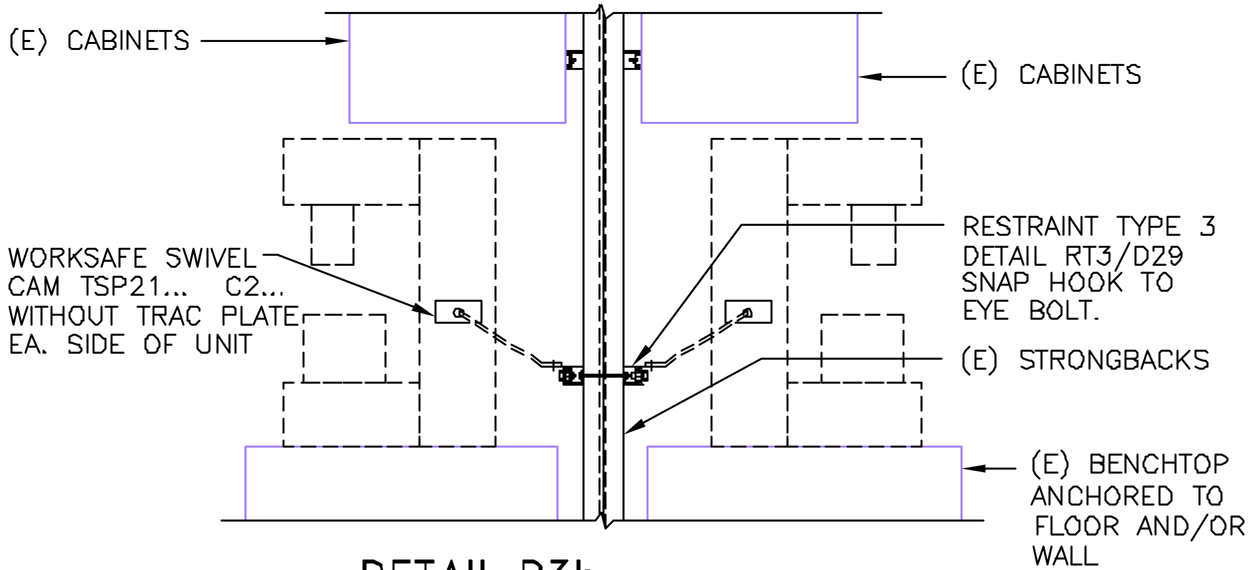
TOP VIEW



DETAIL B2

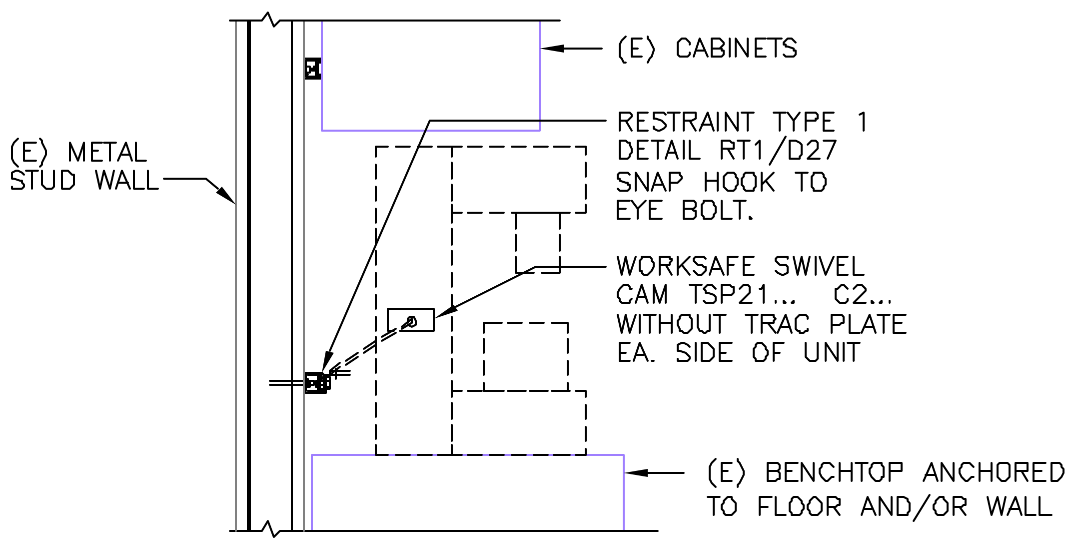
BENCHTOP HEAVY EQUIPMENT
(150 – 250 LBS.)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D23**



DETAIL B3b

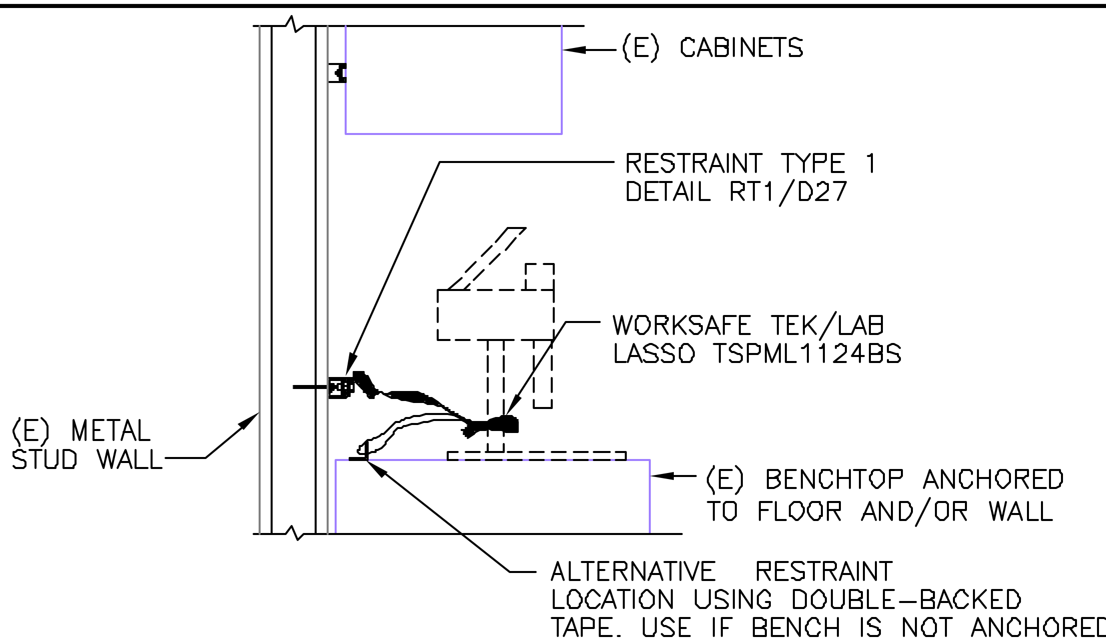
BENCHTOP HEAVY EQUIPMENT AT ISLAND (50 LBS – 150 LBS.)



DETAIL B3a

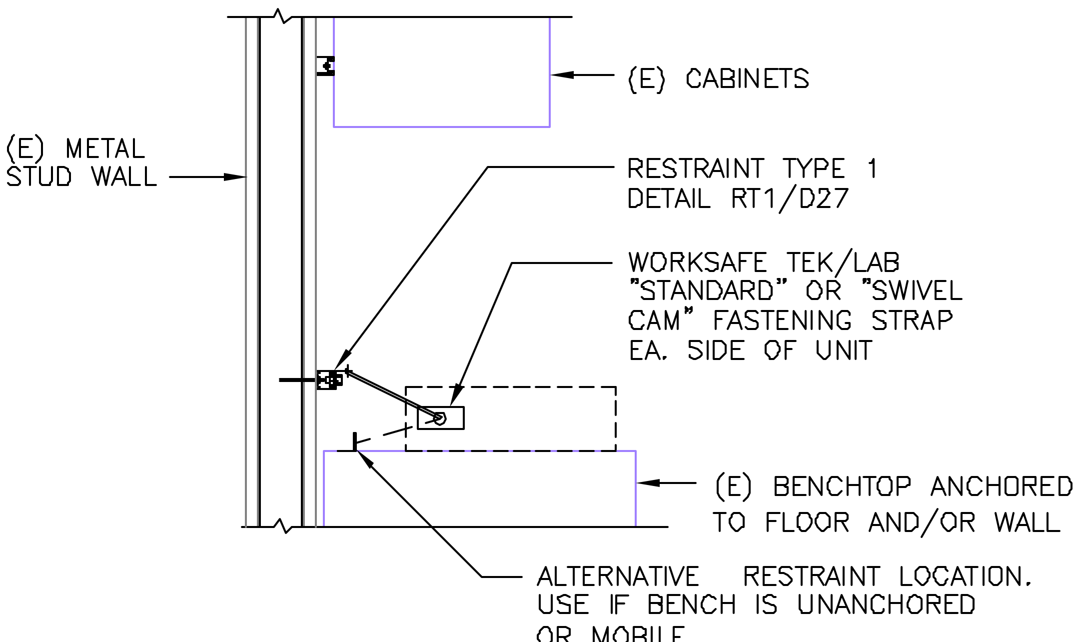
BENCHTOP HEAVY EQUIPMENT AT ALL WALLS (50 LBS – 150 LBS.)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D24**



DETAIL B4b

MICROSCOPES AT ALL WALLS
(< 50 LBS)



DETAIL B4a

BENCHTOP EQUIPMENT
AT ALL WALLS (< 50 LBS)

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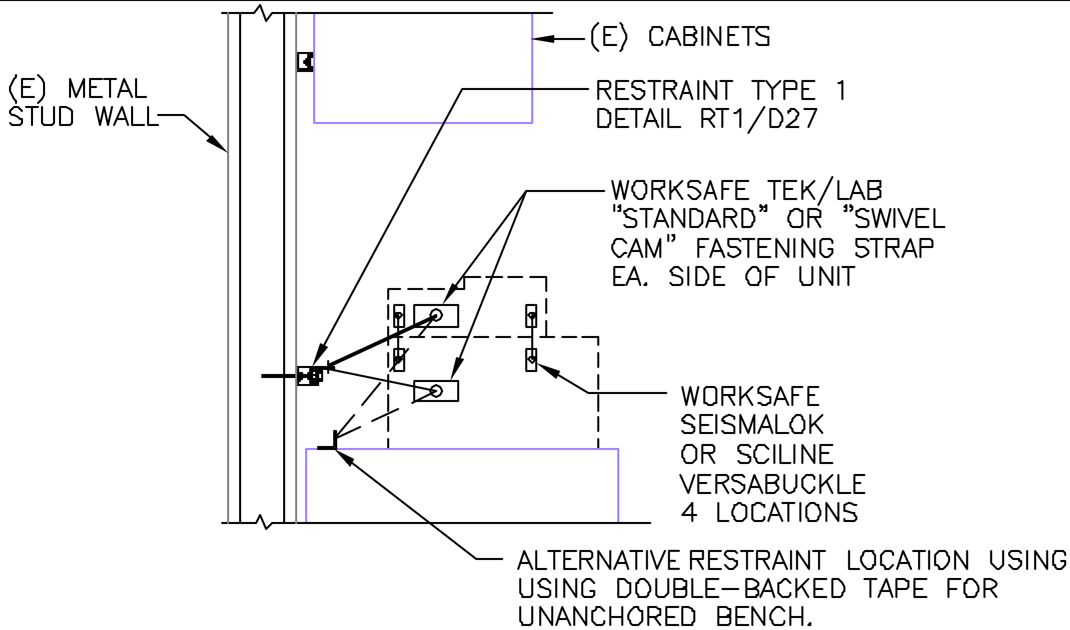
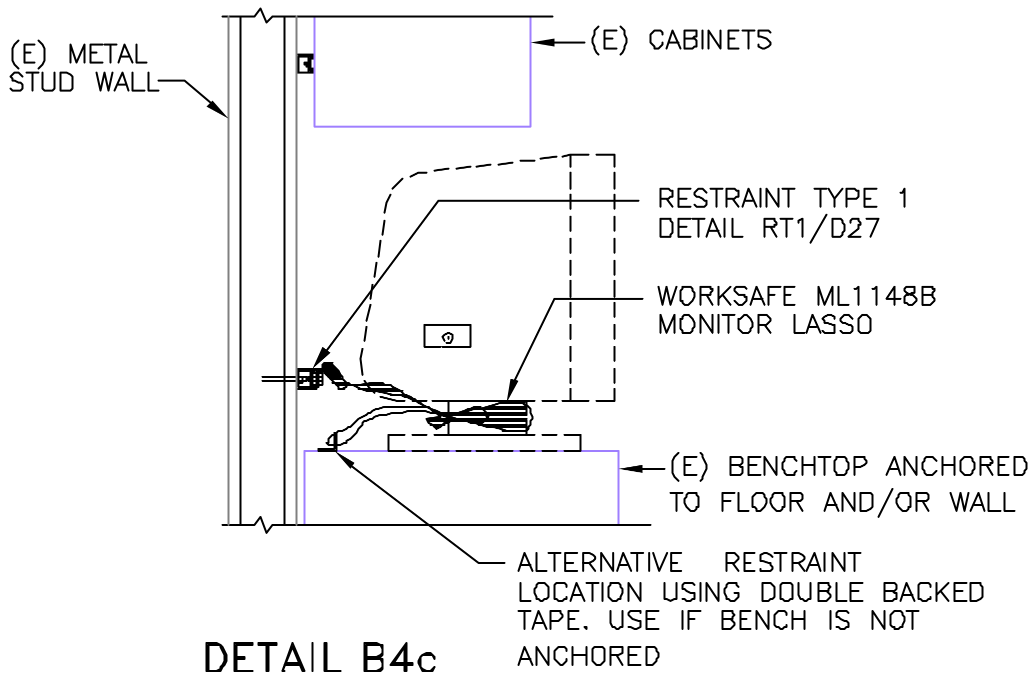


DETAIL B5

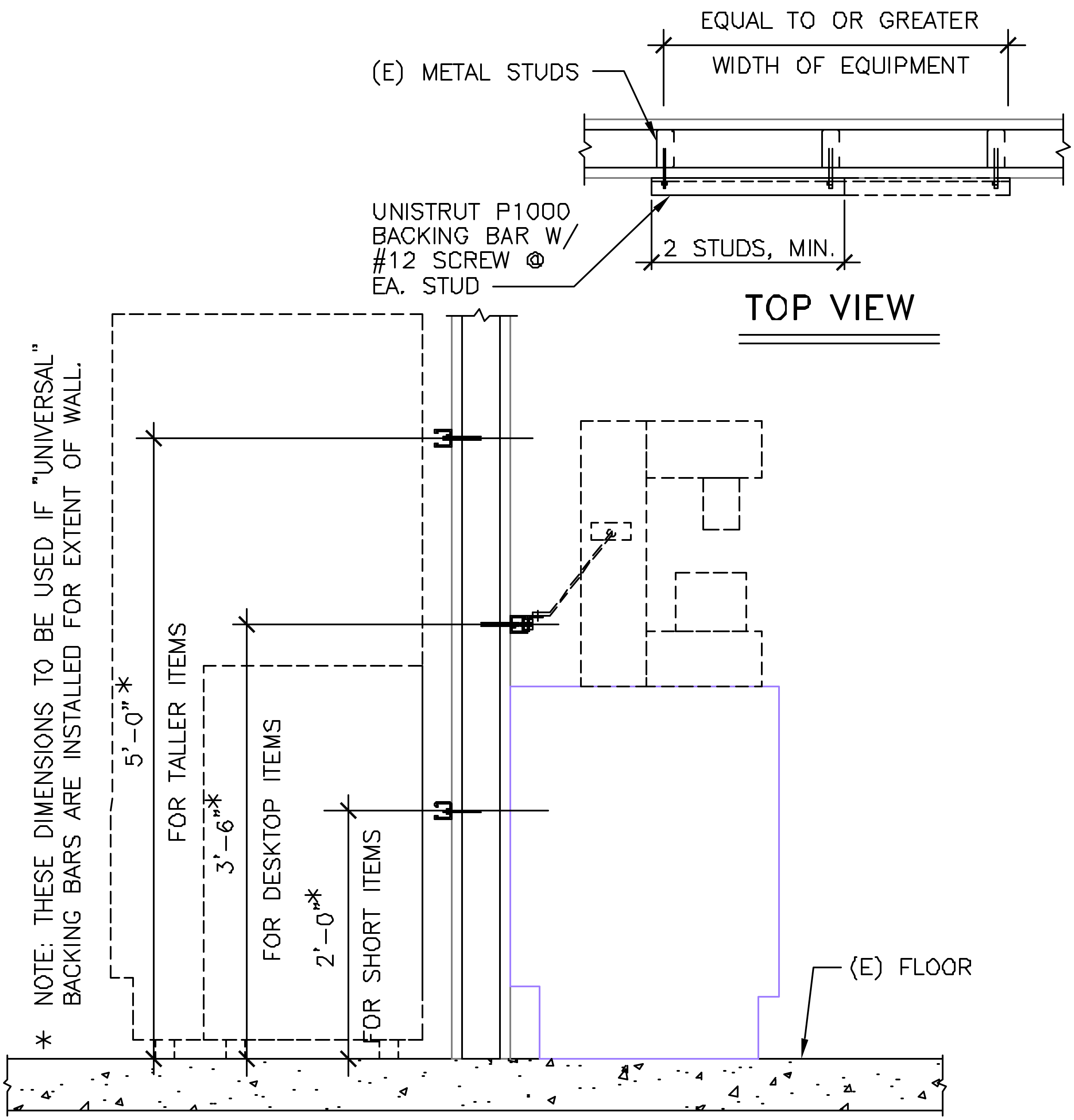
STACKED COMPONENTS
(< 50 LBS)



DETAIL B4c

COMPUTER MONITORS
AT ALL WALLS (< 50 LBS)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D26**

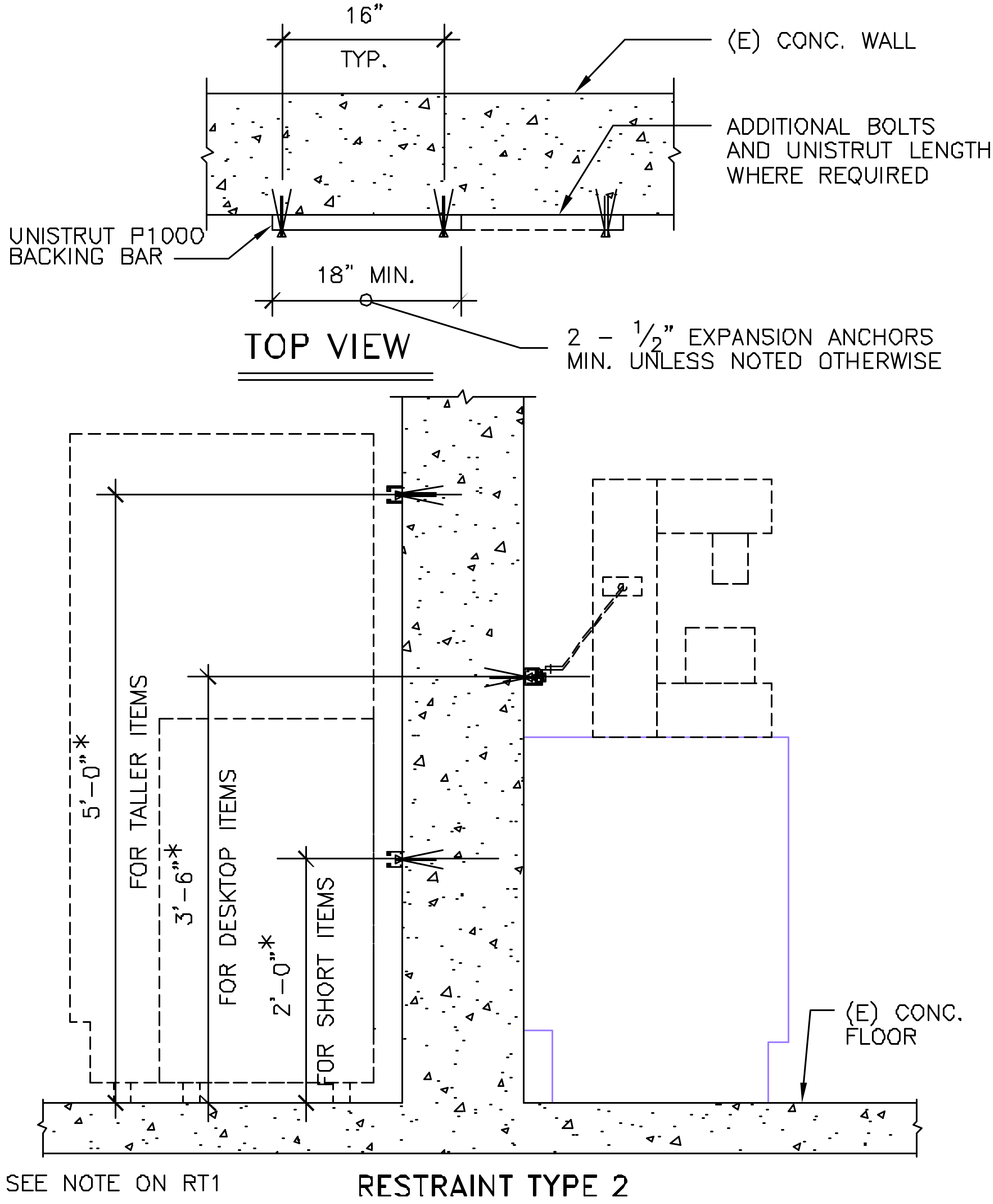


RESTRAINT TYPE 1

EXTERIOR BACKING BAR
@ METAL STUD PARTITION WALLS THAT RUN TO FLOOR ABOVE. WALLS THAT STOP AT CEILING SHALL NOT BE USED FOR RESTRAINT WITHOUT DESIGN BY ENGINEER.

DETAIL RT1

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL RESTRAINT TYPES AT WALLS**	SCALE: NO SCALE SHEET: **D27**

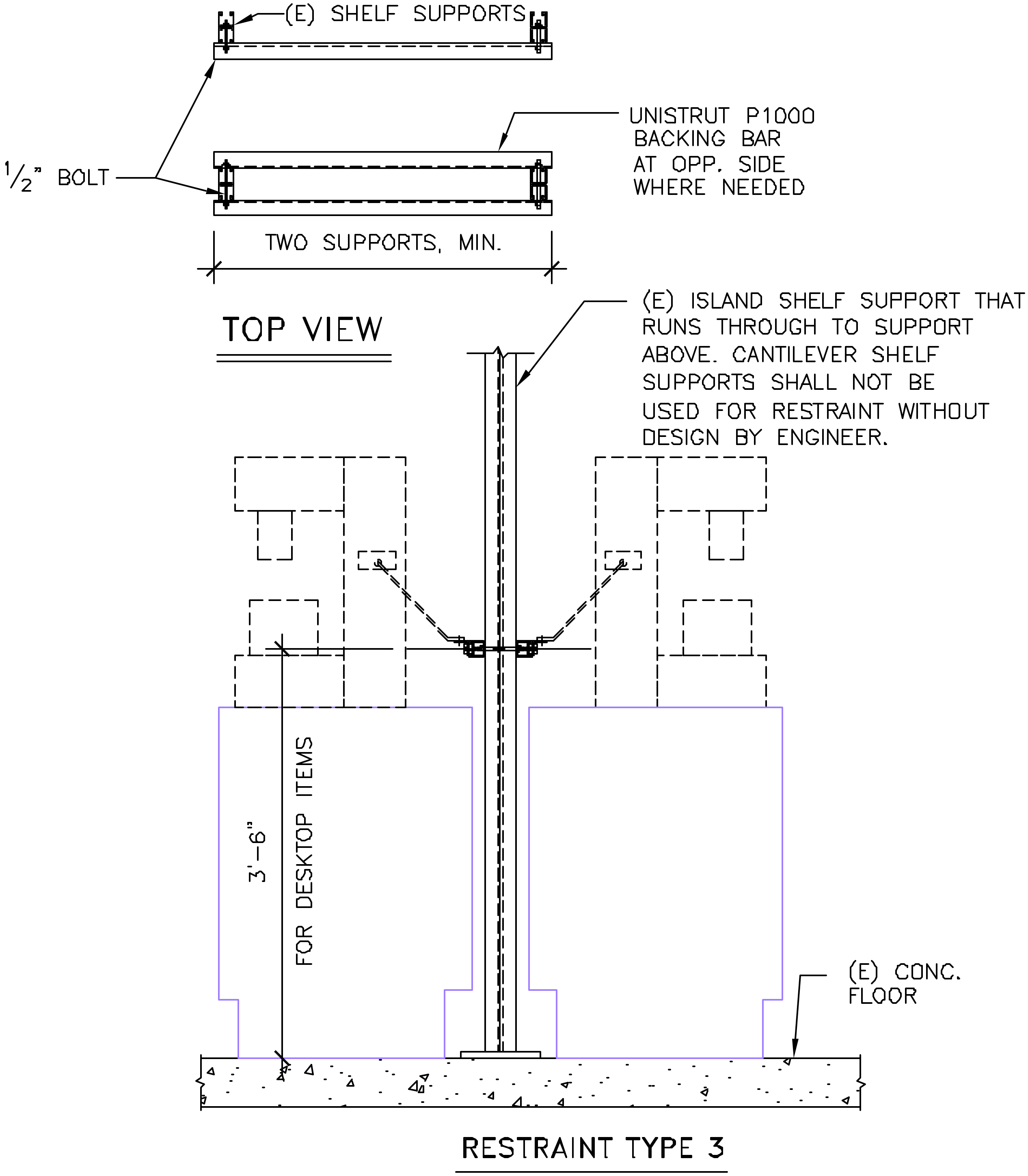


* SEE NOTE ON RT1

EXTERIOR BACKING BAR @ CONCRETE WALLS

DETAIL RT2

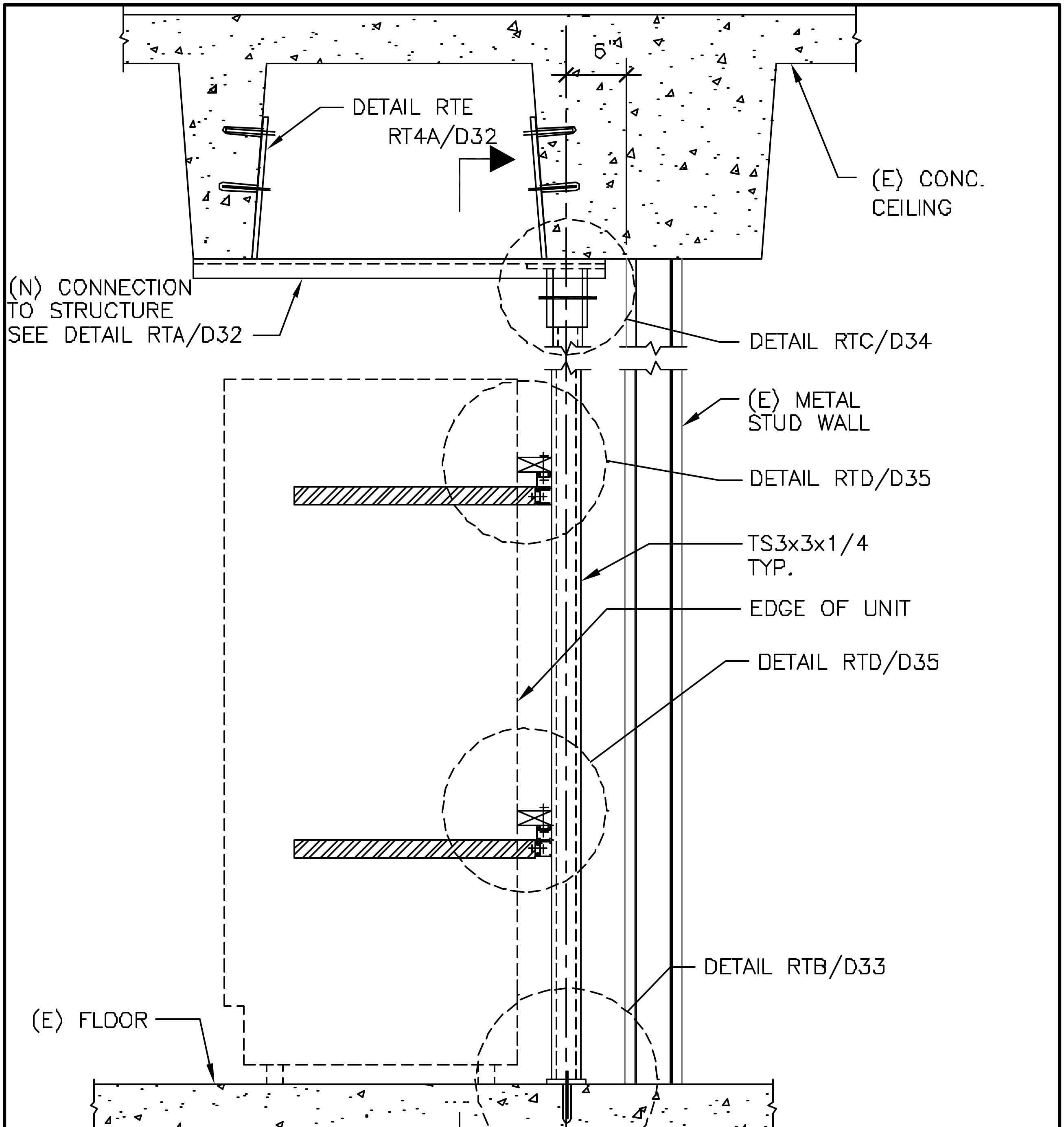
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL RESTRAINT TYPES AT WALLS**	SCALE: NO SCALE SHEET: **D28**



EXTERIOR BACKING BAR @ EXISTING CABINET SUPPORTS

DETAIL RT3

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL RESTRAINT TYPES AT WALLS**	SCALE: NO SCALE SHEET: **D29**



RESTRAINT TYPE 4

TYPICAL STRONGBACK DETAIL

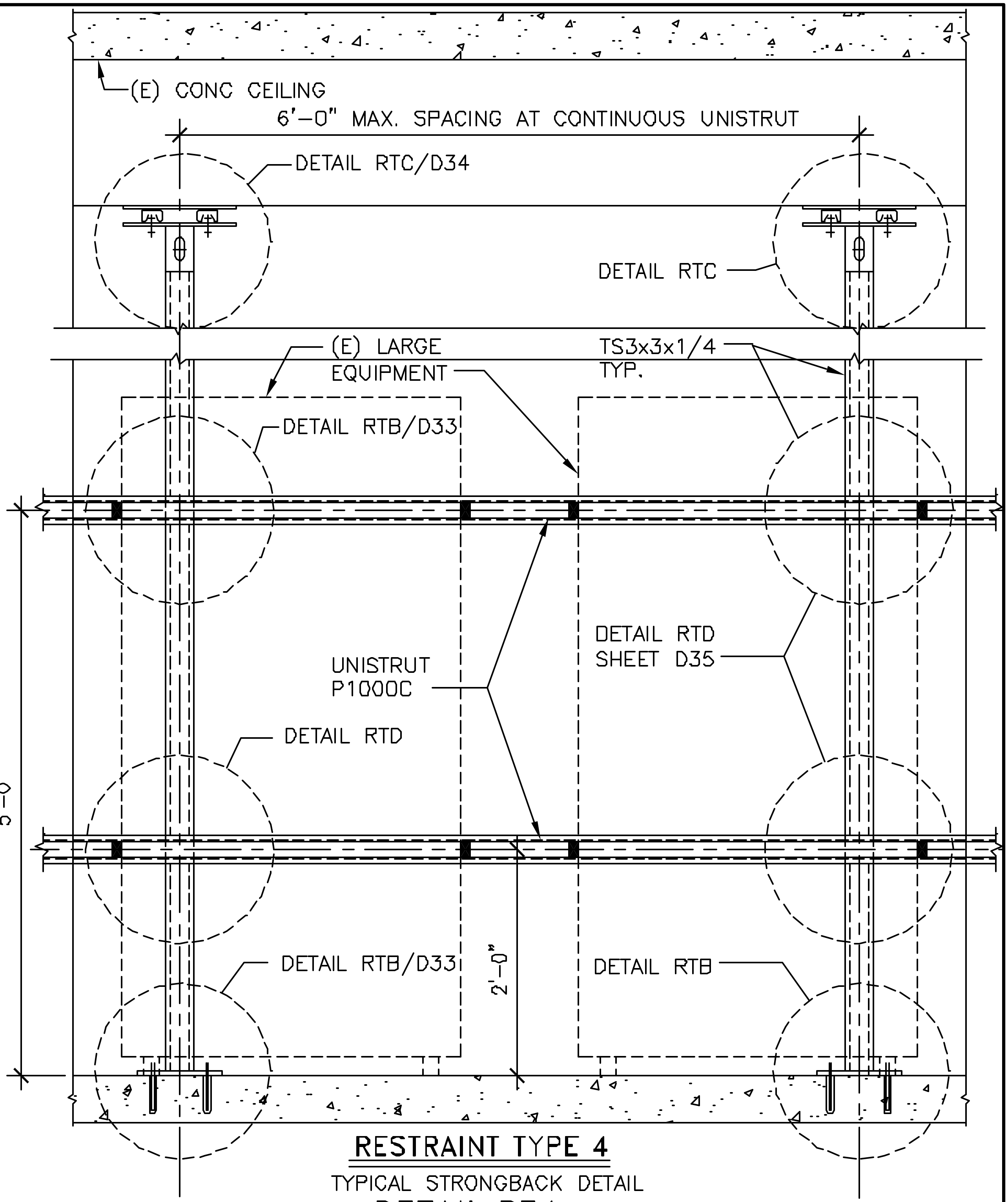
DETAIL RT4

IMPLEMENTATION MANUAL FOR THE
SEISMIC PROTECTION OF LABORATORY CONTENTS
CASE STUDY BUILDING 1

TITLE: TYPICAL RESTRAINT TYPES AT WALLS

SCALE: NO SCALE

SHEET: D30

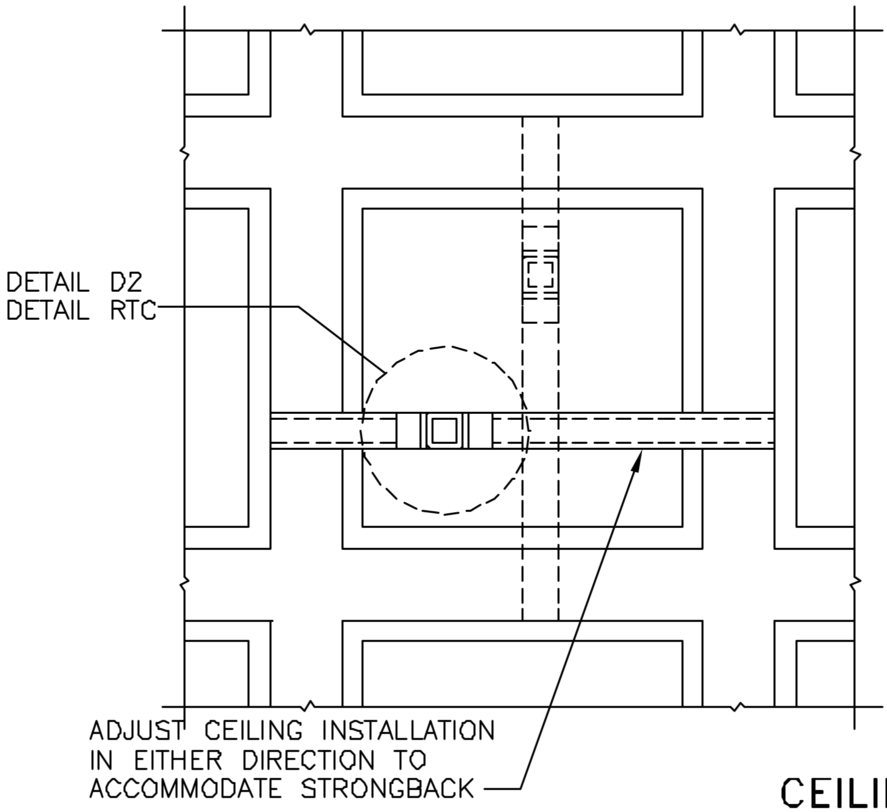


RESTRAINT TYPE 4

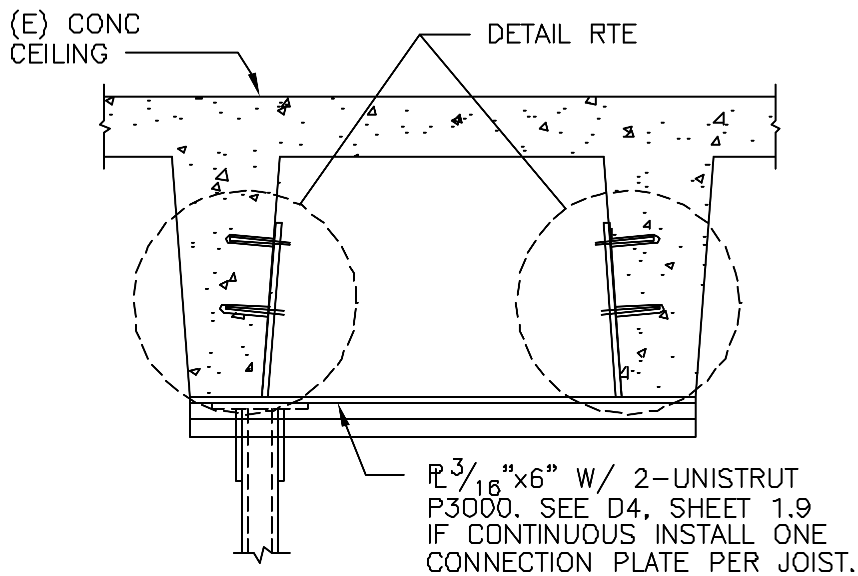
TYPICAL STRONGBACK DETAIL

DETAIL RT4a

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: TYPICAL RESTRAINT TYPES AT WALLS	SCALE: NO SCALE SHEET: D31



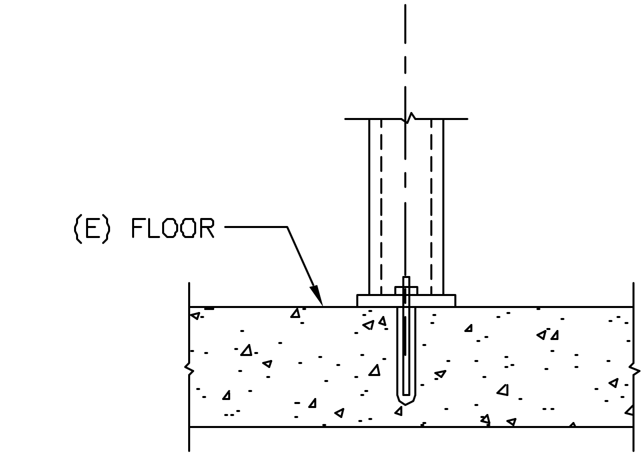
CEILING VIEW



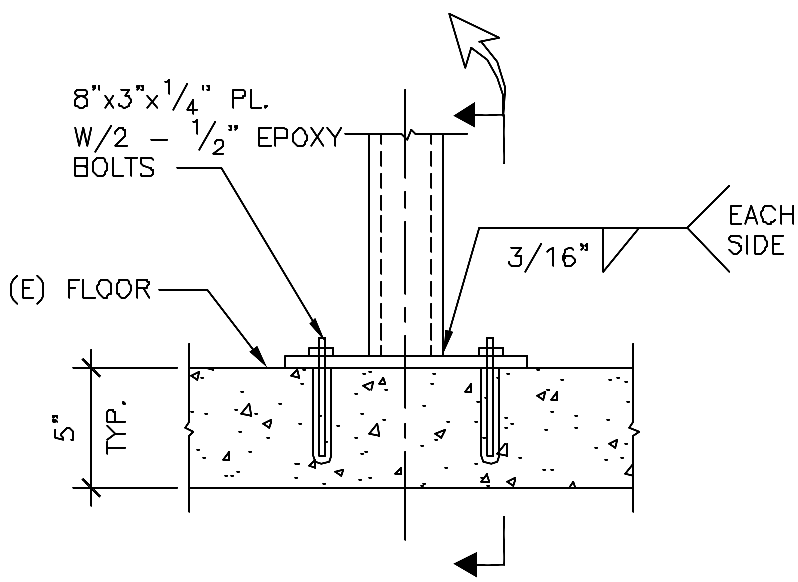
DETAIL RTA

TYPICAL CONNECTION DETAILS AT
CONCRETE WAFFLE SLAB CEILING

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL RESTRAINT TYPES AT WALLS**	SCALE: NO SCALE SHEET: **D32**



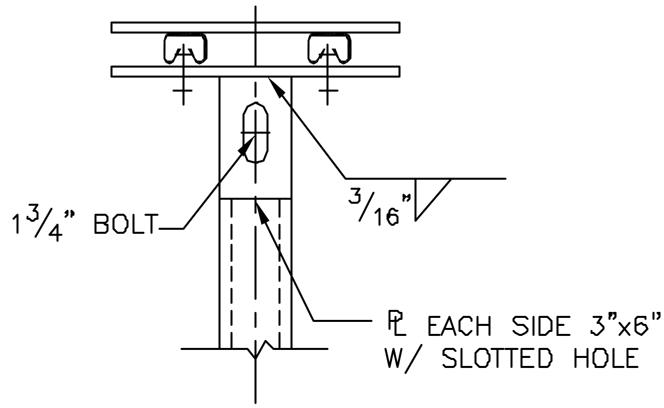
SECTION



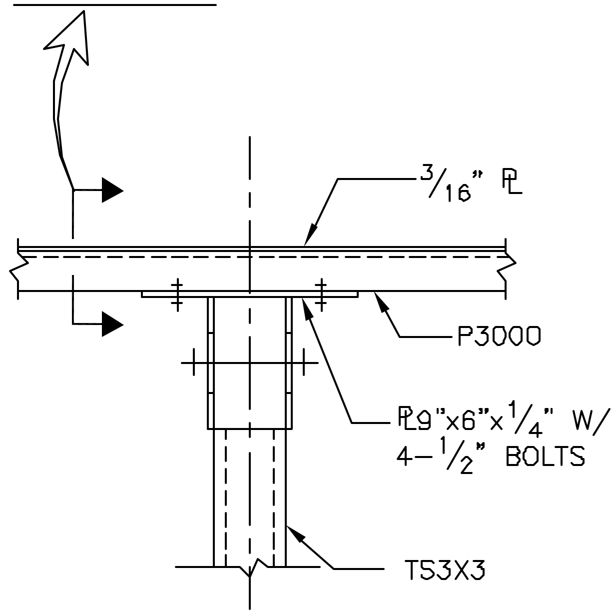
DETAIL RTB

STRONGBACK CONNECTION
TO FLOOR

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL DETAILS**	SCALE: NO SCALE SHEET: **D33**



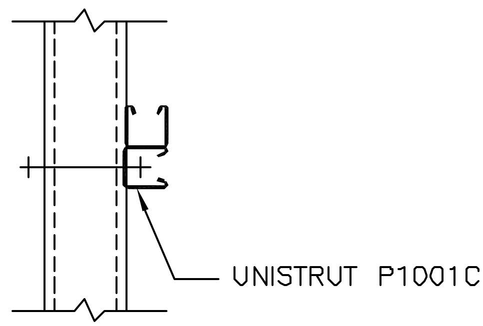
SECTION



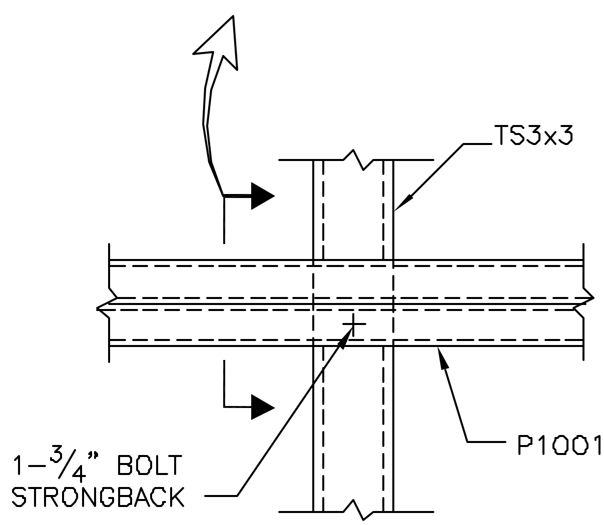
DETAIL RTC

STRONGBACK CONNECTION TO
CHANNEL AT CEILING CONNECTION

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL DETAILS**	SCALE: NO SCALE SHEET: **D34**



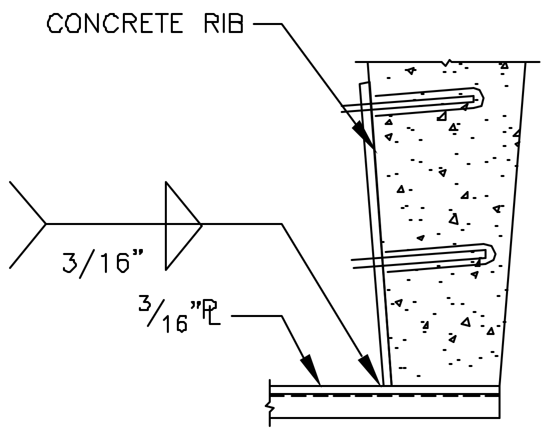
SECTION



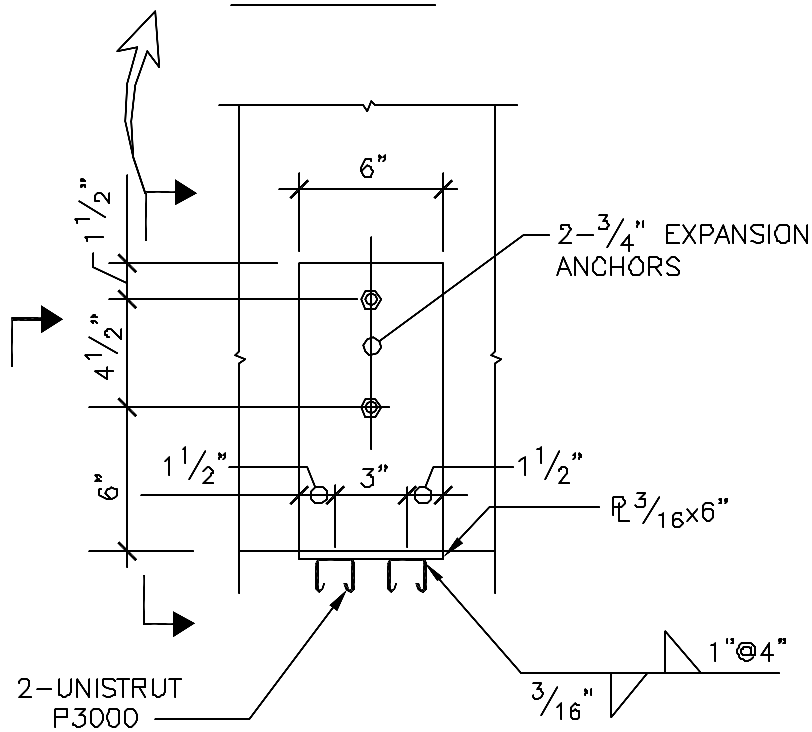
DETAIL RTD

STRONGBACK CONNECTION
AT INTERMEDIATE SUPPORT

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: TYPICAL DETAILS	SCALE: NO SCALE
		SHEET: D35



SECTION



DETAIL RTE

CONNECTION TO WAFFLE SLAB

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 1	TITLE: **TYPICAL DETAILS**	SCALE: NO SCALE SHEET: **D36**

Appendix B: Implementation Manual for the Seismic Protection of Laboratory Contents Case Study Building 2

This appendix contains a fully developed implementation manual for Case Study Building 2, a steel frame and metal deck building with a lateral system of buckling-restrained braces that was under construction at the time of preparation of this manual.

Contents

List of Figures

List of Tables

1 Introduction

It is generally understood that earthquakes damage man-made objects by causing the ground to shake. More specifically, any one spot on the ground moves rather randomly in all directions as the waves generated by the fault rupture pass by, as is shown by the trace in Figure 1. In general, the intensity of the motion, that is the tendency to cause damage, increases with the magnitude of the earthquake, the nearness of the site to the fault rupture, and the softness of the ground at the site. For more information on seismic ground motions, refer to US Geological Survey web site at **www.usgs.gov**.

Buildings respond to this shaking by swaying back and forth (in fact, in all directions, similar to the ground, but it is simple to think about most buildings swaying in one or both of its major orthogonal directions). Commonly, the building's dynamic properties are sympathetic with the ground shaking, and the motion is amplified within the building, getting larger in floors higher in the building.

Earthquake damage in buildings is normally categorized as structural, nonstructural, or contents damage. Structural damage occurs when the sideways motion in the building is more than the columns, beams, braces, or structural walls can take without suffering harm, usually indicated by concrete or masonry cracking and steel stretching or buckling. The nonstructural category refers to permanent or semi-permanent building components other than the structure such as cladding, partitions, ceilings, mechanical, plumbing, and electrical systems. Damage to these components can occur due to excessive movement between two adjacent floors (fracturing a partition that is connected to both), or by high accelerations that create large horizontal forces (breaking a pipe spanning between two adjacent supports or causing equipment to move off its base). Contents comprise everything else in the building, including furniture, non-building related equipment (copy machines, autoclaves, refrigerators, computers, microscopes, etc), supplies (paper, glassware, chemicals, etc.), and work products (computer software and data, experiments, etc.). Contents are most typically damaged by forces created by building-accelerations that cause the item to slide or tip over.

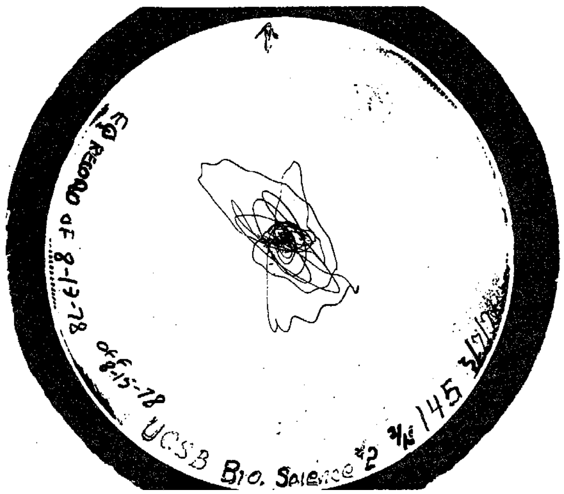


Figure 1. Seismoscope Record from Biological Sciences II, UCSB

Examples of contents in laboratories include:

1. Tanks and cylinders such as gas cylinders, cryogenic containers, and liquid tanks;
2. Unique equipment and experimental setups;
3. Equipment not related to the building's mechanical, electrical, or plumbing systems such as refrigerators, freezers, dryers, dishwashers, and large incubators;
4. Storage elements such as drawers, bookshelves, cabinets, storage racks, and shelving units, and their contents; and
5. Benchtop items such as computers (and accessories), microscopes, mixers, microwaves, water baths, centrifuges, and small incubators.

Most regulations that control the design and construction of buildings contained in the local building code include requirements that minimize or control damage to the building's structural and nonstructural systems (although some parts of the US in lower seismic zones do not require seismic design of nonstructural systems), but have no requirements for contents. This is probably due to the variability of contents and typically, the small effect of damage on public safety. However, 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 occupants and the general public.

At UC Berkeley, laboratories are 30 percent of the overall campus space. The value of their 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. These are the knowledge base of the university.

The potential loss of building operations is a serious issue for a university. However, the dollar value of the equipment, computers, and other contents in laboratories, the priceless nature of experiments in progress, the value of research supported annually, and the immeasurable value of the contribution to knowledge represented in university laboratories make them an obvious focus for mitigation of nonstructural hazards (Comerio and Stallmeyer, 2001).

The seismic motion of the building will cause the contents to tend to slide or turn over depending on the ratio of height to base width and the friction between the base and support surface. The configuration of some items will cause them to rock on their bases, and the combination of rocking and sliding can result in the item “walking” some distance. Any of these responses can be damaging to the item or to nearby items—or occupants. Tipping over can cause direct damage to sensitive equipment, spilling of contents, or can lead to a secondary fall off a counter or shelf. Broken or spilled chemical containers can result in harmful releases or dangerous chemical combinations. Heavier items falling from a shelf will injure occupants. Sliding or walking of heavy equipment will also cause harm to occupants.

Conventionally, seismic protection is afforded contents by anchorage, bracing, or restraining, to prevent damaging movement. However, if all damage is to be avoided, the characteristics of the item must be considered to ascertain appropriate protection measures. For example, rigidly anchoring equipment at its base may impart large accelerations into the mechanism potentially resulting in internal damage. Similarly, anchoring a refrigerator or freezer to the floor will almost certainly cause the door to fly open and the contents to be emptied onto the floor. Adding a positive door latch will keep the door closed but may not prevent the contents from being thrown about inside the box and being damaged. In this case, close-fitting racks may also be needed to prevent damage. Appropriate seismic protection measures therefore depend on the physical characteristics of the item and its support, as well as acceptable performance in an earthquake. In some cases, the mobility needed for the function of small items coupled with their low cost and low potential hazard will result in the conclusion that seismic anchorage or bracing “is not worth it.”

For items deemed extremely valuable due to their dollar worth or rarity, all sources of seismic damage must be considered. As mentioned above, some sensitive equipment may be internally damaged if merely anchored down. Experiments that require outside utilities need backup provisions because it is likely that in large events, some utilities will be disrupted. Lastly, the total building environment should be considered. Concerns about the structural performance of the building may be obvious, but secondary hazards from failure of nonstructural systems must also be considered, ranging from lack of function of the mechanical systems to physical damage from falling ceilings or broken pipes.

This manual gives guidance for providing seismic protection for the contents expected to be common in Case Study Building 2 (CSB 2). Acceptable methods of anchoring to the floors, overhead structure, benchtops, and structural walls and partitions are given, as well as limitations for their use. Some of the methods detailed herein can be installed directly by the user of the laboratory. Some will require the more skilled labor of experienced building or campus maintenance personnel. Some lab contents will be of such large weight or unusual configuration that anchorage details will require custom design by an engineer experienced in providing seismic protection.

2 Building and Site Description

2.1 BUILDING SITE AND OUTSIDE UTILITIES

The new Case Study Building 2 (CSB 2) will be located in the northwest quadrant of the UC Berkeley Campus (as shown in Fig. 2). There are no known non-shaking seismic hazards at the site such as fault rupture, landslide, liquefaction or earthquake-induced settlement. The soil is classified as Code Type B, and is not expected to produce abnormally large local amplification of ground motion. However, the site is located within 1 km of the very active Hayward Fault, and from proximity alone, the site is expected to experience very strong ground motions from moderate or large events on that fault. Building code coefficients for such sites imply that motions expected should be about 1.5 times as intense as for sites 12 km or greater distance from the source fault. The site is also threatened by the San Andreas fault (30 km distant), Calaveras (20 km), Concord-Green Valley (22 km), Mt Diablo Thrust (16 km), Greenville (30 km), Rodgers Creek (32 km), and San Gregorio (36 km) faults. Ground motions at the site from a large event on these faults are also potentially damaging, but not to the extent of events occurring nearby on the Hayward fault.

Reliability of the utilities to be available after an earthquake, as described in a recent campus seismic loss study (Comerio, 2000), is described below:

The campus steam distribution system, the main source for heat and hot water for central campus buildings, runs through two main tunnels, one built near the center of campus in 1904 and one along Campanile Road built in 1930. These are quite a distance from CSB 2, but the impact of damage to old piping and tunnels would be felt campus-wide.

Figure 2. UC Berkeley campus map, Hayward Fault, and site for CSB 2

The nearest electrical source to CSB 2 is Switching Station 5 located in the northeast quadrant fed by the Hill Area Substation. The 12kv feed line runs along Gayley Road, about 100 feet from the back of CSB 2. Power lines from PG&E enter the Grizzly Peak Substation and cross the Hayward Fault to provide campus power. Movement along the Hayward Fault could sever these lines.

CSB 2, as well as the entire Berkeley campus, is entirely dependent on EBMUD's water distribution and storage systems. Piping from EBMUD facilities consists of either older cast iron pipes (pre-1948) or newer, standardized PVC pipes. There is little or no redundancy or backup in the water supply system. Many of the older pipes have deteriorated and can break or leak even without ground motion. The most immediate threat from disruption of the water distribution system is the ability to fight fires. Beyond that, there is a possibility of contamination, disrupted steam generation, and disrupted water flow from seismic activity.

The campus sewer system feeds directly into the City of Berkeley's sewer system and from there to the EBMUD sewage facilities. Piping materials in the campus sewer system include cast iron, ductile iron, reinforced concrete, vitrified clay, and PVC. The oldest segments (vitrified clay) date back to the early 1900s. The current standard is PVC. Failure in the older, non-PVC sections of the system, whether near Stanley or not, would disrupt some or all parts of the campus, making the resumption of classes difficult. Laboratories in CSB 2, which rely on industrial waste disposal, could not restart either. Also, drinking water could be contaminated.

The natural gas supplied to CSB 2 comes from PG&E transmission lines. The nearest entry point to the campus is at the intersection of Hearst and Euclid, at the North Gate of the campus. Most of the campus's natural gas is used by the Cogeneration Plant (primary service entry at Oxford St. and Cross Campus Drive) to produce electricity and steam, which could prompt interruptions in service if any of the campus's 2-4 miles of steel gas piping is damaged during an earthquake. The fire risk from damaged pipes, regardless of their proximity to CSB 2, should be considered as well. There are no easily accessible manual shutoffs on gas mains entering the campus.

Data and voice lines feeding CSB 2 also enter the campus at the North Gate. Plans are under way to relocate much of the communications network to new conduit throughout the campus. The backbone for the network is located in the northeast quadrant at present, but there are plans to relocate that to a new structure at the southwest corner of the campus. All communications systems rely on full electrical power. Internet services enter the campus at two locations – on the north and south sides – although beyond those there is little redundancy. Steam conduits used to hold additional electrical, voice, and data lines are at full capacity.

2.2 BUILDING CHARACTERISTICS

The building provides a multi-disciplinary research environment, allowing interaction between various scientific fields, including chemistry, biology, physics, materials science, and biological and chemical engineering. The 240,000 square foot building includes two below ground low vibration facilities for research in the chemistry of advanced instruments, optical benches, nano-technology, and materials science. Floors above grade will contain research laboratories for chemical and theoretical studies, bioengineering and biophysics, structural biology, and other emerging disciplines.

The building is partially built into the hillside that slopes down to the southwest from Galey Road, and has three levels of basement that are essentially all underground. There are seven floors above this base, the bottom two being partially below grade on the uphill side of the site. See the building section in Figure 3 and the building floor plans in Figure 4.

Construction at and below Level 1 consists of concrete columns, beams, and floor slabs, and concrete exterior retaining walls. There are also a few interior concrete shear walls. See Figures 4a through 4d. Construction above Level 1 consists of steel columns, girders, and beams with a floor of 2 "metal deck plus 4½" concrete fill. See Figures 4d through 4j. See Figure 5 for representative structural framing of floors.

The concrete walls provide resistance to lateral earthquake forces in the basement levels, and the upper steel levels are protected by a special bracing system called buckling restrained braced frames. The diagonal brace members in these frames are designed to yield and absorb earthquake energy without being significantly damaged.

Except for the concrete walls below Level 1 described above, walls and partitions in the building are steel stud and gypsum board. The gypsum product used varies depending on the application, but is typically 5/8" gypsum board. In lab and associated equipment spaces, ceilings are typically made up of hung 2' x 2' lay-in acoustical panels. Floor finishes in the same areas vary and can consist of sealed concrete, concrete with a resinous coating, or sheet vinyl.

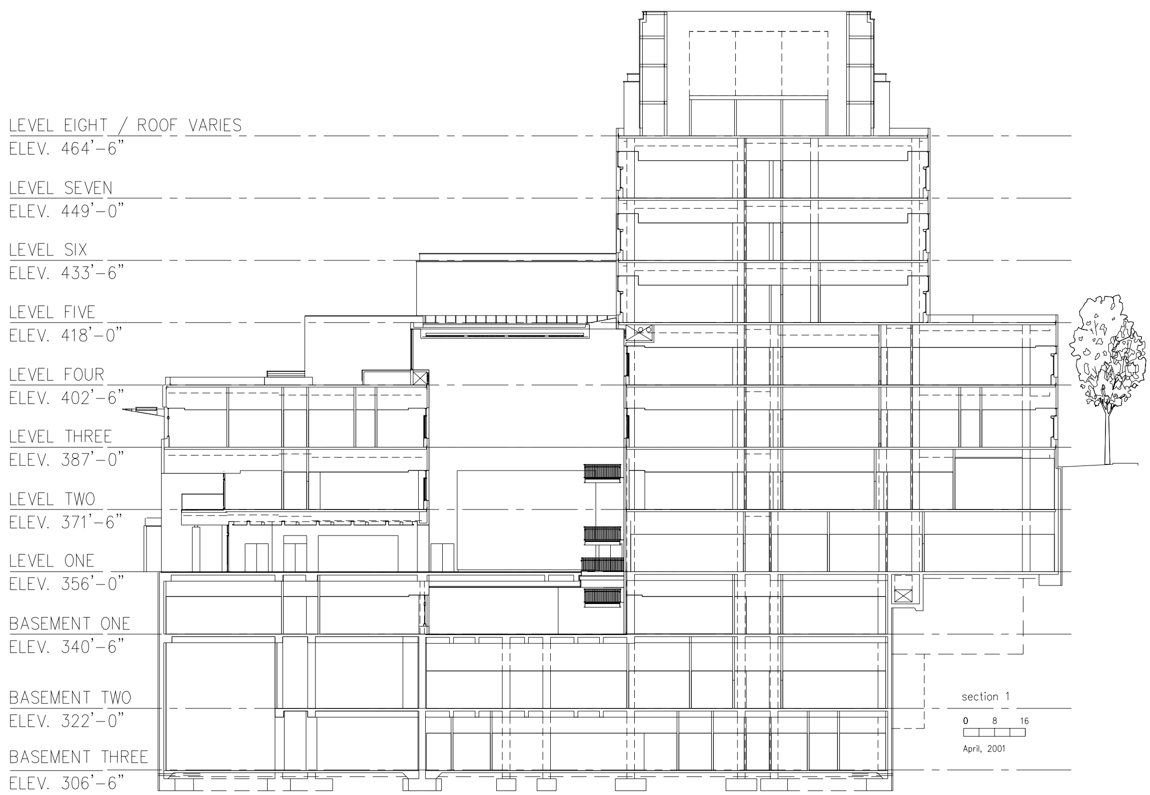
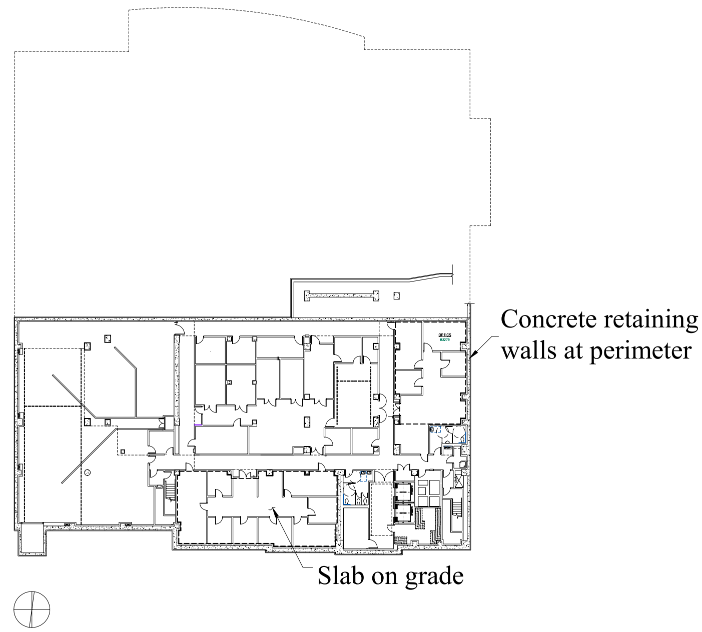
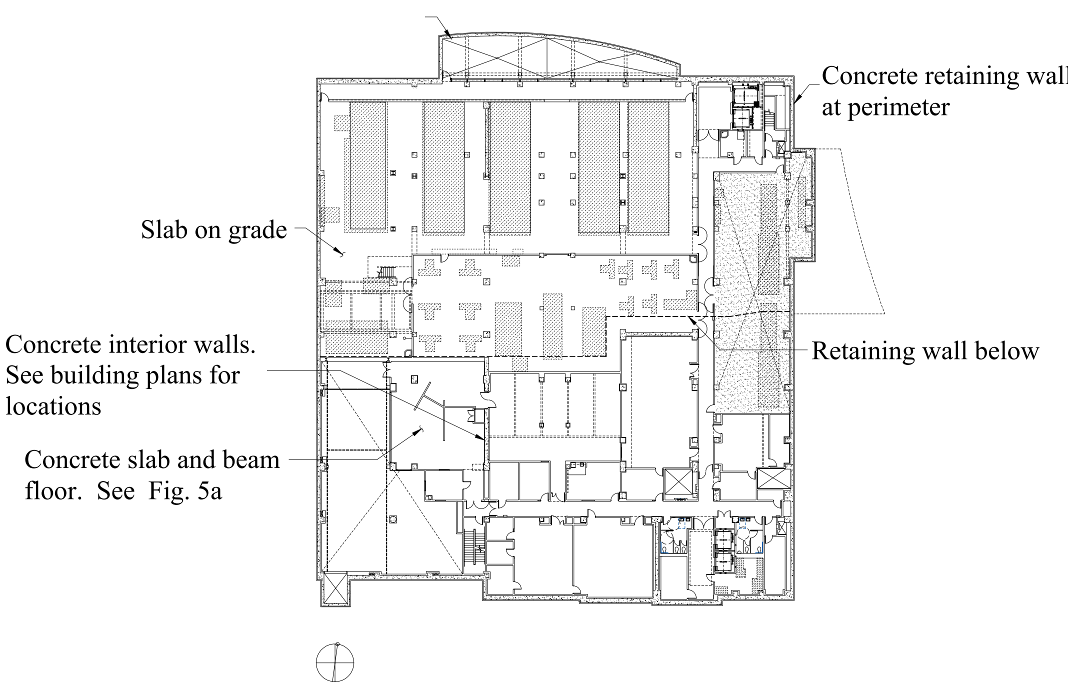


Figure 3. Typical Section

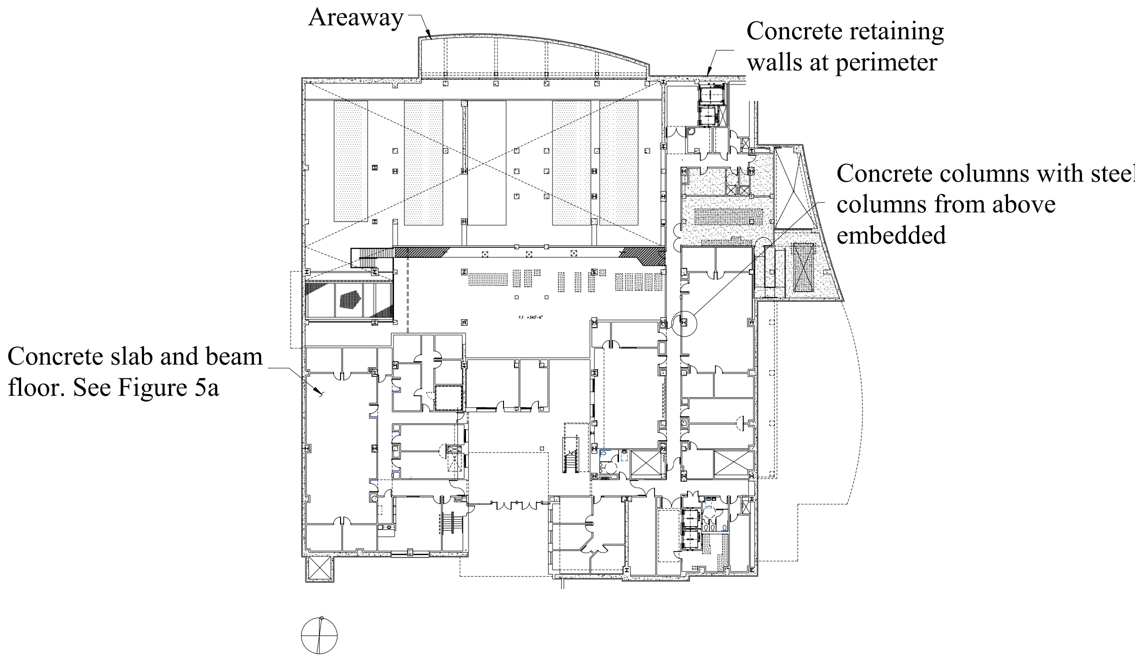


a. Floor Plan, Basement Level 3

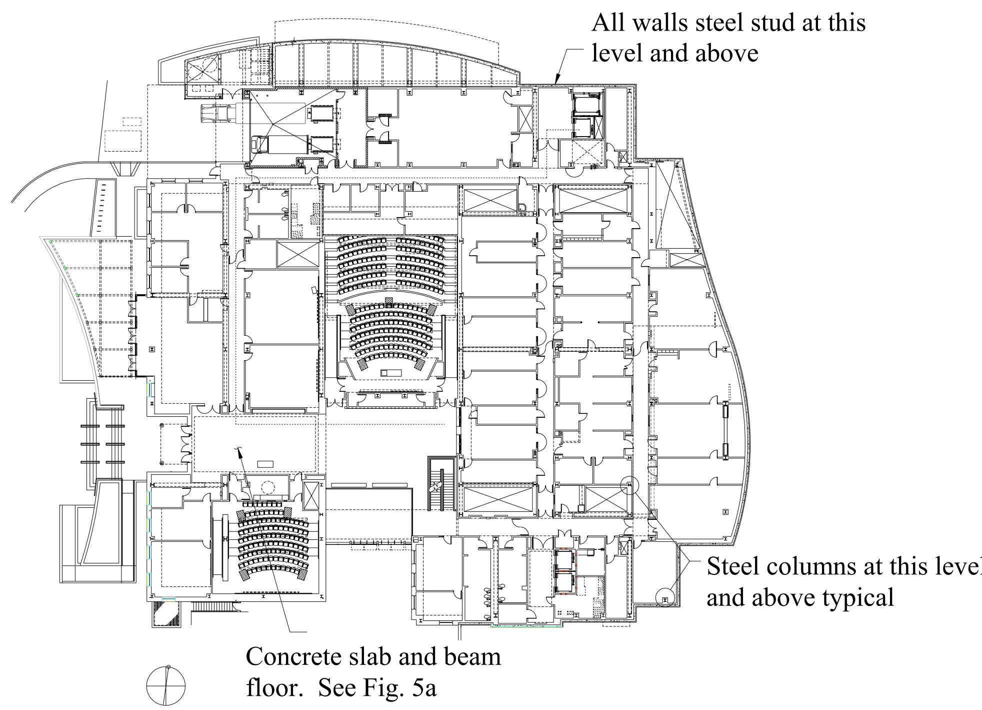


b. Floor Plan, Basement Level 2

Figure 4. Building Plans

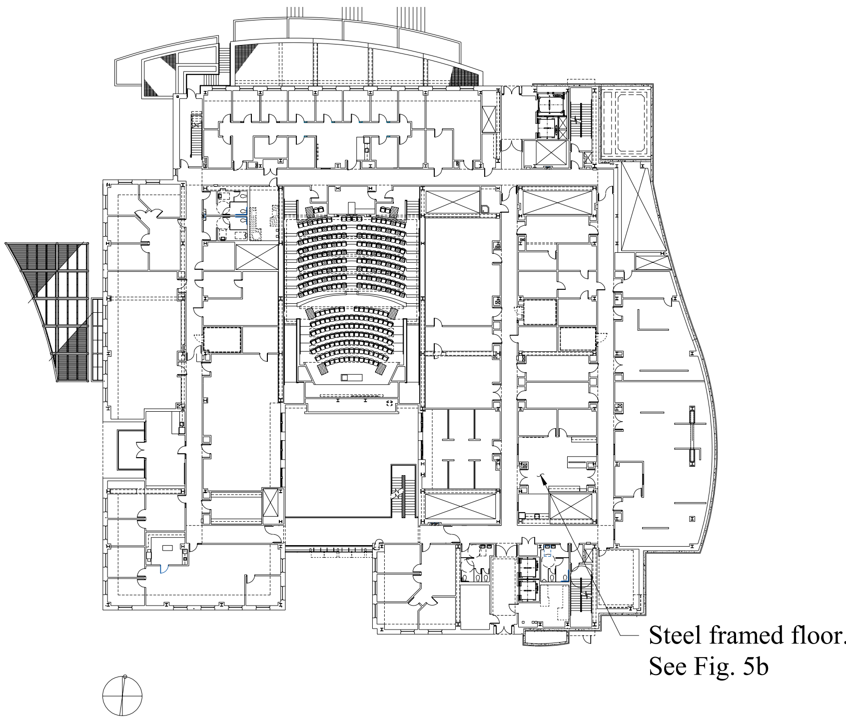


c. Floor Plan, Basement Level 1

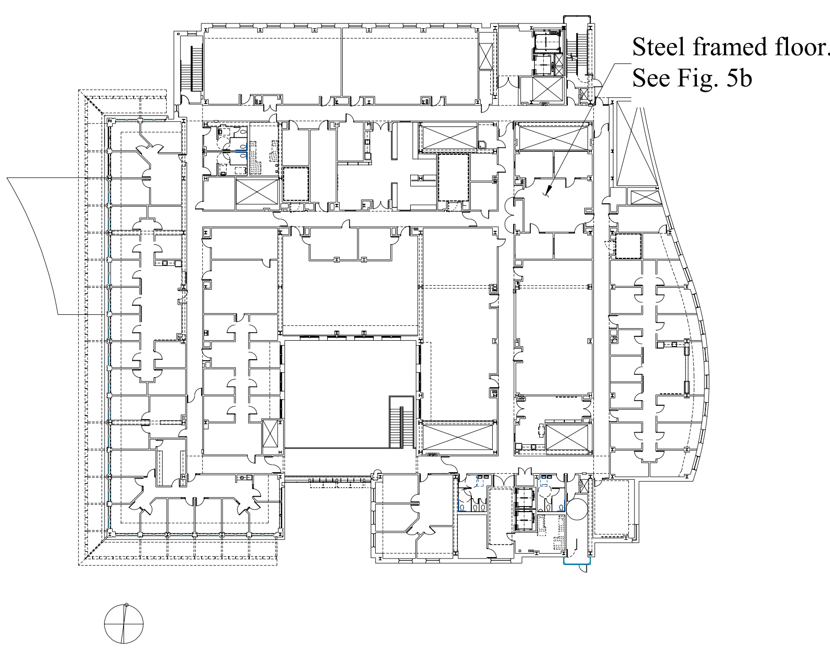


d. Floor Plan, Level 1

Figure 4. Building Plans (continued)

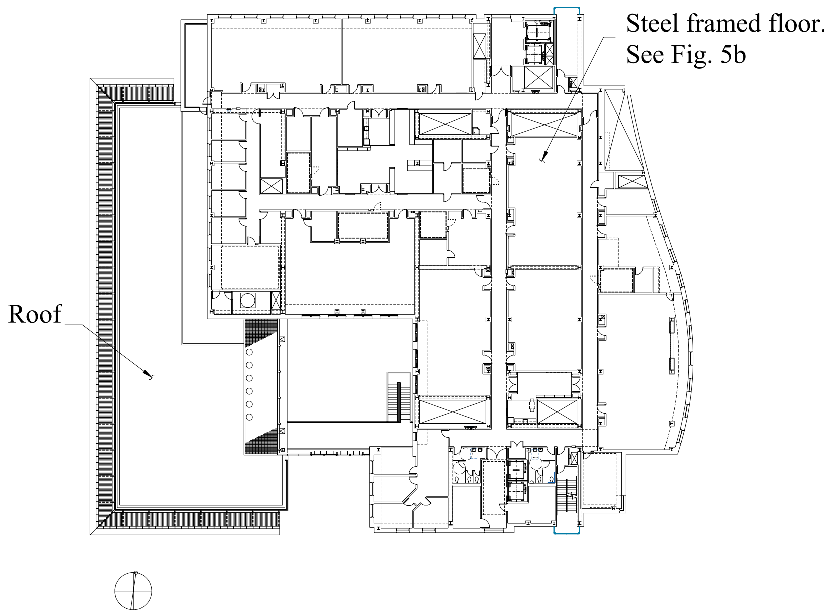


e. Floor Plan, Level 2

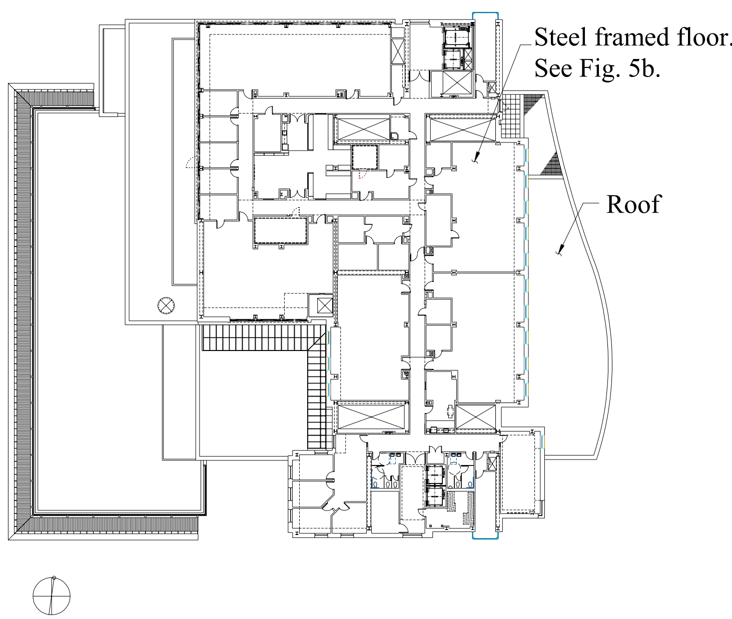


f. Floor Plan, Level 3

Figure 4. Building Plans (continued)

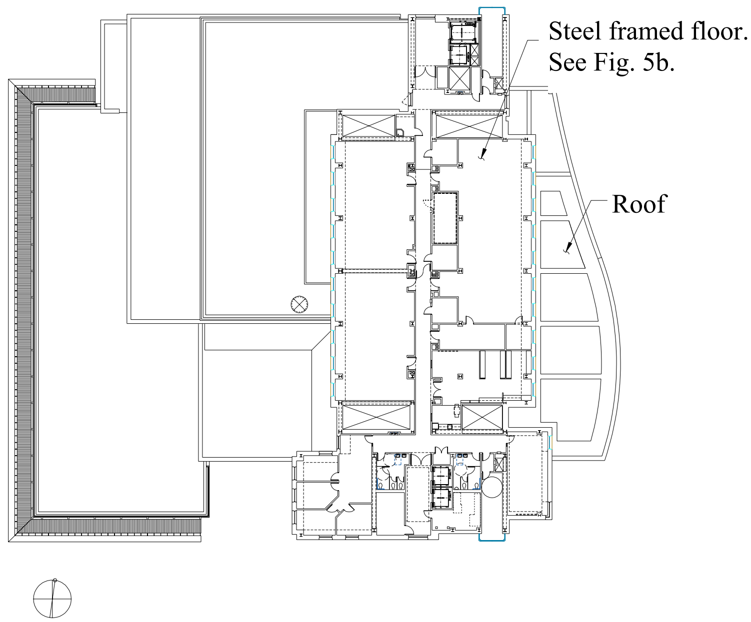


g. Floor Plan, Level 4

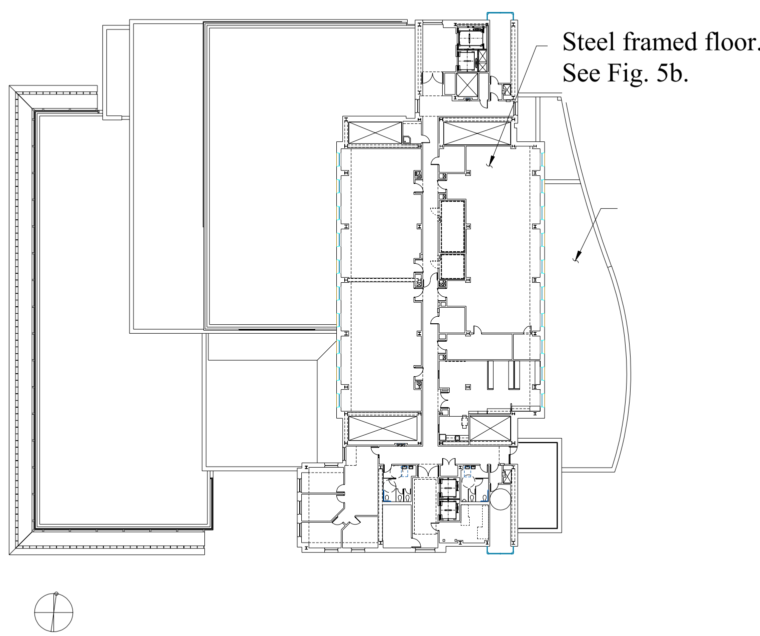


h. Floor Plan, Level 5

Figure 4. Building Plans (continued)

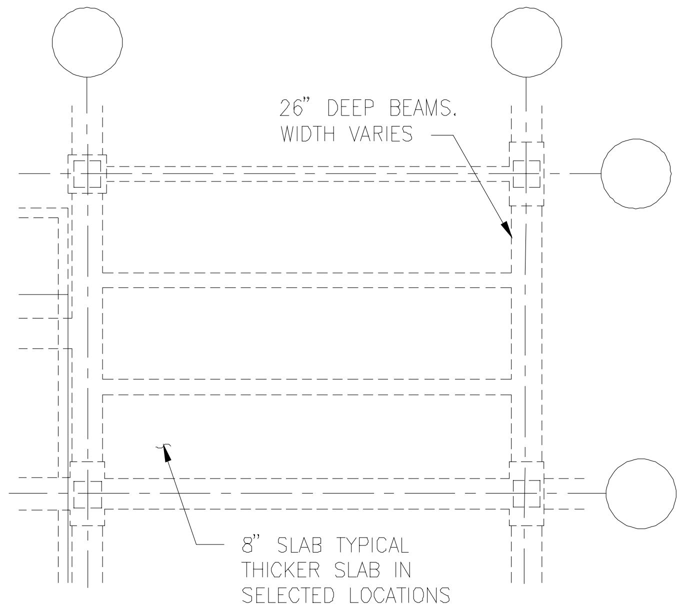


i. Floor Plan, Level 6

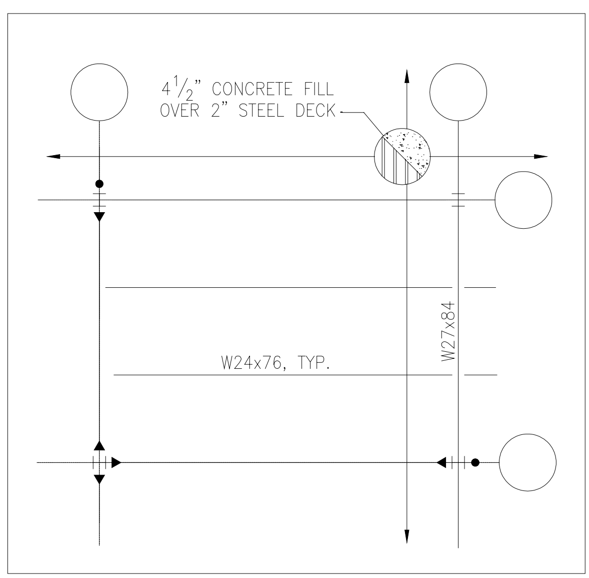


j. Floor Plan Level 7

Figure 4. Building Plans (continued)



PLAN OF FLOOR FRAMING - CONCRETE



PLAN OF FLOOR FRAMING - STEEL

Figure 5. Typical Structural Framing of Floors

2.3 EXPECTED SEISMIC PERFORMANCE

Structural seismic performance in the CSB 2 is expected to be superior. The buckling restrained brace lateral system was chosen because of its ability to protect the primary structural elements from damage as well as for the relative ease of replacement of any braces that may be damaged. A rating system used in a recent campus-wide seismic evaluation (UCB, 1997) assigned expected performance for each building based on a scale developed by SEAOC (Vision 2000, 1995), is shown in Table 1. These ratings were assigned to each building for three different levels of shaking at the site: Occasional shaking, having a 50 percent chance of being exceeded in 50 years (or on average, occurring once every 72 years); rare shaking, having a 10 percent chance of being exceeded in 50 years (or on average, occurring once every 425 years); very rare shaking, having a 2 percent chance of being exceeded in 50 years (or on average, occurring once every 2475 years). The very rare shaking is also sometimes characterized as resulting from the "maximum credible event" and is normally used only in that context — considering worst-case scenarios. For the rare shaking level, the most commonly used "design" level, most buildings were given a damage index in the 4 to 6 range. CSB 2 is expected to perform with a Damage Index range of 7 for this event and in the occasional event will probably suffer only negligible damage — equivalent to a Damage Index of 9. In the very rare shaking, damage no worse than a Damage Index of 6 is expected.

Similarly, the performance of nonstructural building systems is expected to be superior as special effort was focused on creating clear specifications for anchorage and bracing of these systems as well as for monitoring their installation. For this building, the seismic anchorage of the mechanical, electrical, and plumbing system, as well as the contractor-supplied laboratory furniture and equipment, was specified to be designed by the contractor. Submittals were required of these designs prior to installation. Superior nonstructural seismic performance therefore is expected, not because higher forces were specified, but because greater care was exercised in assuring that code-required bracing and anchorage is thoroughly designed and installed. The Damage Index projected from the structural system is therefore not expected to be diluted by poor performance of the nonstructural systems.

The biggest concerns for laboratory users regarding seismic protection of their labs and ongoing experiments, therefore, will be the reliability of the utilities serving the building and the anchorage of contents, as described in this manual. Backups should be provided for outside utilities deemed critical for protection of the laboratory environment or experiments as little control can be exercised within the building for external campus or regional utilities. Contents can be protected with varying levels of completeness as described in Section 4.

Table 1. Damage States and Performance Level Thresholds

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

2.4 SEISMIC DESIGN REQUIREMENTS

Building codes like the Uniform Building code [ICBO, 1997] contain requirements for anchoring many architectural and building service system components to the structure for seismic forces. The applicability of these anchoring requirements to contents is vague and the boundary between nonstructural building components and contents is blurred. For example, no components that could be classified as contents are listed in the code other than storage racks and floor-supported cabinets over six feet in height. Traditionally, items classified as contents are installed by the owner or user after construction is complete and there is little jurisdictional control. However, because of the similarity of the classes, code anchoring requirements for nonstructural components can be directly applied to contents when such anchorage is deemed appropriate.

For nonstructural components, codes require anchorage to sustain specified lateral forces measured as a percentage of element weight. This proportion of weight is sometimes referenced in terms of the acceleration of gravity, *g* (e.g., 0.5g meaning 50% of component weight), but is more accurately simply written directly as 0.5 times the Weight (or 0.5W). The magnitude of the code loading for nonstructural components, termed F_p in most codes, is dependent on the location of the building relative to potential source faults, site soils conditions, and the height of the component within the building. Also in the formula for F_p, is an importance factor, I_p, intended to give additional reliability for anchorage of important equipment or other components. Additional factors include a_p, a measure of dynamic amplification of seismic forces created by flexibility of the component, and R_p, a measure of ductility or toughness of the connection. Maximum and minimum loadings are also specified that override the results from the formula. The full code formula for forces on nonstructural elements and contents, then is:

$$F_p = \frac{a_p C_a I_p}{R_p}\left(1 + \frac{3h_x}{h_r}\right)W_p$$

where

a_p is the component dynamic amplification factor

C_a is a seismic coefficient dependent on seismicity and site soils

R_p is the component anchorage factor

I_p is the component importance factor

H_x is the height above grade of the component attachment

H_r is the structure roof height above grade

Although for most components in this manual, a_p will be 1.0 and R_p will be either 1.5 or 3.0, this formula should be applied by an engineer knowledgeable in seismic design and is given here for general information only. For the CSB 2 site $C_a = 0.6$. Using $a_p = 1.0$ and $R_p = 1.5$, the required loading on each floor of CSB 2 is shown in Figure 6.

The NEHRP Provisions (BSSC, 2001), a national source document for future codes, contains a method of determining appropriate design forces for nonstructural elements based on dynamic analysis of the building. In this case, a_i is determined directly from a modal or time history dynamic analysis and can be substituted for the code values at each floor. If such results are based on a nonlinear dynamic analysis, the required loadings for each floor will likely be shown to be less than required by the code formula. Such a nonlinear analysis is not available for CSB 2 and code loads are therefore recommended for those cases where a full design is required. The typical details contained in Section 5 are assigned already considering the code loads and the weight of the element, so these loadings will not be needed unless an engineering design is performed.

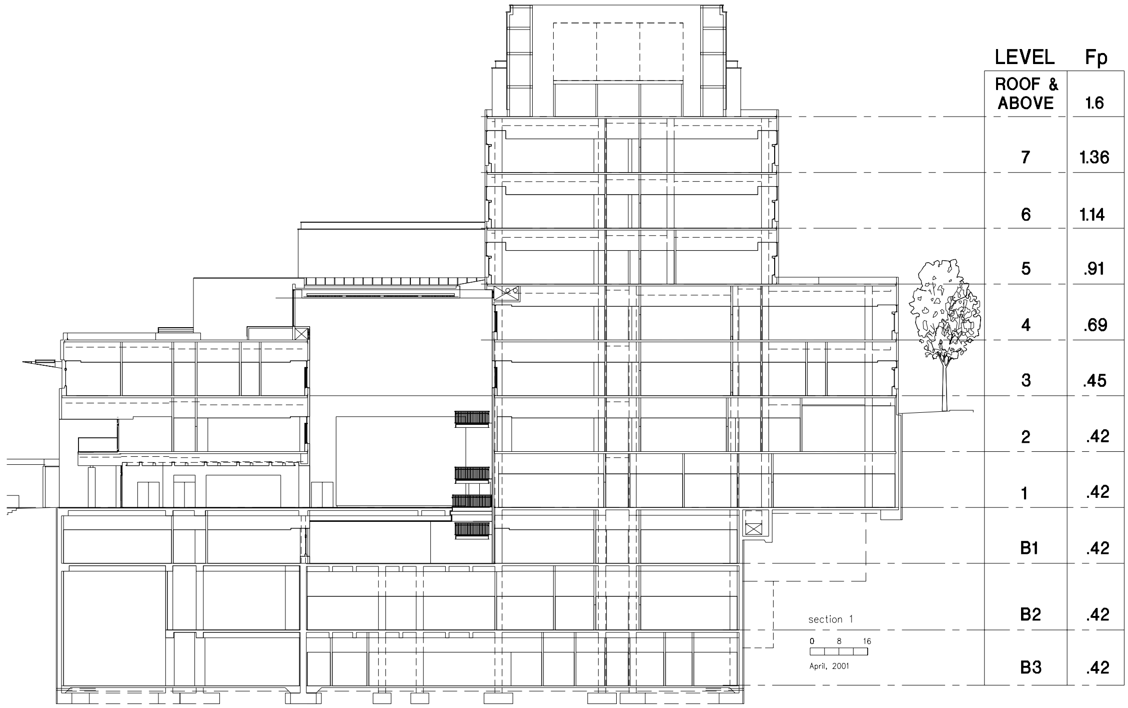


Figure 6. Design force for components within CSB 2 from 1997 UBC using a_p = 1.0; R = 1.5

3 Seismic Anchorage in the Lab Environment

Most seismic protection of contents consists of restraint against sliding or tipping during the building motion induced by an earthquake. This restraint is obtained by attaching the item to a stable building component that itself is strong enough to resist the shaking and provide anchorage. Anchorage details must be conservatively designed and be reliable because it is likely that they will be in place months or years and be fully tested only once — by the earthquake. This section describes types of anchorage often used for restraint of contents and caveats for their use. This section also describes building components in CSB 2 that can be used for anchorage, including floors, ceilings and overhead structure, walls, and built-in furniture.

Section 5 contains specific details for anchorage of various contents and limitations on their use for CSB 2.

3.1 ANCHOR TYPES

3.1.1 Concrete

Anchorage to concrete slabs is achieved by drilling a hole and inserting one of a variety of bolts made for this purpose. Mechanical-type drilled-in anchors expand against the sides of the hole to provide a tight and secure fit (Fig. 7). Many of these type of anchors are sensitive to installation procedure to achieve their rated value. Care must be taken to drill the right diameter and depth of hole and to tighten the nut in accordance with the manufacturer's instructions. Chemical anchors are installed by filling a narrow annulus around the bolt with specially formulated epoxy (Fig. 8). The epoxies are normally two-part mixes that must be combined immediately before installation. Systems are available that require hand mixing, that automatically mix the two parts in special caulking guns, and that place the two chemicals in a cartridge that is placed in the hole, broken, and mixed in place. The rated value of chemical anchors is also sensitive to installation procedure, and the type of drill used and cleaning of the hole must be strictly in accordance with the manufacturer's instructions.

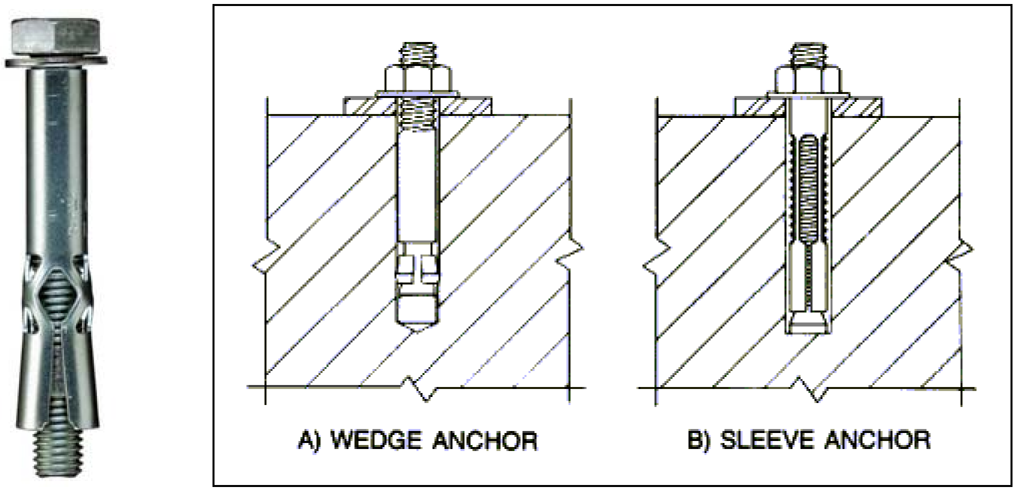


Figure 7. Typical Expansion Anchors

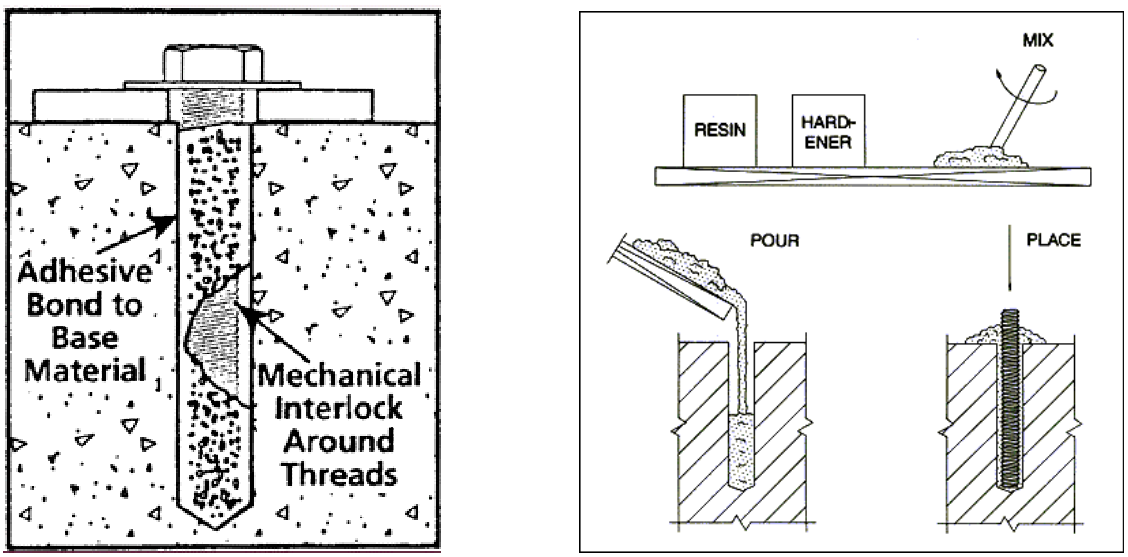


Figure 8. Typical Chemical Anchors

3.1.2 Metal

Items are connected to sheet metal or steel with bolts, sheet metal screws, or welding. Welding requires a high level of expertise, and cumbersome equipment and is not normally used for seismic anchorage of contents. Use of bolts requires pre-placed holes of the correct size in the items to be connected. Sheet metal screws can be installed through predrilled holes of the correct size, or, more conveniently and more reliably, can be "self-drilling." (See Fig. 9) When using self-drilling sheet metal screws, it is important to use the correct type and size for the application in accordance with manufacturers instructions.

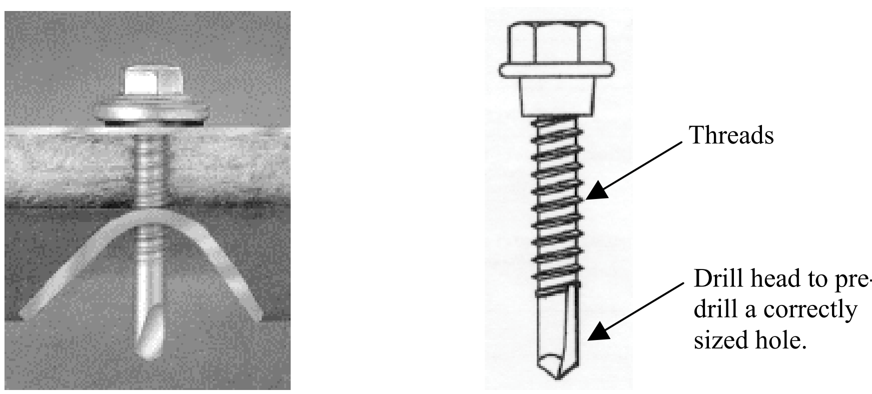


Figure 9. Typical Self-Drilling Sheet Metal Screws

3.1.3 Wood

Wood screws are normally used to connect seismic anchorage to wood because of their high tensile load capacity and their removability. Larger wood screws may also need a predrilled hole to facilitate installation and to prevent splitting.

3.1.4 Adhesives

A wide variety of adhesives are available for wood, metal, and plastics, and even concrete, including glue, epoxy, and double-backed tape. Considerations for use of these products as attachments of seismic restraint are discussed below.

· Nondestructive removability: In most circumstances of restraining contents, it will be desirable to remove the restraint with a limited amount of damage to surfaces of the item as well as the restraining building element. Many adhesive products will permanently damage surfaces. "instant" industrial adhesives based on cyanocraylate, for example, provide extremely high strength, but are difficult to work with and are difficult to remove without damage or use of powerful solvents.

· Resistance to environmental effects: The strength of some adhesives, notably epoxies, degrade when exposed to sunlight or certain chemicals, or with aging. The characteristics of the adhesive should be investigated, although the information may be difficult to obtain from manufacturers.

· Sensitivity to installation and overall reliability: Most adhesives are sensitive to installation procedures and the manufacturer's recommendations must be strictly followed. For example, when raised computer floors came into use, the small pipe- or tube-columns used for support were installed by gluing the column's steel base plate to the structural floor. Although in the ideal case these connections were very strong, their installation conditions varied widely, and ultimately the adhesive connection was judged unreliable to resist seismic forces, and building codes now require bolted connections.

Industrial double-backed tape (VHB™ by 3M®) is often used in commercial seismic restraints for contents because of its convenience and potential strength. Other than cleaning of surfaces, no installation instructions are normally given. However, 3M recommends applying a pressure of 15 pounds per square inch of area to gain full contact and adhesion. For light countertop devices that consist of small plates with double-backed tape, this pressure (about 25 pounds for a 1.5 inch square plate) may automatically be applied by a user. However, a 2x3 inch plate would require 90 pounds of pressure, unlikely to be applied without specific instruction, particularly on a vertical surface.

· Strength ratings: For nonindustrial adhesives test results are seldom available to determine reliable strengths in different circumstances of use. Although each and every seismic restraint need not be designed, the range of expected loading is known and should be considered if preapproved restraints are not used. From Figure 6, code loads in CSB 2 vary from about 0.4W to 1.6W. If a conservative rule of thumb for installation of restraints in the building was desired, the basis should be the highest load. Using an appropriate factor of safety to assure the reliability of the installation, such restrains should be able to carry about three times the weight of the component.

However, the load "rating" of any device should be carefully examined, particularly if the rating is dependent on an adhesive. Consider the case of double-backed tape for attaching flat plate elements or angles to a benchtop, cabinet wall, or to a flat surface of the component itself. Such an installation is shown in Figure 10. Loading *T*, pure tension, shown in Figure 10a, assumes that the load is applied either to the exact center of the plate, or uniformly across the plate (which is seldom the case). Double-backed tapes commonly used for seismic restraints will hold 100 pounds per square inch (psi) of contact surface in such a loading case. Figure 10b shows a similar pure loading case in shear, where the load, *V*, is applied almost in line with the adhesive (practically impossible to achieve), and tests have shown that the tape will also hold 100 psi for this loading case. Figure 10c shows the more common case in actual applications, where the load is applied to the edge of the plate, tending to "peel" the plate from the substrate. Loading capability of the tape for this case is considerably smaller, as little as 20 psi. Loading similar to the *T* case, but at an angle to the plate, or the *V* case, where the load may be located an inch or more above the surface of the adhesive, can also cause significant reductions to the 100 psi "rating" of the tape. Similarly, this tape is not at all intended for constant loading (a hanging weight for instance), and the load capacity drops to less than 5 pounds per square inch in that situation).

Details suggested in this manual using these kinds of adhesives take these characteristics in account.

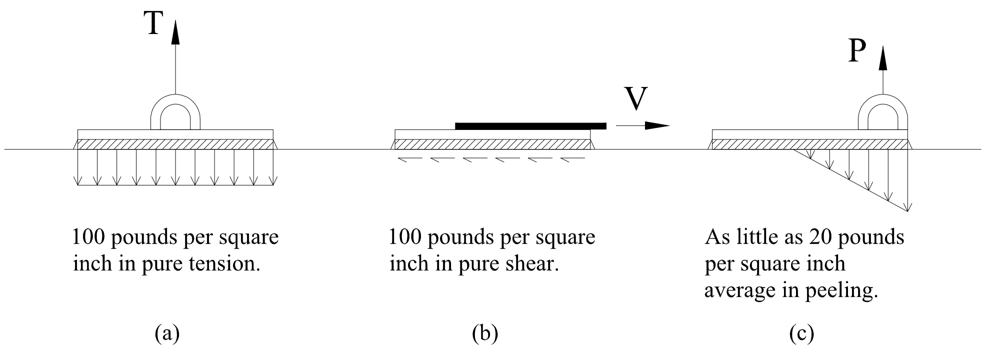


Figure 10. Adhesive Installation and Loading

3.1.5 Various Connectors for Gypsum Wall Board or Plaster

Nonstructural walls in buildings, are most often made up of steel or wood vertical elements (studs) spaced at one to two feet apart and covered with ½" to 1" of gypsum wall board or plaster. There are many fasteners manufactured to attach light loads to these surfaces such as plastic plugs that expand when a screw is inserted, or "mollybolts" and "butterfly" anchors that open up to create a threaded nut on the inside face of the wall. These anchors are intended for pictures, light shelving, or other decorative items, are dependent on the integrity of the gypsum board or plaster for their strength, and, in general, should not be used for seismic anchorage. However, plaster surfaces, depending on the thickness of plaster and the style of lath, can be quite strong, and can be suitable for seismic anchorage for smaller loads. In instances where such uses are unavoidable and backing plates are not available, a simple testing program can establish reliable tension loads for various styles of anchors. A safety factor of 3 against pullout, established by test is recommended.

3.2 COMPONENT ANCHORAGE LOCATIONS IN THE CSB 2

Typical conditions in labs in CSB 2 are shown in Figure 11. There is typically an acoustical ceiling 9'4" above the floor with the overhead structure 15' above the floor. Floors and the underside of the floor above could be concrete slab construction or steel beam and metal deck construction, depending on the location within the building. See Figure 3. The floors are generally protected against fluid spills by sheet linoleum or coatings. Partition walls are of steel stud and gypsum board. On floors B2 and B3 there are a few concrete walls, furred with light metal and finished with gypsum board. The typical built-in island lab benches are wood and secured directly to the floor. Vertical steel posts run between benches from the floor to a height of 90". These posts are designed to support shelving and their contents. Other built-in benches, cabinets, and shelving are located adjacent to walls and are also anchored in place. Several types of moveable tables and benches are provided to permit flexible layouts in the laboratory. Unless restrained, this furniture could slide or overturn in an earthquake, particularly if loaded with heavy equipment. Equipment should not be seismically anchored to this furniture unless the furniture itself is also restrained.

The typical office area is similar and is shown in Figure 12.

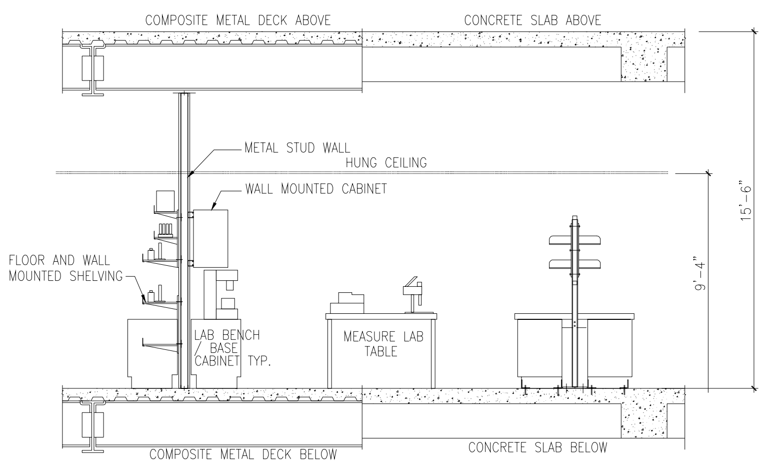


Figure 11. Typical Lab Configuration

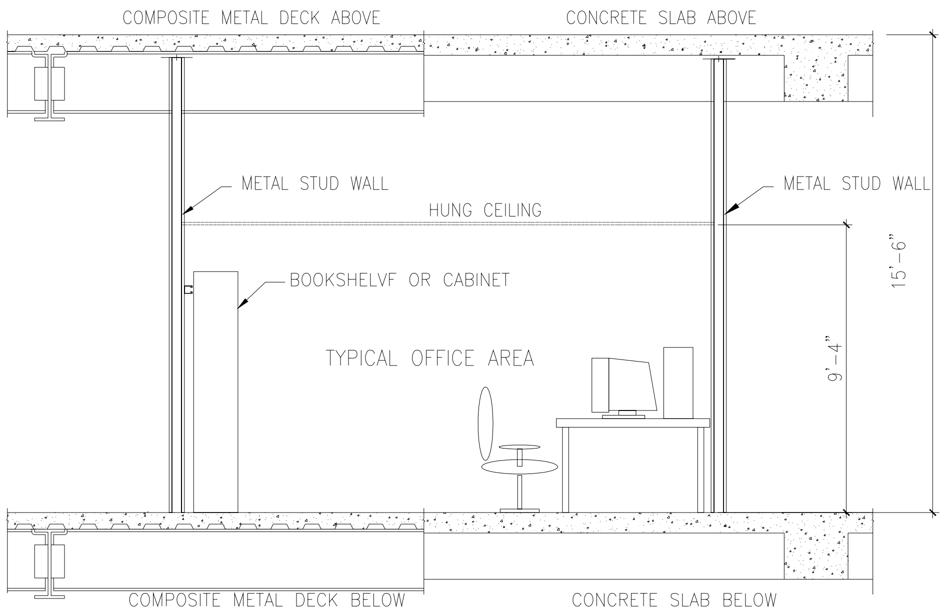


Figure 12. Typical Office Configuration

3.2.1 Anchors to Floors

Floors throughout the building are concrete. The floor of level B3 is a 6" slab on grade, at the three concrete framed floors, basement levels B2 and B1 and level 1, an 8" thick structural slab over concrete beams, and on all other floors, 4.5" of concrete over metal deck. Current requirements for laboratory floors include resistance to moisture or chemical penetration that could easily be compromised by drilled-in seismic anchors. A completed installation of a mechanical anchor will certainly break a surface seal and could lead to a penetrable floor as well as corrosion of the anchor inside the hole. Chemical anchors are less likely to cause these problems, but the acceptability of any anchorage into laboratory floors should be checked with the appropriate building staff. Unless specifically detailed by an engineer, care should be taken to not drill through the slabs; a reasonable general rule for this building is to keep drilled holes 3" or shallower, although depending on the exact location, deeper holes could be placed. Many drilling systems used for installation of mechanical and chemical anchors will easily cut through reinforcing steel embedded in concrete. Magnetic bar detectors can be used to find bars located close to the surface that could possibly be cut. Main reinforcing steel is located directly over concrete beams at a depth of approximately 2" and these bars should not be cut. Smaller bars are also located in the slab areas and they should also be avoided if possible; however, these bars can be cut if it is difficult or impossible to relocate a hole.

3.2.2 Anchors to Overhead Structure

Anchors may be placed generally anywhere on the undersides of the concrete slabs but not on the bottoms of beams, as main reinforcing is located there. If drawings are reviewed to determine the configuration of reinforcing, anchors may be placed into the sides of beams above the bottom reinforcing. On steel-framed floors, anchors can be placed in the up-flutes of the metal deck where the configuration allows, or on the centerlines of down flutes. Steel plates or channels may need to be installed between two or more down-flutes to provide a flat surface for anchorage. Chemical anchors should not be used in a configuration that will put them in constant tension (e.g., hanging them from the slab soffit) because epoxy under constant loading will creep.

Supports or braces should not be attached to steel framing without the input of a structural engineer. First, this framing is covered with fire-proofing that should not be penetrated without appropriate repair, and secondly, certain attachments to steel beams can compromise their structural integrity.

Bracing can not be anchored to suspended ceilings. Similarly, it is not recommended to attach anything to the mechanical, electrical or piping utilities in the building.

3.2.3 Anchors to Concrete Walls or Columns

Concrete columns and walls are located in CSB 2 in the basement levels, as noted on the plans in Figure 3. The walls are typically furred with 2.5"-20 gauge steel studs and gyp board. This furring is attached to the wall at spacing to make the strength at least equivalent to the typical partitions. See Section 3.2.4.

The concrete walls themselves have much greater strength than partition walls, and substantial equipment and content load could be anchored directly to these walls. However, because the conditions vary, anchorage to walls behind furring should be designed by an engineer.

3.2.4 Anchors to Partition Walls

Nonstructural walls in this building are steel stud partitions consisting of 20 gauge studs, 4" deep with 1.625" wide flanges spaced at 16" on center spanning vertically between the concrete floors and the bottom of the structure above, which could be concrete beam-slab or metal deck and concrete. Continuous channel-shaped steel tracks support the studs top and bottom. The studs are positively attached to the floor track with screws. The studs at the top are only laterally restrained to allow for differential movement between floors. This restraint is provided by a track attached to the studs and nested into, but not connected to, a second track attached to the structure. The inner track is 20 gauge material and the outer track is 16 gauge material.

Gypsum board covered partitions also occur as a furred finish over concrete walls and also on both sides of structural steel diagonal braces, creating a cavity for the brace. Studs used in these cases are also 20 gauge, but are 2.5" or less deep. The connections of the furring studs to the concrete wall and the connections of cavity studs to each other are configured to give these surfaces the same strength as the typical wall for support of cabinets, bookshelves, or for restraint of contents.

Connections to steel stud walls must be attached either directly to a stud or through a backing bar. Connection to the studs is limited by location and surface area. Normal backing bars are steel plates or channels installed at the time of original construction under the gypsum board spanning between studs. Internal backing bars were installed in this building during construction at known anchorage locations such as built-in cabinetry or shelving. The location of any additional internal backing should be documented during and after construction. Backing bars for equipment can also be installed when construction is complete, but wall finishes must be locally removed and replaced in a significant area of wall. When anchoring contents in locations with no internal backing bars, it is more common to add an external backing bar on the surface of the wall consisting of a unistrut element extending across three or more studs and attached directly to them with self-tapping screws. The elements of a steel stud wall are shown in Figure 13.

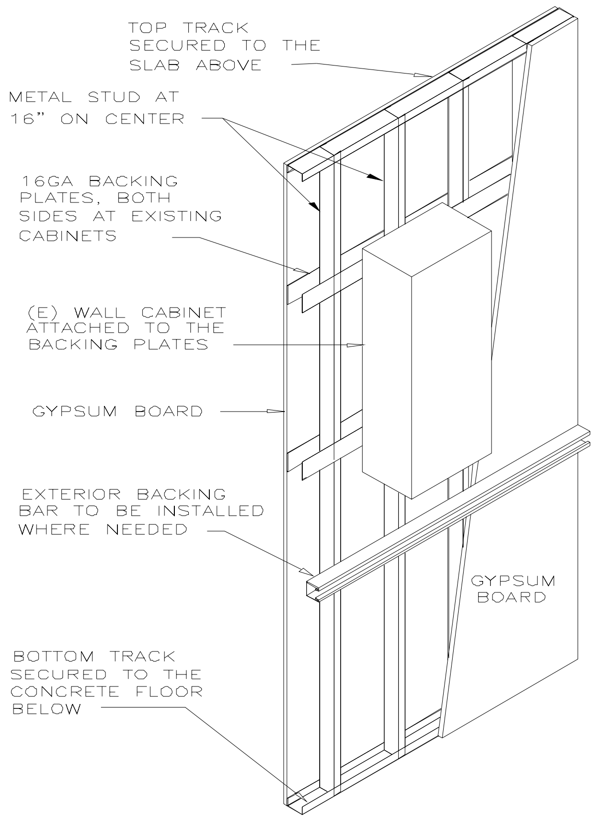


Figure 13. Typical Office Configuration

It is difficult to anchor most floor-supported equipment to the floor because it is not designed for such anchorage (exceptions include some tanks and other equipment that have legs and suitable mounting holes). The attachment itself may damage the equipment, and anchorage loads during an earthquake can damage the frame, the mechanisms, or the contents. The partitions in laboratories are conveniently located to provide restraint not only for floor-mounted equipment and moveable tables and racks, but also for heavier bench- and table-mounted equipment. However, the typical stud size and gauge used in this building limit the use of partitions as a source of seismic restraint, particularly in the upper floors where seismic loads are highest. These limits, in the form of maximum weight or location in the building, are indicated in the seismic anchorage details recommended for the building in Section 5. If equipment does not meet the limits given for the wall restraint detail, new vertically spanning structural elements, called “strongbacks,” must be installed. Other engineered solutions, such as anchoring to the floor, or restraining from the structure above are also available, but are not detailed in this manual.

3.2.5 Anchors to Built-In (Anchored) Lab Furniture

A common component of a laboratory is the island bench. It consists of two rows of freestanding back-to-back benches, often with shelving above them supported by steel posts running floor to floor or cantilevered up from the center of the benches. See Figure 14. These benches are secured to the floor and can be used to restrain light and medium weight equipment resting on the benchtops.

In the CSB 2's island benches, 2" x 2" x 12 gauge steel tubes cantilever from the top of the benches up to a total height of 90". In labs where this design was used, vertical shelf supports should not be used to support additional equipment or to provide seismic restraint for anything on the benchtop. If shelf support systems different than this are present, limitations must be calculated on a case-by-case basis.

Where non-moveable lab benches, cabinets, or bookshelves are located next to a wall, they are typically anchored to the concrete floor below, the wall behind, or both. Original lab furniture in CSB 1 may be considered anchored. Anchorage of furniture that has been moved or installed as part of a remodel must be verified. Limits on using built-in casework for restraint are given with typical details in Section 5.

“Moveable” tables, benches, cabinets, files, or shelves may be considered as possible candidates to restrain other light objects. However, the element itself must be secured before any such restraint can be considered effective.

4 Guidelines for Providing Seismic Protection

Examples of items considered user-supplied contents are given in the Introduction. Protection of these items against damage caused by earthquake shaking, even though such shaking may be rare, may be desirable to avoid the following types of losses:

- Life safety of occupants: Life safety can be threatened by heavy objects falling or tipping directly onto occupants, or by sliding or tipping into a position that blocks egress from a work area. Life safety risks can also be created in a laboratory by release of hazardous materials, either directly by broken containment, or by two or more released materials combining to create a hazardous substance.
- Protection of data, other results of experiments, or ongoing experiments: Data or other results of experiments may be one of a kind, difficult to "backup," or take years to replace. Ongoing experiments may represent investment of enormous time and/or resources. Even if protected from direct physical damage due to shaking, interruption of certain utilities or supplies could damage or ruin future results.
- Protection of valuable or hard-to-get equipment: Specialized equipment in labs often represents a large investment that should be protected, or may be difficult or time consuming to replace, or both.

The obvious response to the threat of damage from earthquakes is to provide restraint for all contents in the laboratory environment. The two primary reasons why this may not always be necessary or appropriate are cost and the potential effects of seismic restraint on the function of the element or the lab as a whole. Costs of providing seismic protection to the complete contents of typical labs could cost as much as $20 per square foot. Restraining a portable benchtop instrument with a quick-release system to facilitate changes in location may affect efficiency and is likely to not always be implemented by staff. Providing a docking station for wheeled equipment may take up space and inhibit movement in the room. In addition, in areas of lower seismicity, serious damage is far less likely and only the highest priority items may warrant protection.

It is therefore prudent to prioritize contents with respect to their potential to cause losses in the three categories discussed above. It is possible to develop evaluation systems that will result in a single priority rating for each element based on concerns for all three types of losses, but such systems are complex and require many qualitative judgments.

Rather than complex evaluation systems that combine the potential for each type of loss, it is suggested that a simple linear system be used that considers the risk presented by each element in each category in turn. It is recommended that *Life Safety* issues be considered first, then *Importance*, and *Dollar Value* third, although any order could be used. Any element that is judged high priority in the first category need not be considered for the second and third categories and so on.

Considerable judgment will be required by the users to place the contents of their lab into one or more priority levels, but the systematic approach suggested will greatly assist the process. Some users may conclude that all the contents of their lab should be provided with seismic restraint. Studies of five labs at UC Berkeley concluded that the cost of providing complete seismic restraint ranged between $10 and $16 per square foot of lab. It is recommended that $15 per square foot be used for a budget figure. Based on subsets of priorities developed from consideration of potential losses discussed above, costs of providing seismic restraint can be estimated as a proportion of this $15 per square foot figure (e.g., if approximately 50% of all items will be restrained, assume it will cost $7.50 per square foot). The costs of providing various levels of seismic restraint must be weighed against the potential damages and losses to arrive at an appropriate scope or work for each situation.

Additional guidance for setting priorities within each category is given below.

4.1 LIFE SAFETY

Life Safety is a well-known phrase dealing in general with the health and welfare of people. In earthquake engineering, an acceptable state of life safety is somewhat undefined but is normally interpreted as the prevention of deaths—and possibly life-threatening injuries—but certainly not prevention of all injuries. In other words, considering the rarity of seismic events, providing an injury-free environment is not considered cost-beneficial—if possible at all. There exist little data from which a direct relationship can be made between seismic restraint of laboratory contents and seismic protection intended by the building code with respect to life safety. The guidelines in Table 2 are aimed at prevention of *serious* injury as opposed to *life threatening* injury, although the distinction may be subtle. Being struck by a 20-pound object falling from 5 feet or more from the floor clearly could cause a death, but is more likely to cause a serious injury. The limit of 20 pounds and the height of 5 feet are both arbitrary limits and are taken from the State of California's code governing hospital construction. Similarly, the size and weight of unrestrained floor-mounted equipment that could become dangerous during earthquake shaking are unknown. 400 pounds is often used as a limiting weight, but the source and validity of this weight is questionable. 200 pounds is suggested as such a limit in this manual. Lastly, building codes and other standards sometimes consider a permanent connection to utility systems (gas, water, and power, etc.) as a trigger for seismic protection, presumably due to the potential secondary hazard from breaking such a connection. The guidelines in Table 2 therefore should be considered judgmental and are given for general guidance.

There is virtually no guidance available for limits on the sliding of large and heavy objects. Sliding, presumably with considerable friction between the device and the floor, is differentiated from rolling, such as the case with a heavy, wheeled cart or tank. Once set in motion from impact with a wall or lab bench, the wheeled device has little to slow it down and could become a dangerous projectile. On the other hand, friction at the base of the nonwheeled object will quickly slow and stop the movement, and additional movement will only come from additional seismic floor motions. If overturning is unlikely and prevention of sliding is not required to prevent breakage of connected utilities, the level of risk to life safety is unknown, but probably small. The device could pin an occupant against a wall or other fixed object and could even create crushing injuries, or, could gradually slide into a position to block an exit. These events are unlikely but possible. The benefits of restraint of such elements must be weighed against the "costs," including the cost of providing restraint itself, a potential disruption of operations, and a potential of increased damage to the contents of the device due to transfer and possible amplification of floor motion from the anchorage.

Any items that are determined to present a *Life Safety* risk, and will be restrained for that reason, can be set aside from evaluation for *Importance* or *Dollar Value*.

Table 2. Life Safety Risk Levels

Of Concern	**Intermediate Concern**	**Low Concern**
• Potential spill of hazardous substance or chemical combination into hazardous substance • Item weighing 20 lbs or more stored or mounted 5 ft or more above floor • Countertop equipment permanently connected (hard wired or plumbed) to building or laboratory utility systems • Freestanding storage racks, or cabinets over 5 ft tall • Floor mounted equipment weighing more than 200 lbs, over 5ft tall, or with width less than 2/3 of height • Wheeled equipment, tanks, or racks normally weighing over 200 lbs (including contents): o When over 5ft tall or with width less than 2/3 of the height • Other items judged by users to be dangerous to occupants in earthquake shaking	• Countertop items weighing 50 lbs or more • Unrestrained storage cabinets or racks less than 5 ft tall and with width less than 2/3 of height • Wheeled equipment, tanks, or racks normally weighing over 200 lbs (including contents): o When less than 5 feet and with width greater than 2/3 of height (could be tethered when not in use) • Items on wheels weighing less than 200 lbs	• All items not fitting, or similar to, other categories

4.2 IMPORTANCE

Importance in a lab environment is not always proportional to size and weight. The importance of an item with respect to its value as data, results of experiments, or in saving, protecting, or maintaining data, other results of experiments, or ongoing experiments can be judged only in each lab. Importance can be assigned in any number of priorities, but complexity of the rating system is directly proportional to the number of categories. One lab decided that this rating could be simplified into only two characterizations: “important” or “not important.” Assuming that important items will be seismically protected, these items can be set aside from evaluation for *Life Safety* or *Dollar Value*. See Table 3 for suggestions of parameters to determining relative importance.

4.3 DOLLAR VALUE

Similar to *Importance*, the threshold for concern about dollar losses from damaged equipment or other items in the laboratory can be set only by the individual lab or institution. The time that replacement would take should also be considered, although this issue may also be considered under *Importance*. Since many fairly common computers, microscopes, and similar equipment are valued at $5000 or less, this figure could be used to describe the lowest priority category (assuming *Importance* is judged independently). An upper value, for example, of $100,000 or $250,000, to which the highest priority is assigned, should also be set. Setting such high and low figures creates three categories prioritizing seismic protection.

Table 3. 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)

5 Recommended Anchorage Details

This section describes detailed anchorage and restraint that will apply to most contents of CSB 2 labs. Lab users can install some of the restraint details, but some details will require installation by experienced trades-persons that are part of the building staff, the university staff, or are employed by private contractors. Very specialized lab equipment or experimental setups may be heavier, larger, or of configurations that do not fit into the categories covered. Seismic restraint for these items must be custom-designed by a civil or structural engineer experienced in earthquake engineering.

Contrary to anchorage of most mechanical and electric building systems equipment, it is not generally recommended to restrain owner-furnished contents by bolting to the floor. Exceptions include tanks with mounting legs, certain cylinder restraint products that are designed with plates and bolt holes for floor mounting, and the base connection of strongbacks. Most floor-supported equipment is mounted on wheels, leveling legs, or a framework not designed to anchor the weight of the equipment for earthquake loads. Unless the manufacturer certifies the base of such equipment for such anchorage, it is recommended to provide restraint from existing partitions or to install steel strongbacks. In addition, it is desirable to minimize drilling holes into the floor structure which compromises the moisture proofness of the floor, may form a trip hazard, and will be hard to satisfactorily repair when no longer needed.

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. 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. The details shown for this equipment in CSB 2 uses a commercially available strap attached to the equipment by stud bolts on a plate adhered to the surface 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 designs are not available, or require load testing. An alternative to this detail is shown in Figure 14. The restraint provided by overhead "hangers" will prevent overturning or excessive sliding and will probably reduce shock transmission. The cost of the sizable strongbacks and overhead beam must be weighed against the cost of installation of the smaller strongbacks required for the commercial device. In addition, this system requires engineered design for the specific location in which it will be implemented.

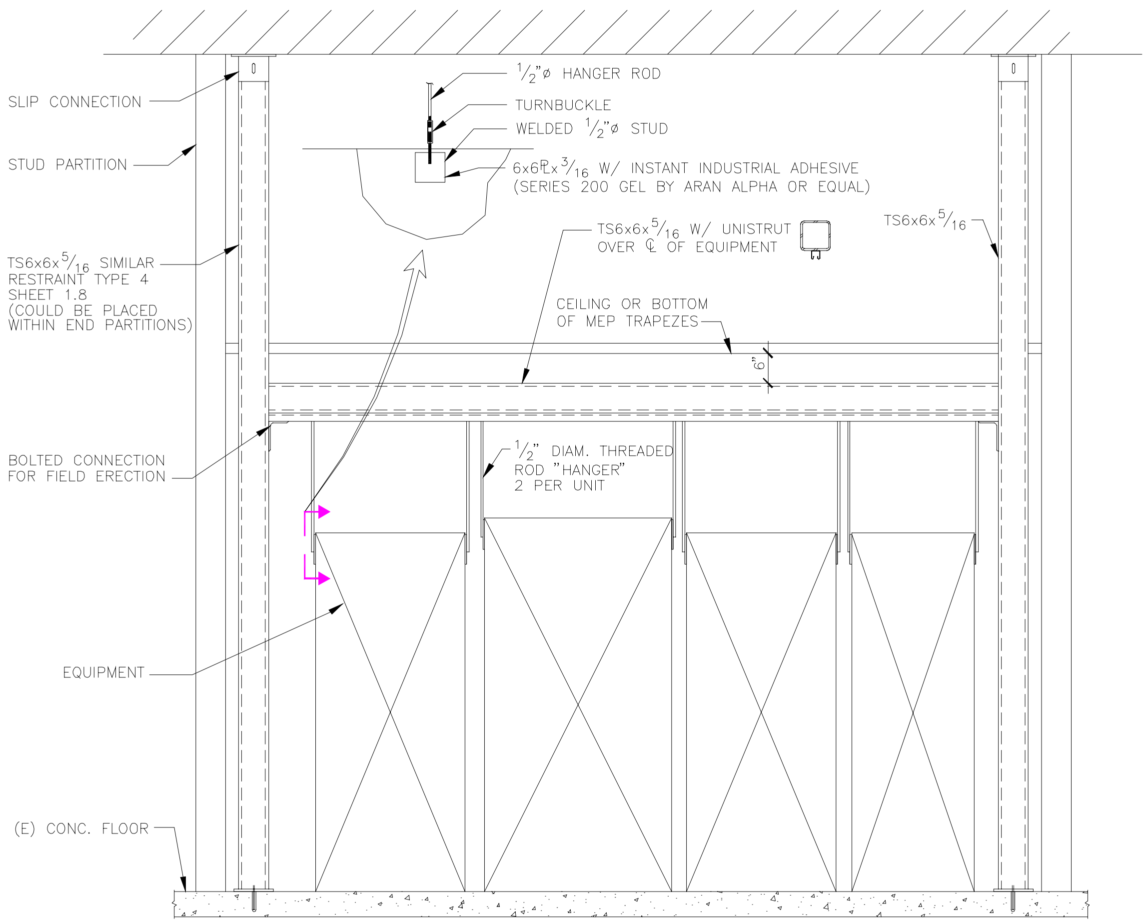


Figure 14. Alternative Equipment Restraint System at Equipment Halls
(Requires Engineering Design)

Limitations of use are given for the recommended details. For equipment that falls outside the load or configuration limitations shown, engineered design is necessary for seismic restraint.

General Notes

1. Building Configuration: The structure and configuration of the existing building is based on construction drawings, dated February 14, 2003.

2. Intent of Basic Restraint: The details shown are intended to prevent excessive movement of the various elements during strong earthquake motion. This restraint is expected to protect occupants from serious injury and significantly reduce the incidence of functional damage to the component.

   A. Protection of Functionality: In addition to the Basic Restraint, continued functionality of restrained components following an earthquake is primarily dependent on the susceptibility of the component to damage from shocks transmitted through the restraint or, for smaller benchtop equipment, from potential overturning. Functionality may also depend on continued utility services such as water, electricity, or gases that are not addressed by these details.

   B. Protection of Contents: In addition to the Basic Restraint, the contents of shelving, racks, refrigerator/freezers, incubators, etc., must be protected from falling from storage location.

      1) Shelving: Typical shelving is provided with perimeter lips approximately $1\frac{1}{2}$" high. For sensitive contents, or for contents with heights of 3" or more, lips of one half the height of the contents should be installed. For further protection, protective racks or trays separating individual contents should be installed on shelves.

      2) Refrigerator/Freezer: These components should be provided with a positive door latch. For further protection, protective trays separating individual contents should be used on interior storage racks.

3. Materials, Fabrication, and Installation:

   A. Prefabricated restraint devices: Devices noted "Worksafe" are references to Worksafe Industries products. Alternative manufacturers of similar products shall certify equality of load capacity.

   B. Slotted channels: Devices noted "Unistrut" are references to Unistrut Corporation products. Alternative manufacturers of identical products are available.

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **NOTES**	SCALE: NO SCALE SHEET: **D1**

C. Fabricated Steel components (structural steel tubes and connectors): Fabrications shall comply with the Code of Standard Practice for Steel Buildings and Bridges.

1) Materials:

   i Steel Plates, Shapes, and Bars: ASTM A 36

   ii Steel Tubing: ASTM A 500

   iii Steel Pipe: ASTM A53

2) Fabrication:

   i All welders shall have passed AWS (AWS D 1.1, Structural Welding Code) qualification tests for the welding processes involved and, if pertinent, have undergone recertification.

   ii Shear and punch metals cleanly and accurately. Remove burrs.

   iii Ease exposed edges to a radius of approximately 1/32 inch.

   iv Shop Primer: Fast-curing, lead- and chromate-free, universal modified-alkyd primer complying with performance requirements in FS TT-P 664; selected for good resistance to normal atmospheric corrosion and ability to provide a sound foundation for field-applied topcoats.

D. Fasteners:

1) Bolts and Nuts: Regular hexagon-head bolts, ASTM A 307, Grade A, with hex nuts, ASTM A 563.

2) Self-drilling screws for metal-to-metal or wood-to-metal: ITW Buildex TEK Screws or equal.

3) Lag Bolts: ASME B18.2.1

4) Wood Screws: Flat head, carbon steel, ASME B 18.22.1

5) Expansion Anchors to Concrete: Anchors with current ICBO/ICC-ES approval for use under conditions called for (diameter, embedment, through metal deck, etc.). Install in strict conformance with approval requirements and manufacturer's recommendations. Twenty-five percent of anchors shall be torque tested in accordance with approval requirements.

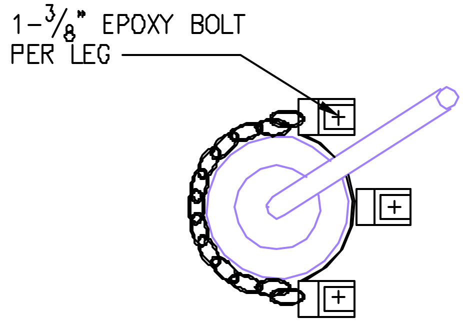
6) Epoxy Anchors: Anchors with current ICBO/ICC-ES approval for use under conditions called for. Select to minimize chemical off-gassing. Confirm with occupants that use is acceptable prior to installation. Do not use in overhead configuration. Install in strict conformance with approval requirements and manufacturer's recommendations.

7) Adhesive double-backed tape: 3M® UHB™ (does not gain full strength for 72 hours)

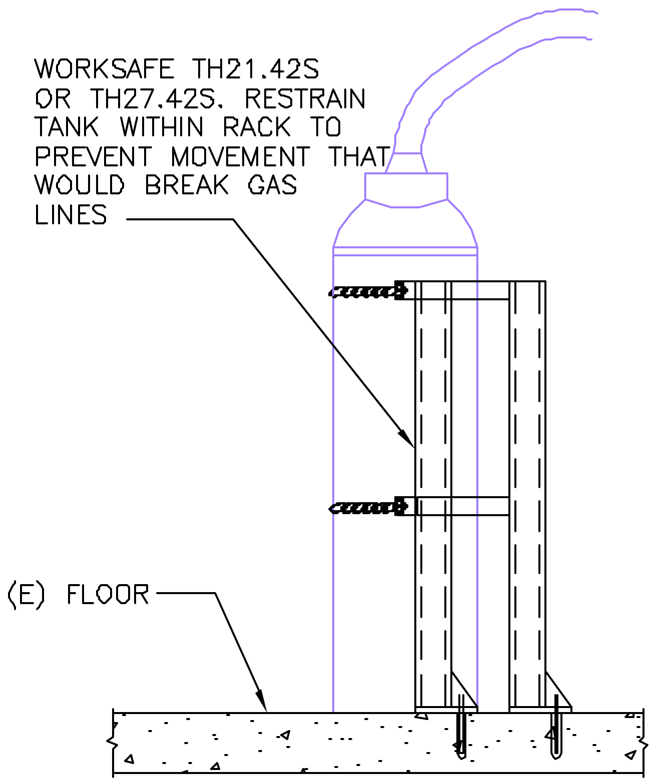
i For use on plates less than or equal to 4 square inches: Clean surfaces with isopropyl alcohol/water or heptane. Remove protective sheet immediately before applying. Apply with as much pressure as possible and hold to allow full contact and adhesion.

ii For use on plates greater than 4 squre inches: Plate shall have one pad factory applied. An identical pad shall be field applied to the target surface. After cleaning the surface, the field pad shall be applied incrementally while applying pressure with a metal or wood squeegee slightly wider than the pad. The entire surface will then be rolled with a 1" wide wood roller with firm pressure. The strap plate shall then be applied with as much pressure on the two pads as possible applied with a roller over the strap plate.

E. Exterior backing bars: Slotted channel members as called for in details, directly connected to the flanges of three metal studs minimum. The end of the slotted channel shall be extended 1" minimum and 6" maximum beyond the centerline of the outside stud. Exterior backing bars may be installed over 4 or more studs to provide a wall attachment location for various equipment. Stud locations shall be determined with a metal detector or probing. Connection of backing bars for use with seismic details shown here to gypsum board, plaster, or other wall surface material is not permitted without design by Engineer.



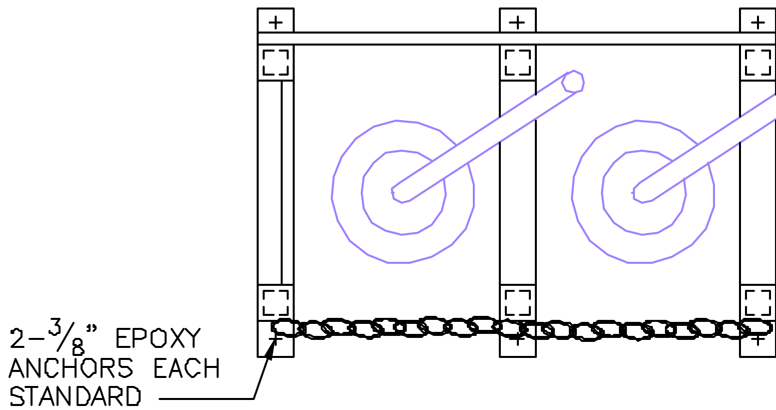
TOP VIEW



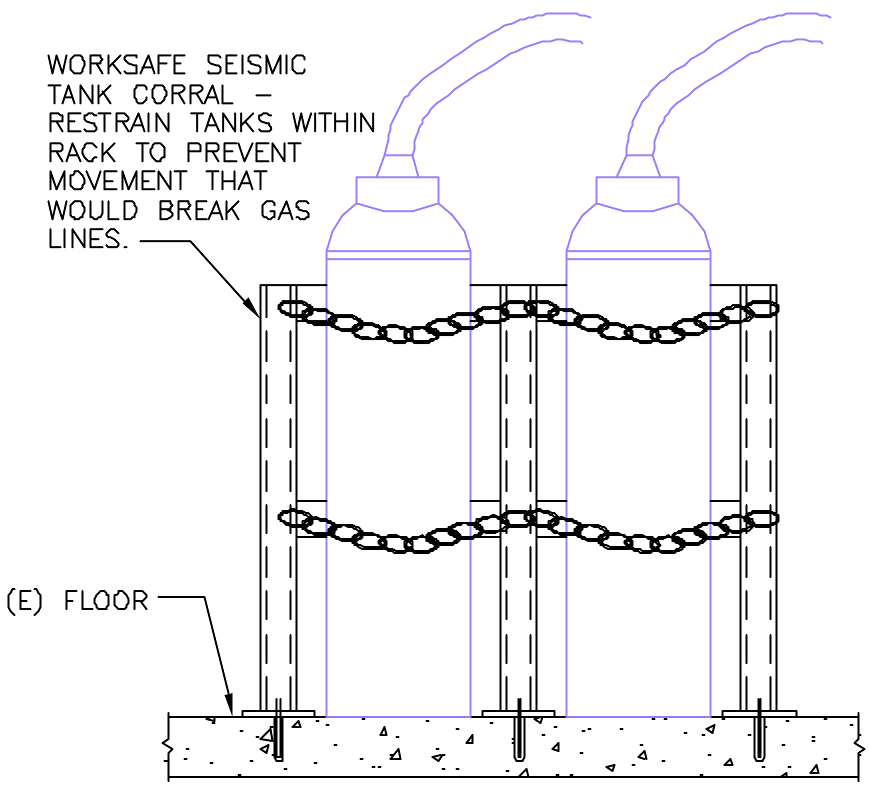
DETAIL T1

GAS CYLINDER RESTRAINT
(FREESTANDING – SINGLE CYLINDER)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D4**



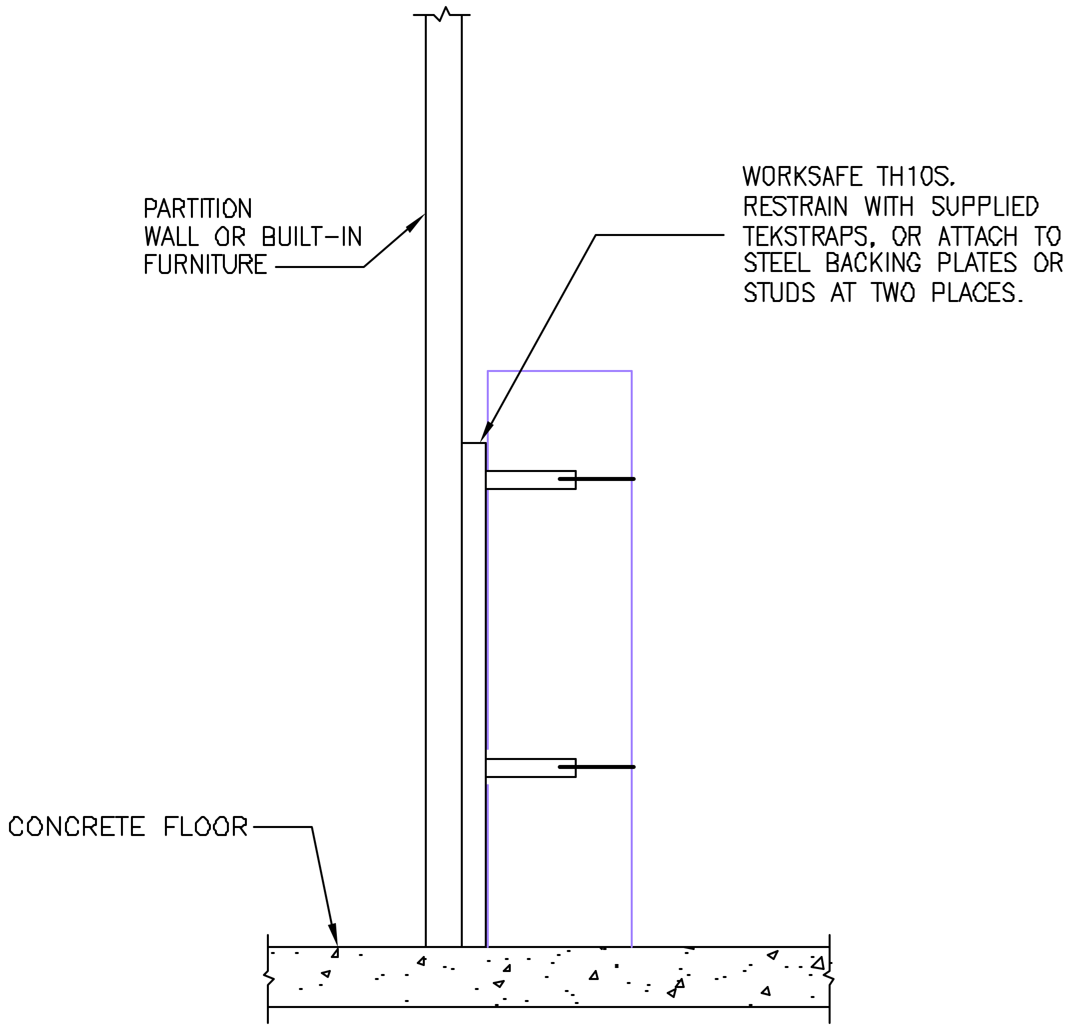
TOP VIEW



DETAIL T2

GAS CYLINDER CORRAL
(FREESTANDING – MULTIPLE CYLINDERS)

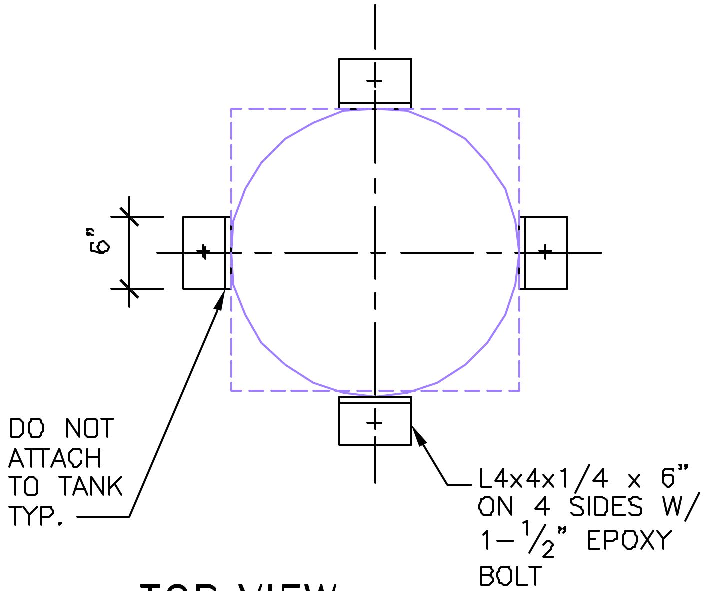
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE **D5**



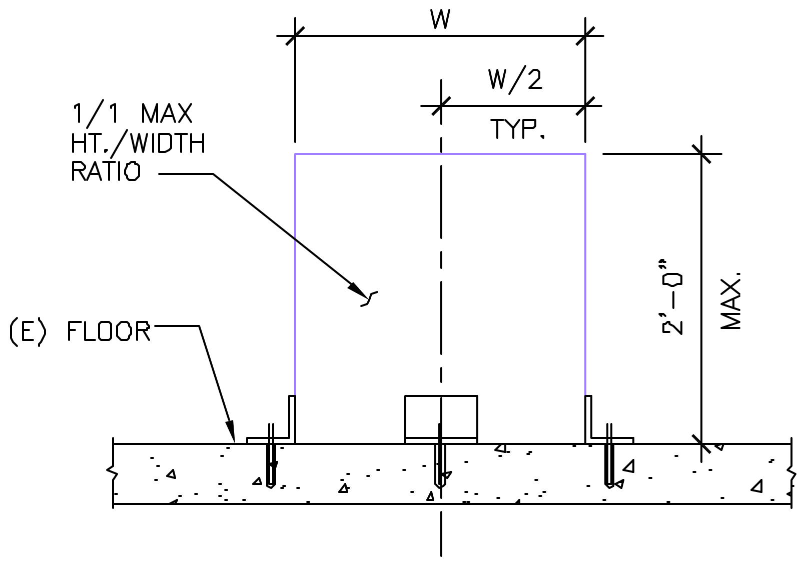
INDIVIDUAL TANKS
10–12" DIAMETER

DETAIL T3

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE **D6**



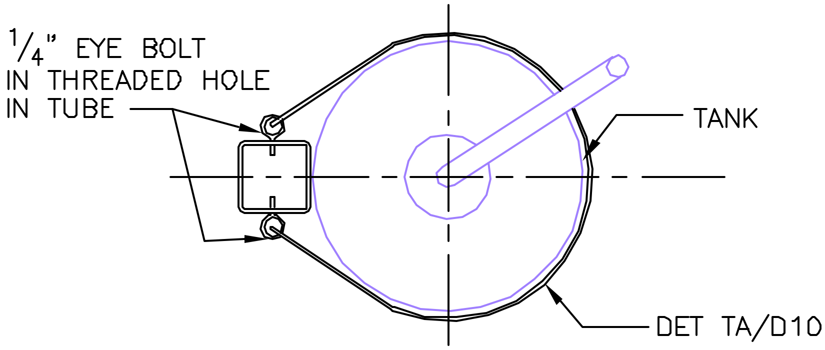
TOP VIEW



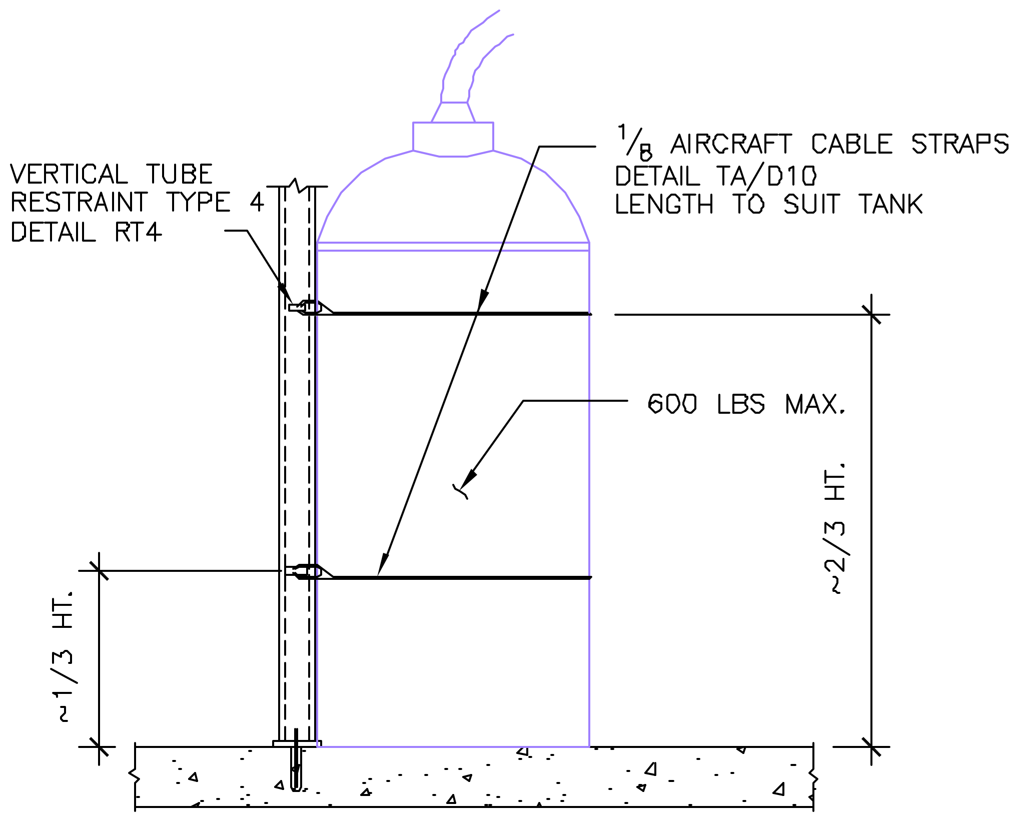
DETAIL T4

LOW PROFILE TANK RESTRAINT
(FREESTANDING)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D7**



TOP VIEW

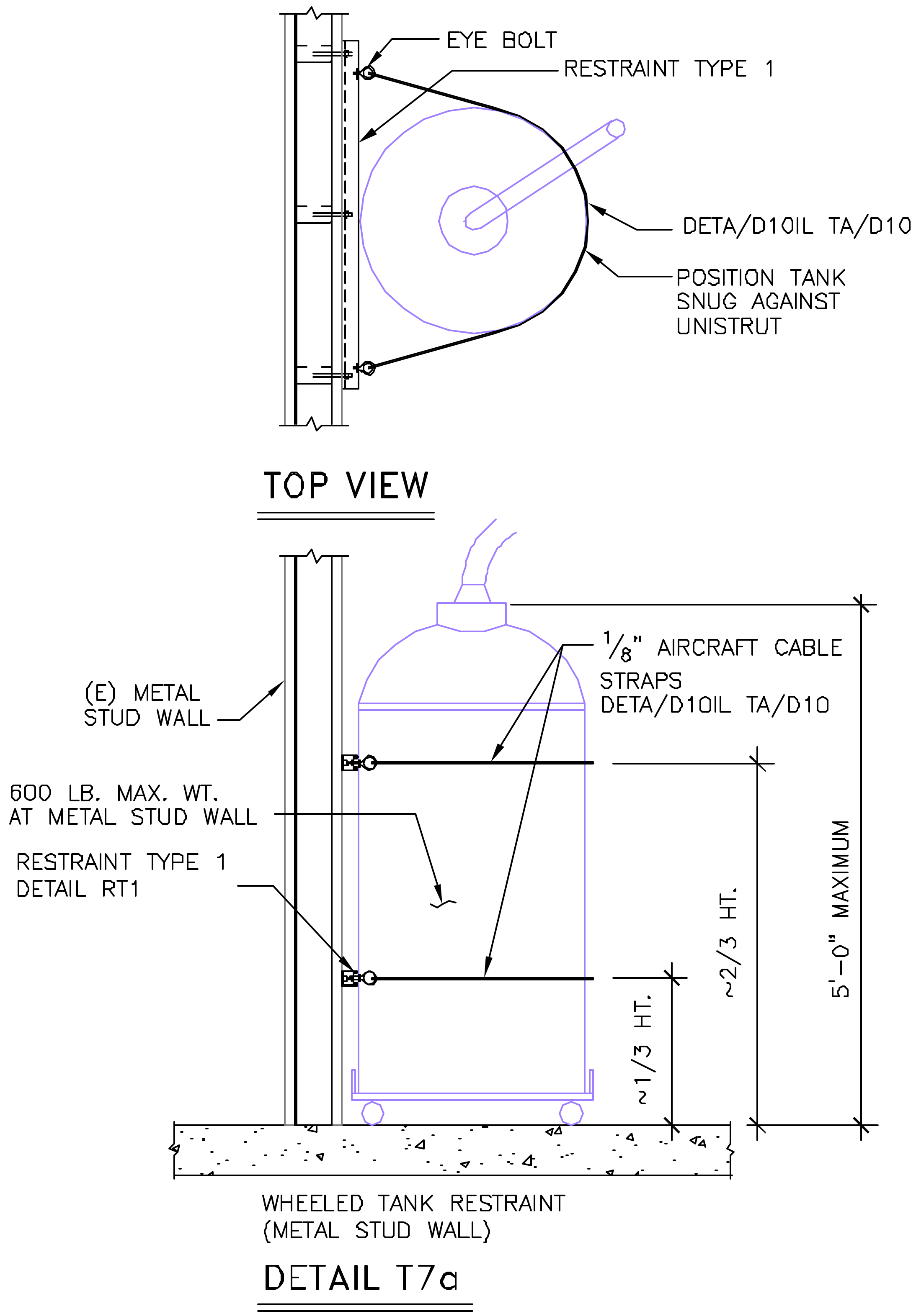


NOTE: IF TANK HAS BUILT-IN BASE OR LEGS, IT CAN BE BOLTED TO FLOOR W/ 3 MIN. 1/2" EPOXY BOLTS.

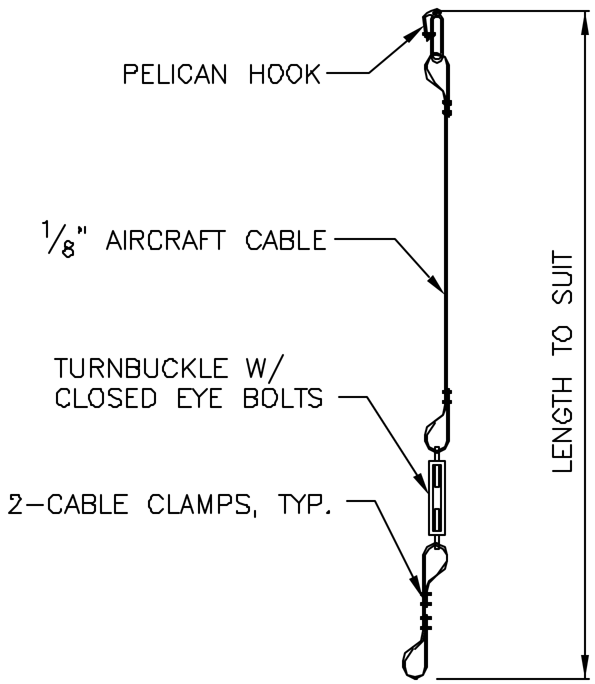
DETAIL T5

LARGE TANK RESTRAINT
(FREESTANDING)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D8**



IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL TANK RESTRAINTS**	SCALE: NO SCALE SHEET: **D9**

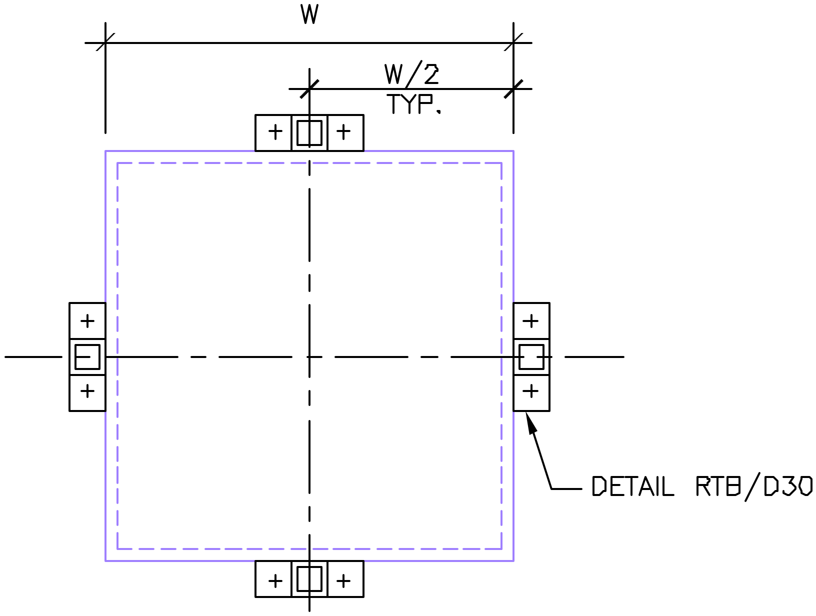


NOTE: IF LENGTH IS MADE SUCH THAT CABLE IS TIGHT WHEN PELICAN HOOK IS ENGAGED, TURNBUCKLE CAN BE ELIMINATED

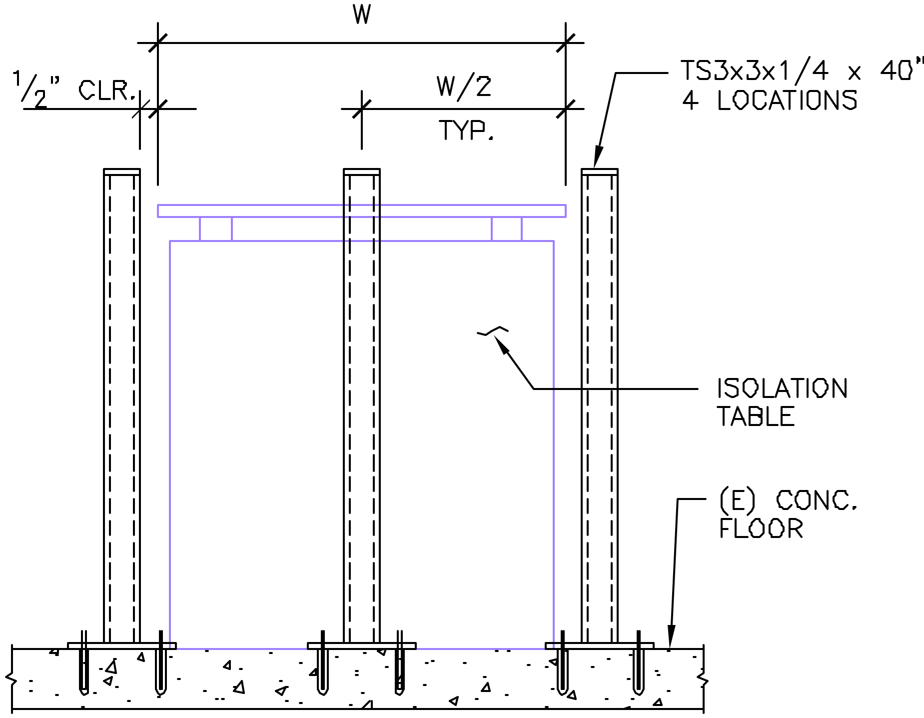
AIRCRAFT CABLE STRAP

DETAIL TA

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: TYPICAL TANK RESTRAINTS	SCALE: NO SCALE SHEET: D10



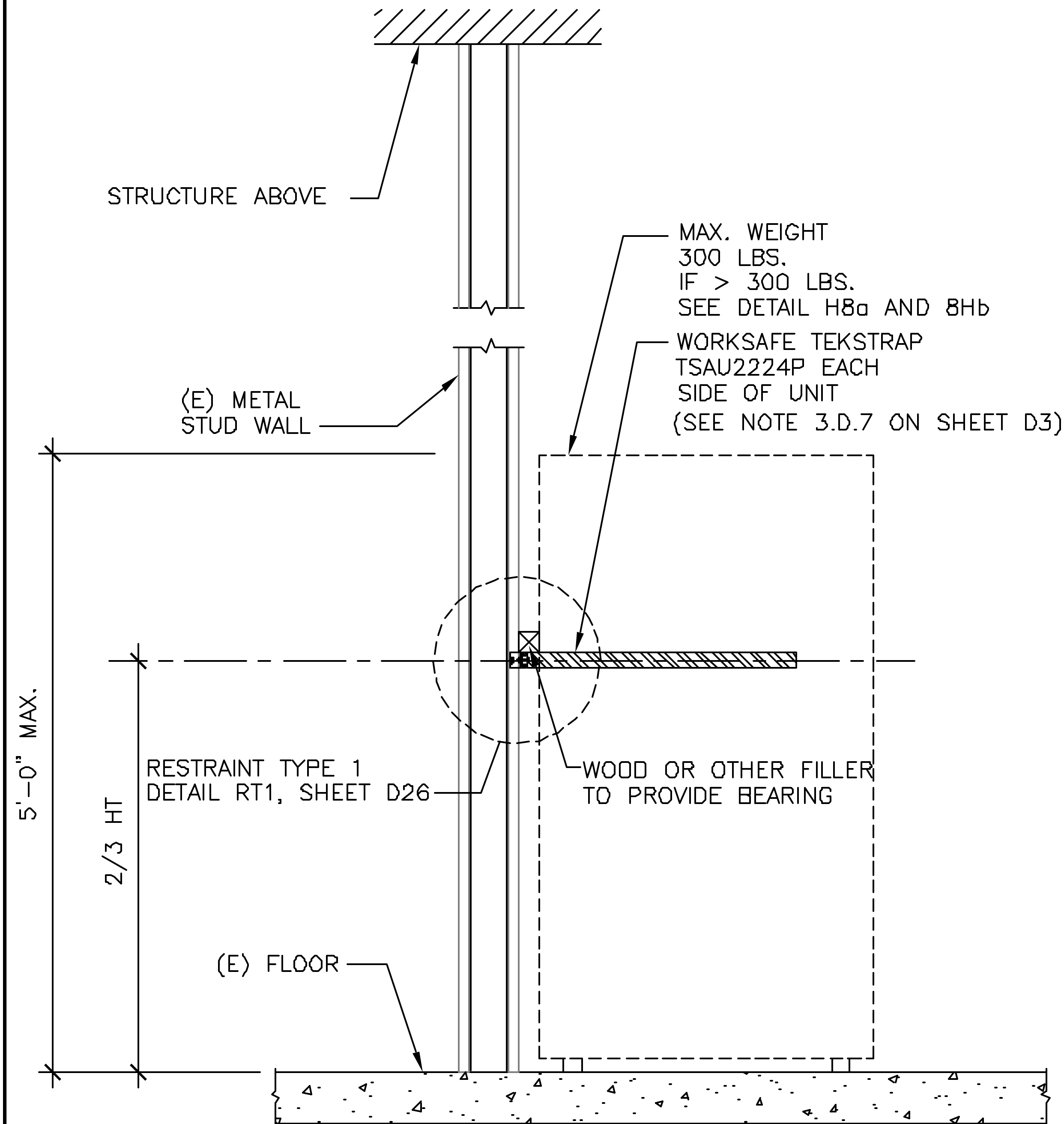
TOP VIEW



DETAIL U1

VIBRATION ISOLATED TABLE RESTRAINT

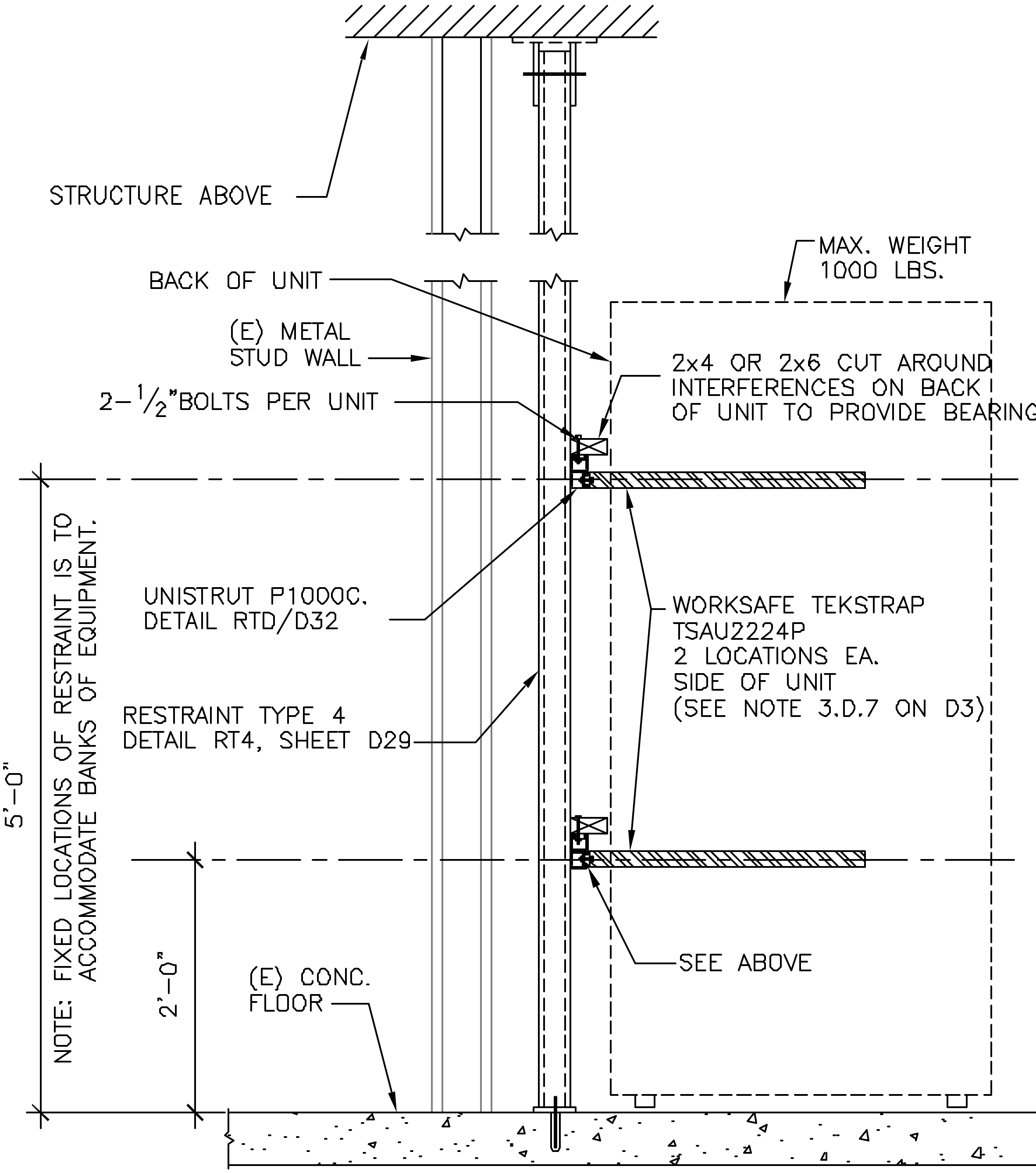
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: MISCELLANEOUS EQUIPMENT	SCALE: NO SCALE SHEET: D11



DETAIL H7

RESIDENTIAL STYLE REFRIGERATOR

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL LARGE EQUIPMENT RESTRAINTS**	SCALE: NO SCALE SHEET: **D12**

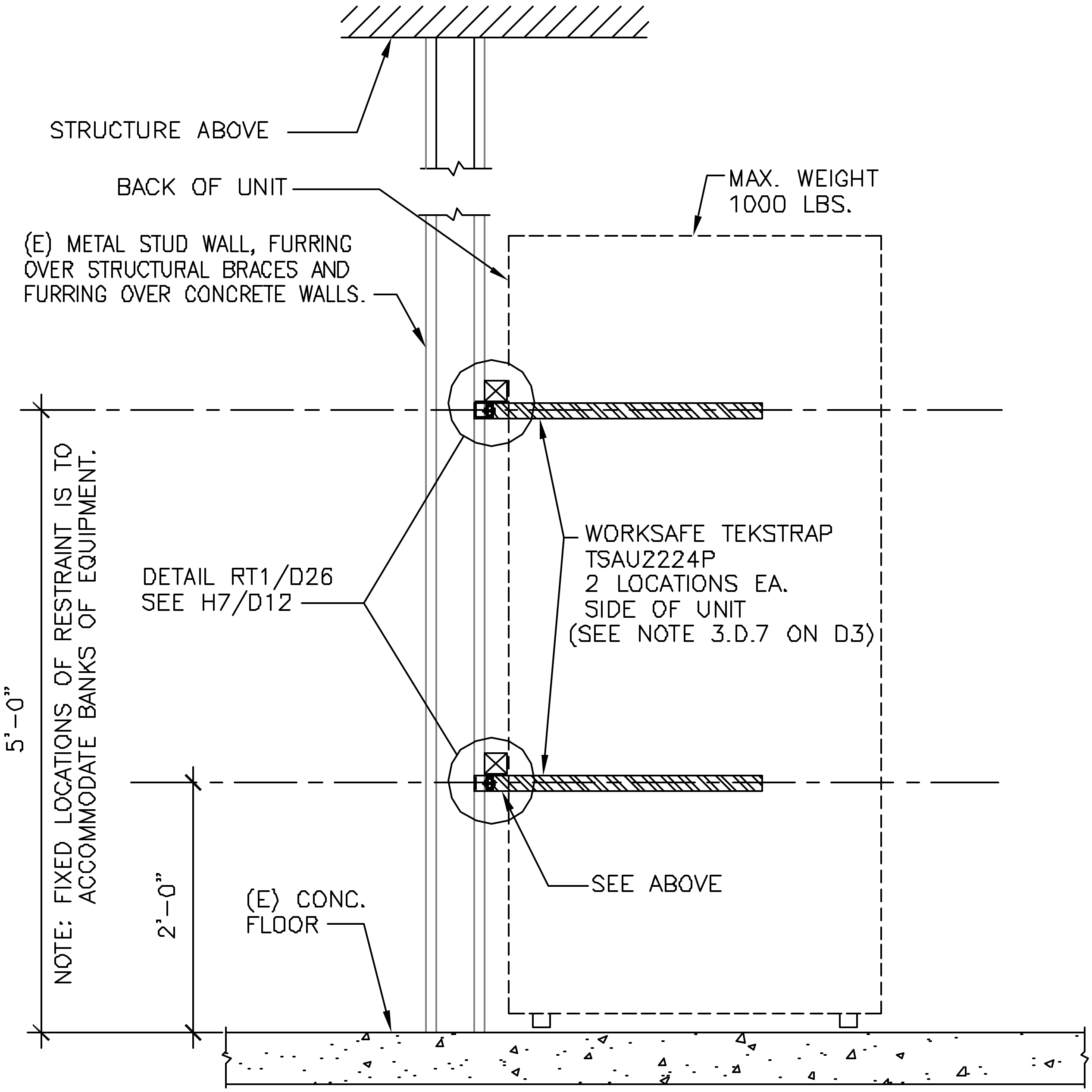


SEE DETAIL H8b FOR OTHER LOCATIONS

DETAIL H8

LARGE REFRIGERATOR/FREEZER/INCUBATORS AT 5TH FLOOR AND HIGHER PLACES

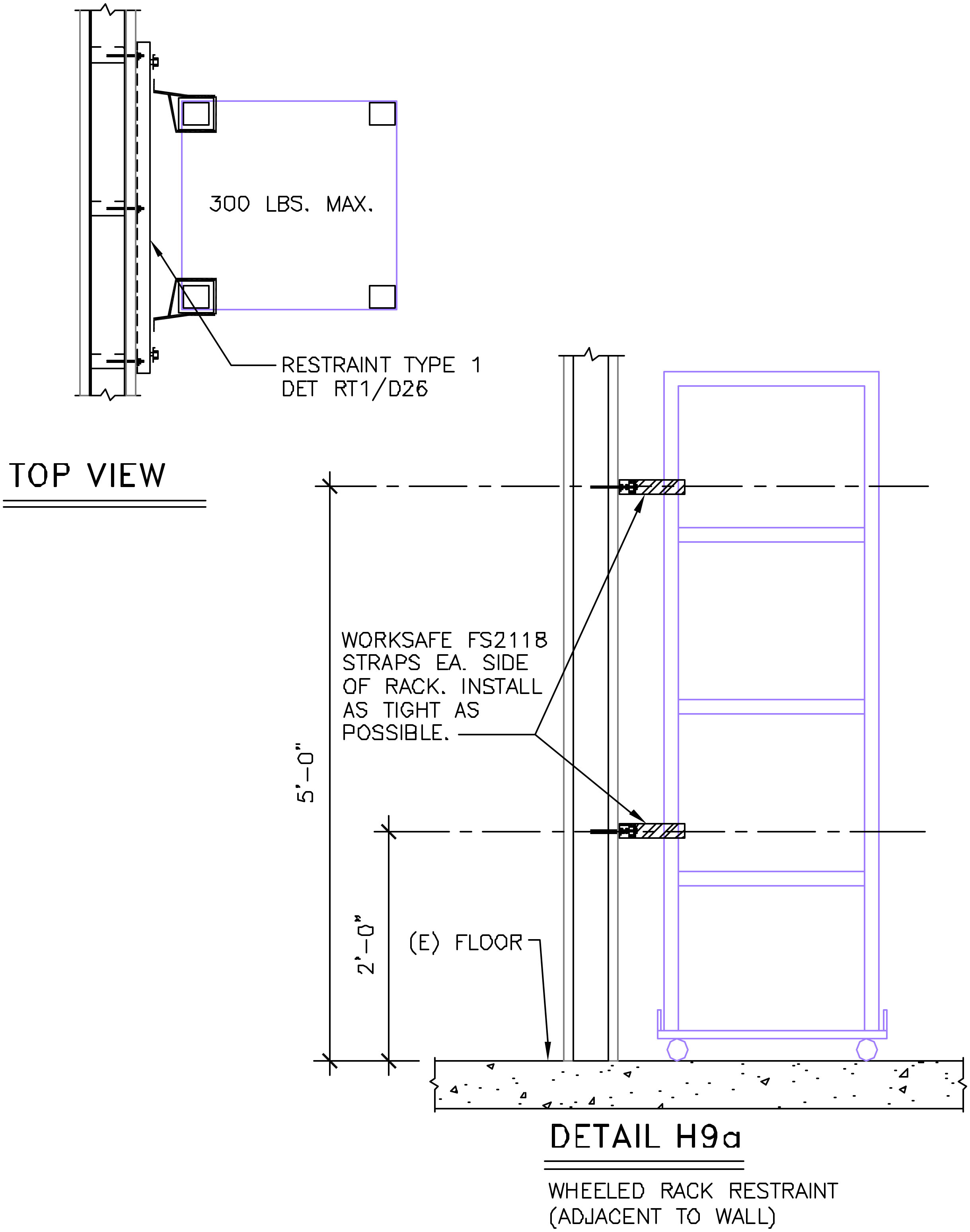
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL LARGE EQUIPMENT RESTRAINTS**	SCALE: NO SCALE SHEET: **D13**



DETAIL H8b

LARGE REFRIGERATOR/FREEZER/INCUBATORS AT 5TH FLOOR AND LOWER FLOORS. SEE DETAIL H8a FOR OTHER LOCATIONS.

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL LARGE EQUIPMENT RESTRAINTS**	SCALE: NO SCALE SHEET: **D14**

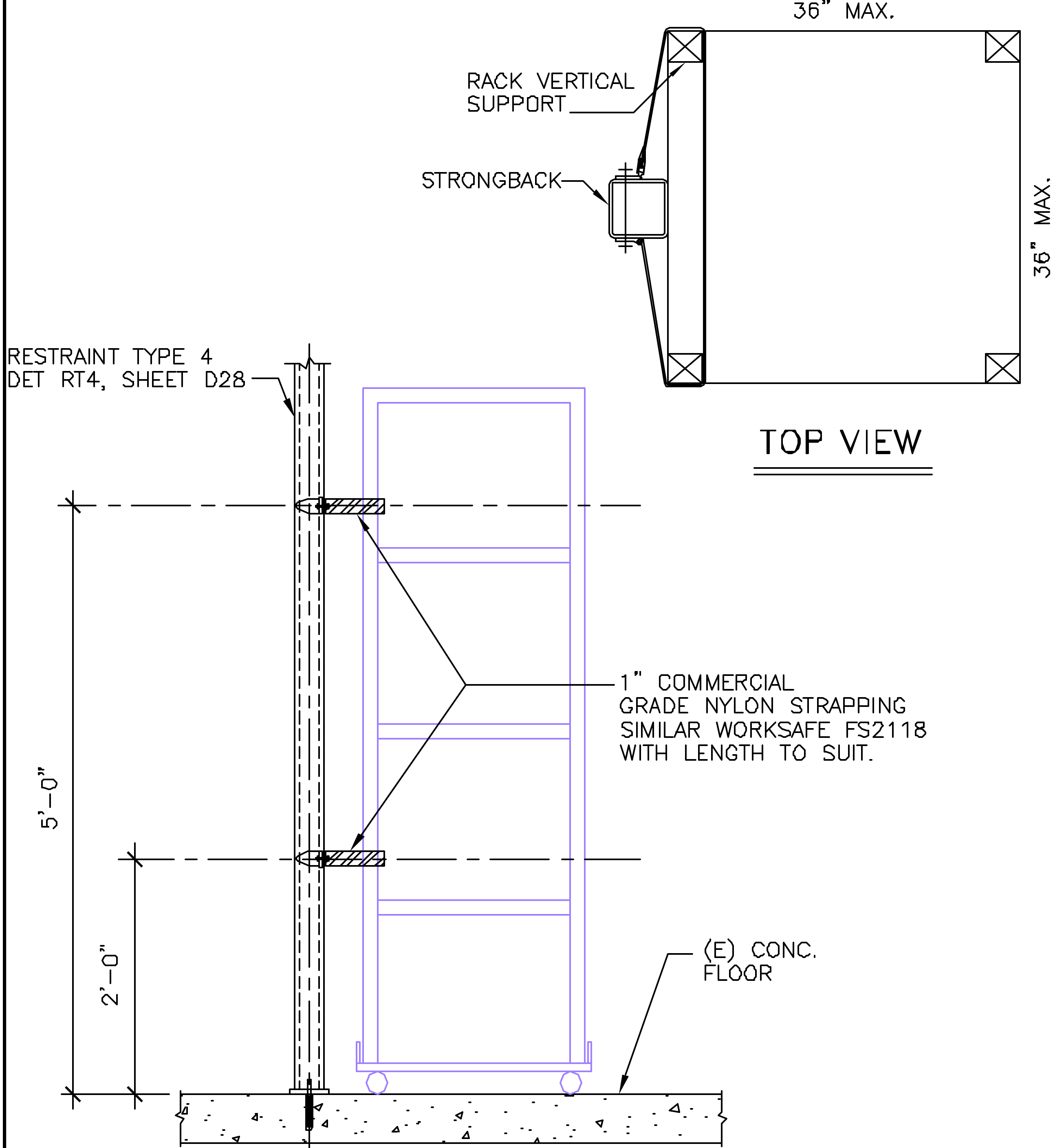


IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2

TITLE: **WHEELED RACKS**

SCALE: NO SCALE

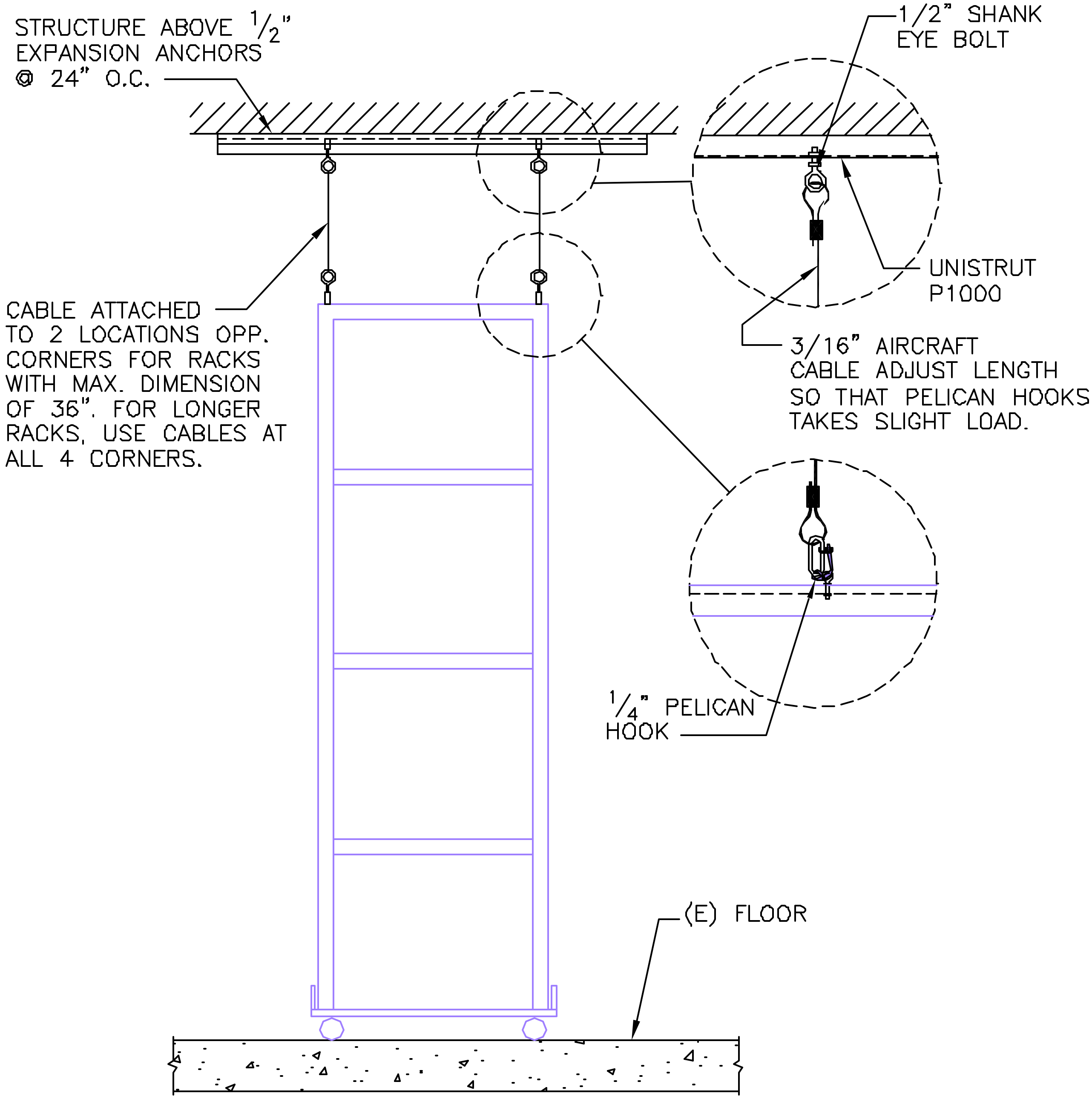
SHEET: **D15**



DETAIL H9b (SEE ALSO H9c)

WHEELED RACK RESTRAINT (FREESTANDING)

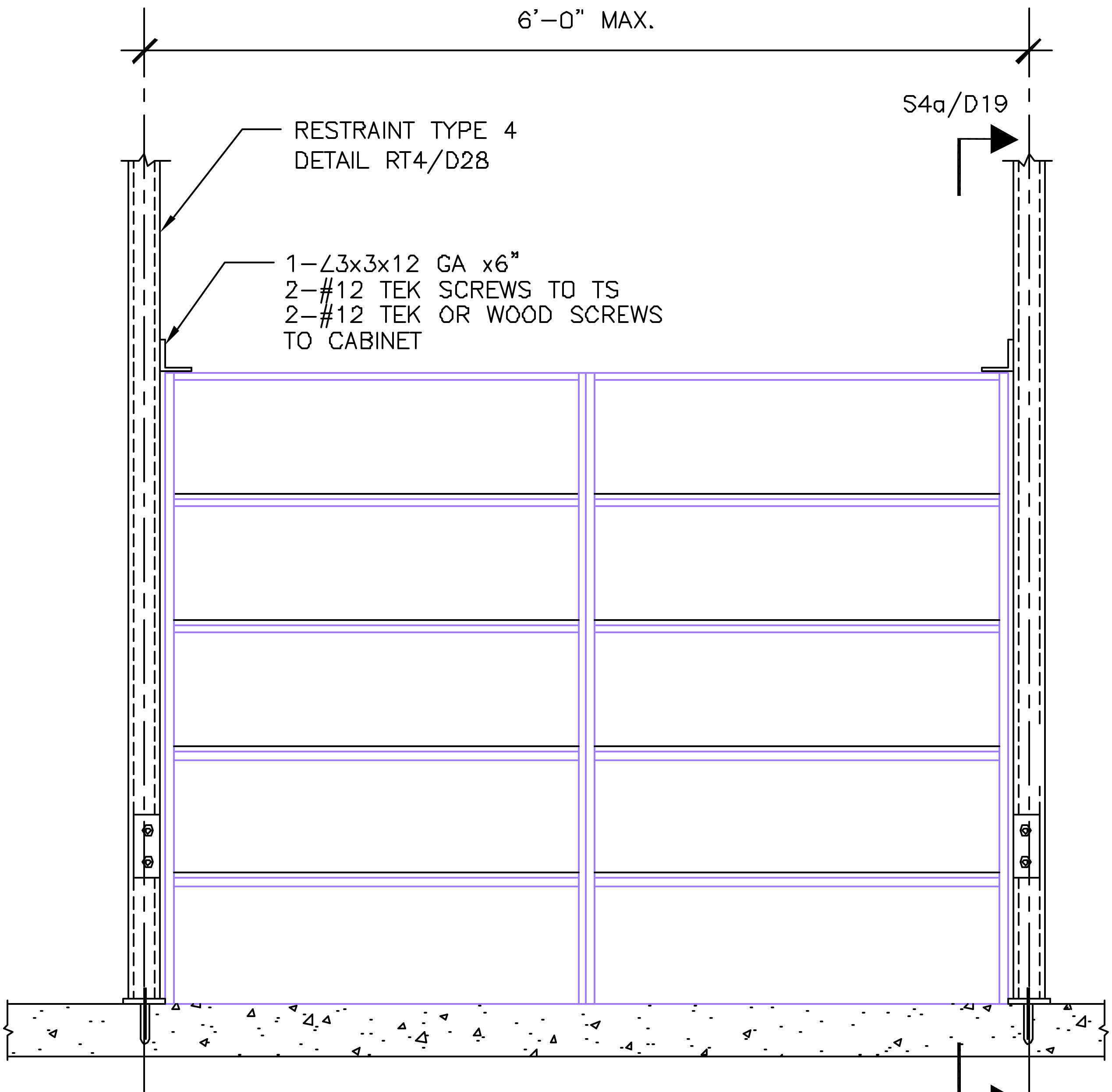
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: WHEELED RACKS	SCALE: NO SCALE SHEET: D16



DETAIL H9c (ALTERNATIVE TO H9b)

WHEELED RACK RESTRAINT (FREESTANDING)

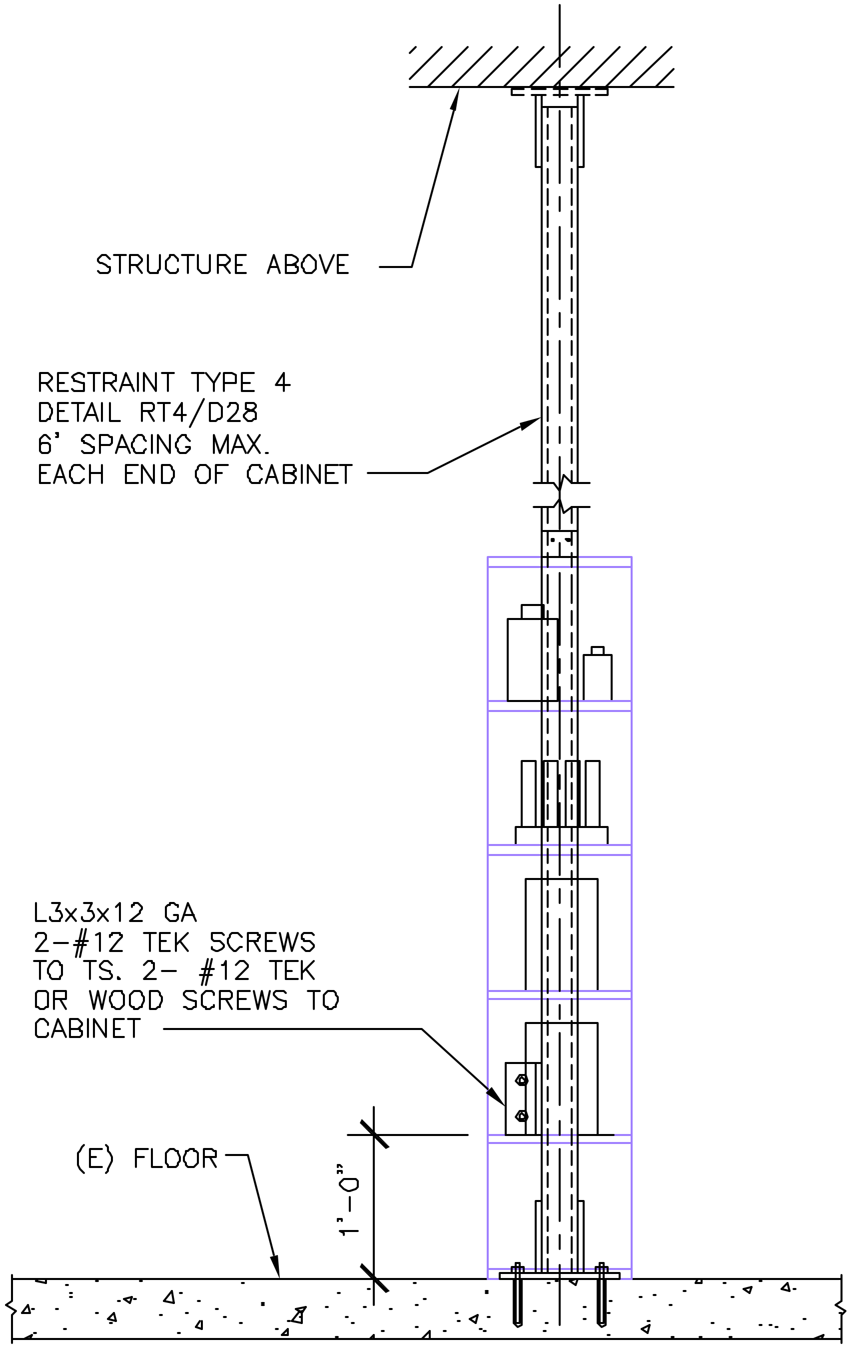
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: WHEELED RACKS	SCALE: NO SCALE SHEET: D17



ELEVATION

DETAIL S4

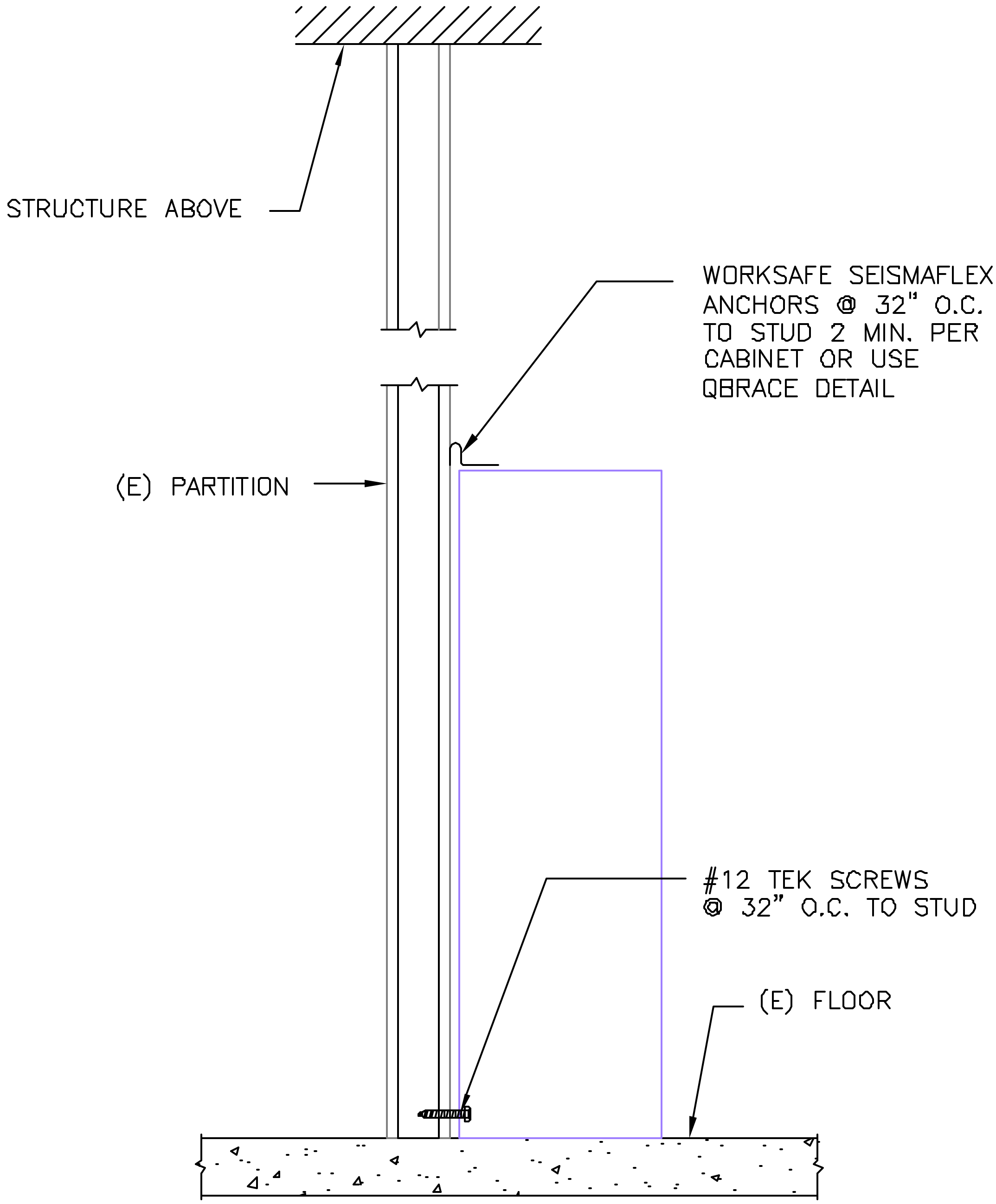
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: BOOKCASES	SCALE: NO SCALE SHEET: D18



SECTION S4a

FREESTANDING BOOKCASES
FLOOR TO CEILING RESTRAINTS

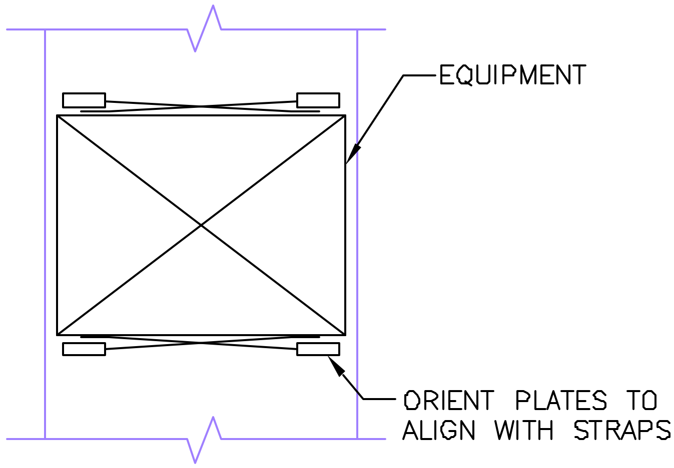
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **BOOKCASES**	SCALE: NO SCALE SHEET: **D19**



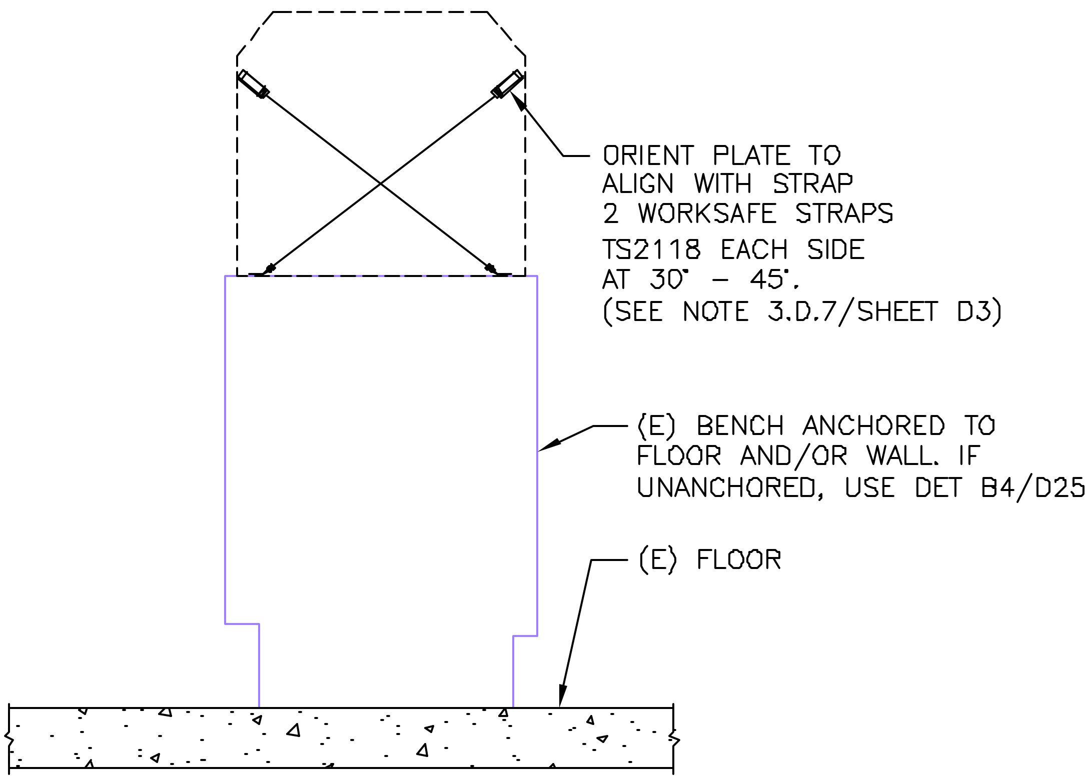
DETAIL S6

BOOKSHELVES/METAL CABINETS
ADJACENT TO WALLS

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **BOOKSHELVES CABINETS**	SCALE: NO SCALE SHEET: **D20**



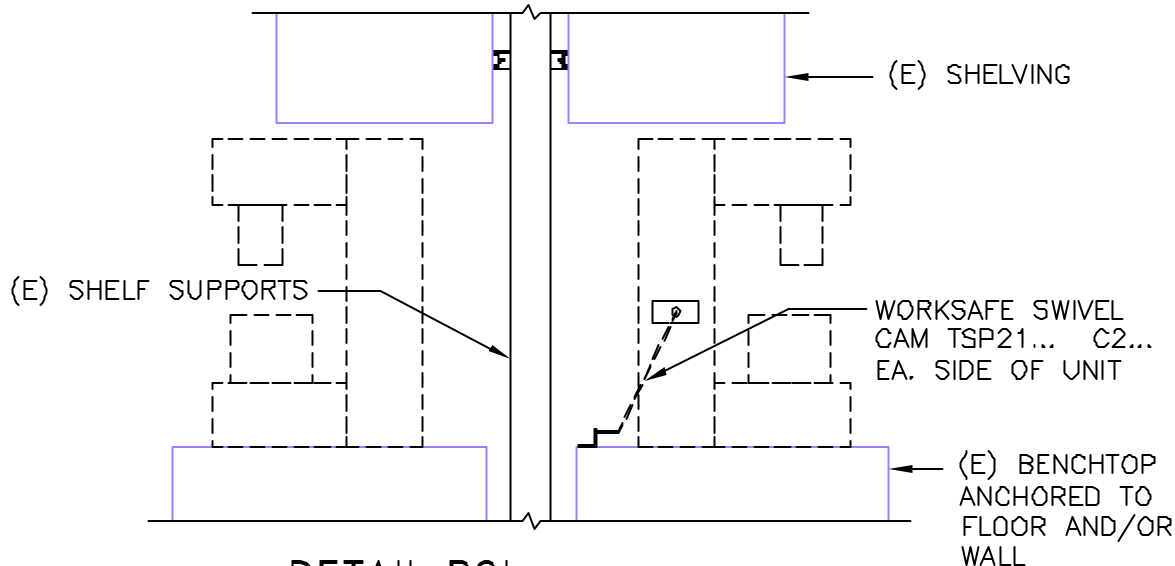
TOP VIEW



DETAIL B1

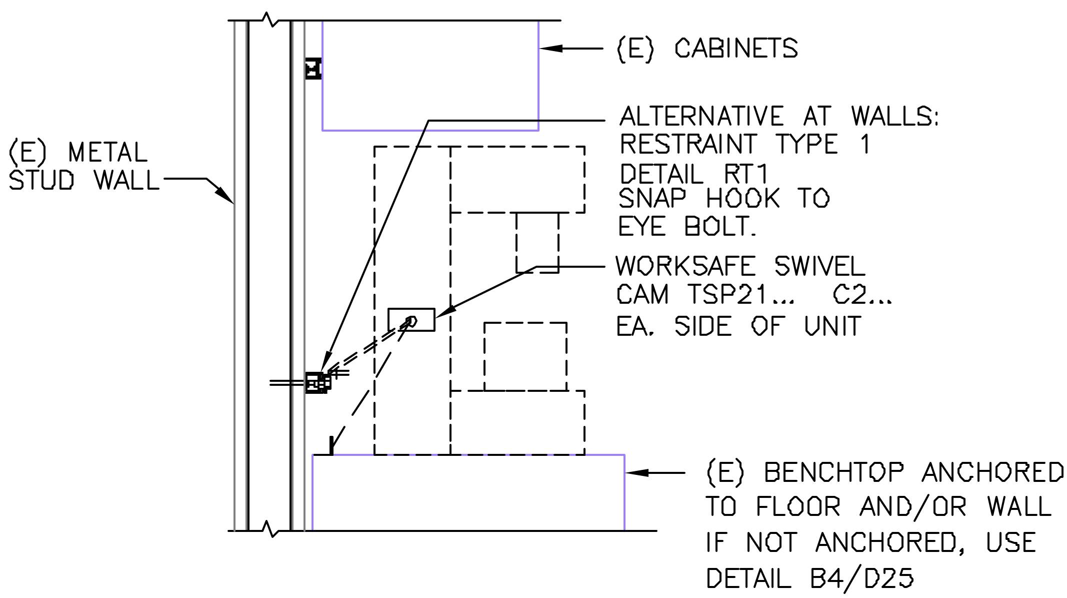
BENCHTOP HEAVY EQUIPMENT
(150 – 250 LBS.)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D21**



DETAIL B2b

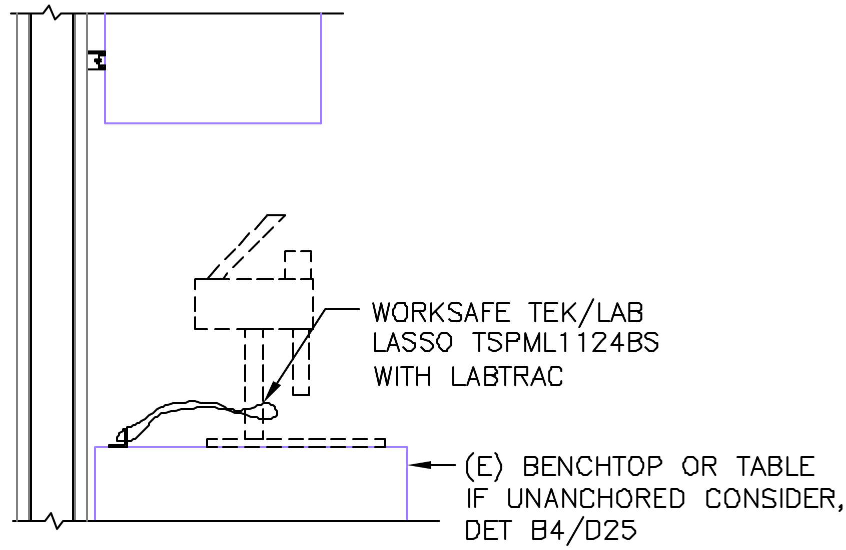
BENCHTOP HEAVY EQUIPMENT AT ISLAND (50 LBS - 150 LBS.)



DETAIL B2a

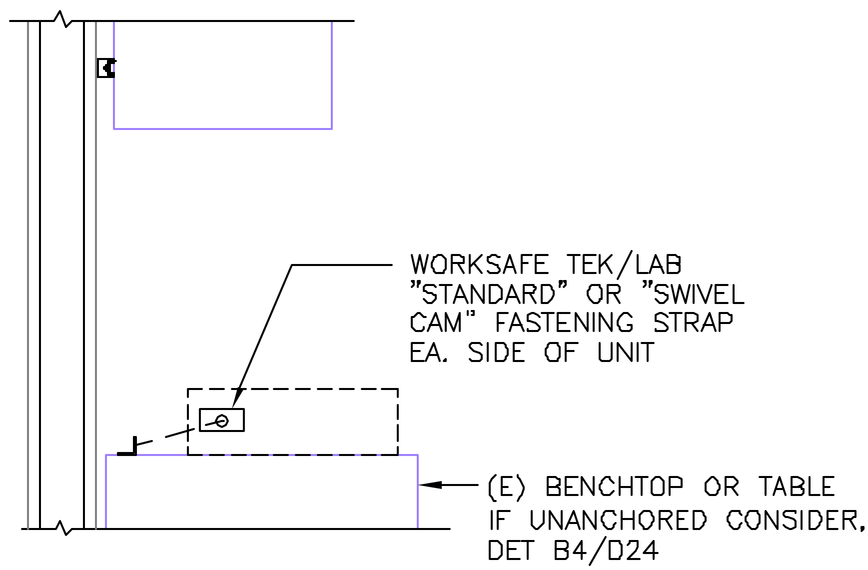
BENCHTOP HEAVY EQUIPMENT AT ALL WALLS (50 LBS - 150 LBS.)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D22**



DETAIL B3a

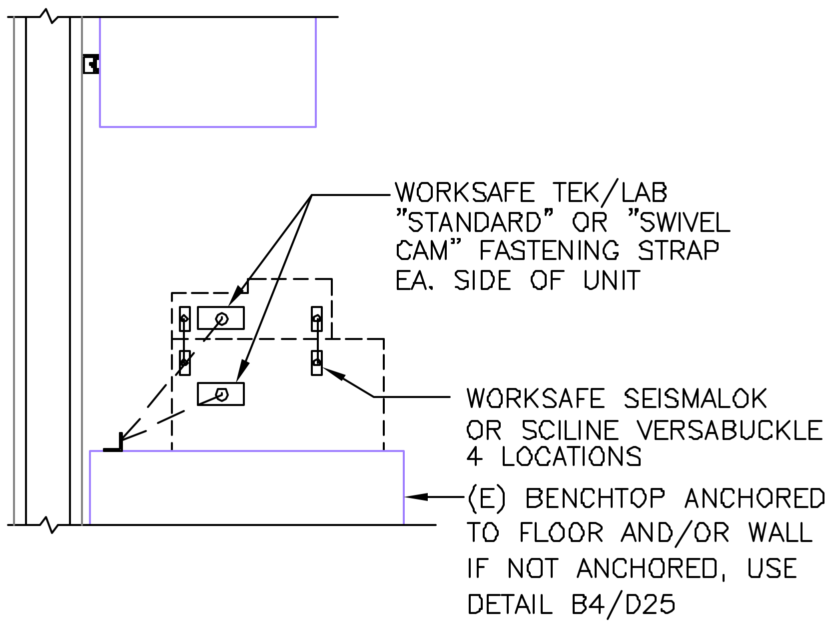
MICROSCOPES AT ALL WALLS (MONITORS SIMILAR)
(< 50 LBS)



DETAIL B3b

BENCHTOP EQUIPMENT
AT ALL WALLS (< 50 LBS)

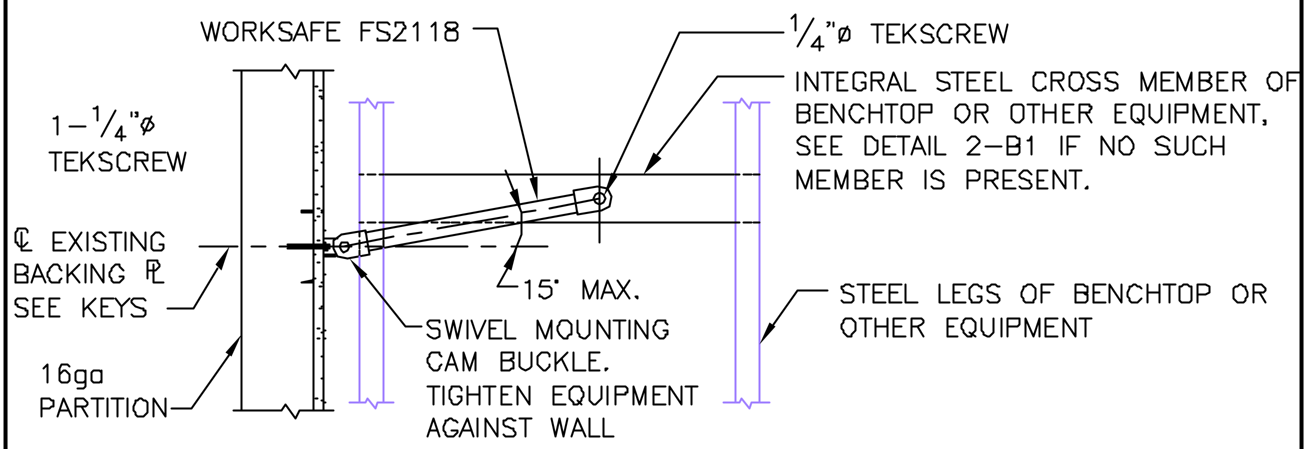
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **BENCHTOP EQUIPMENT**	SCALE: NO SCALE SHEET: **D23**



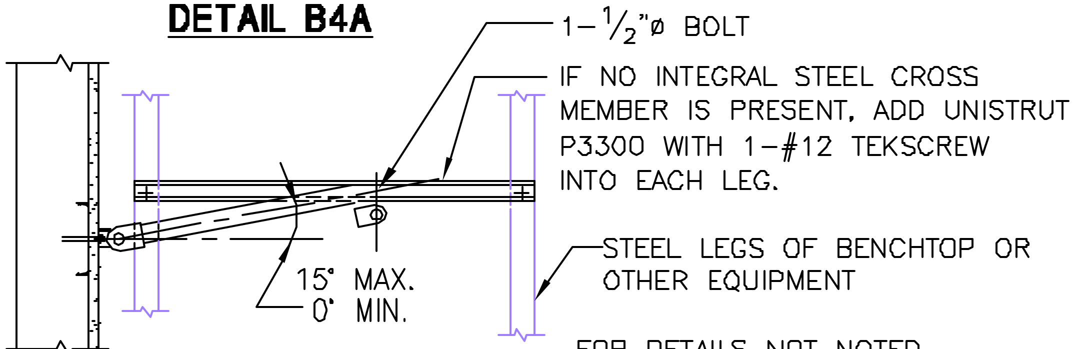
DETAIL 3c

STACKED COMPONENTS
(< 50 LBS)

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: BENCHTOP EQUIPMENT	SCALE: NO SCALE SHEET: D24

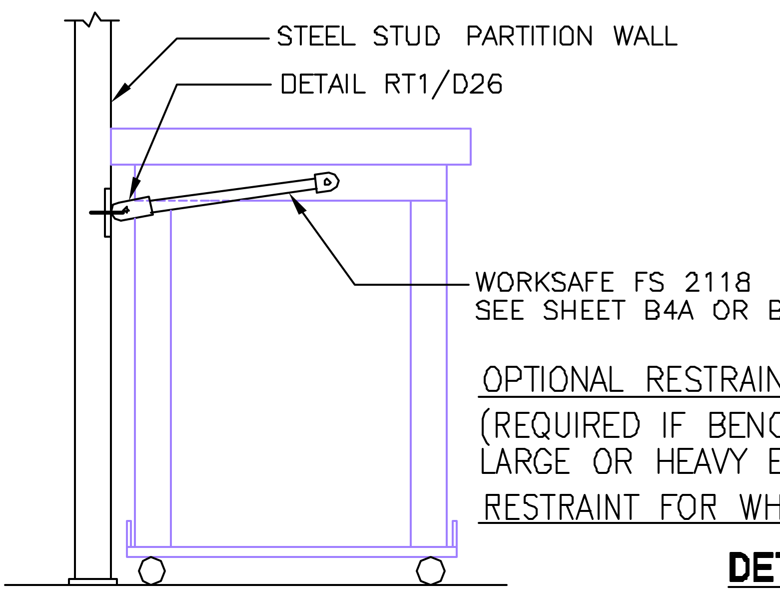


DETAIL B4A



DETAIL B4B

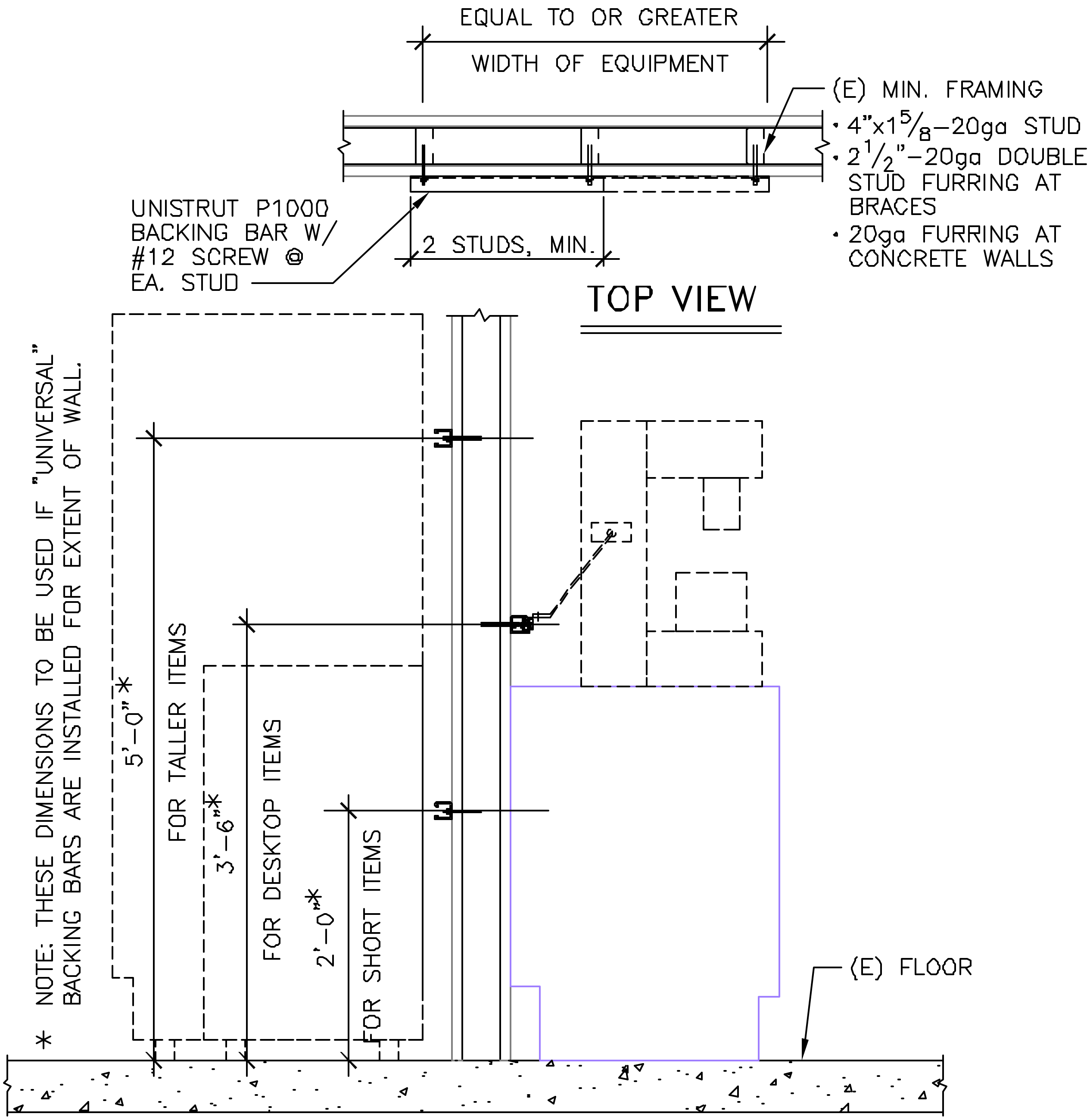
FOR DETAILS NOT NOTED
SEE DETAIL B4A



OPTIONAL RESTRAINT FOR PORTABLE BENCHTOPS
(REQUIRED IF BENCHTOPS SUPPORTS
LARGE OR HEAVY EQUIPMENT)
RESTRAINT FOR WHEELED RACKS SIMILAR)

DETAIL B4

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **ANCHORAGE OF PORTABLE OR MOBILE TABLES AND BENCHES**	SCALE: NO SCALE SHEET: **D25**

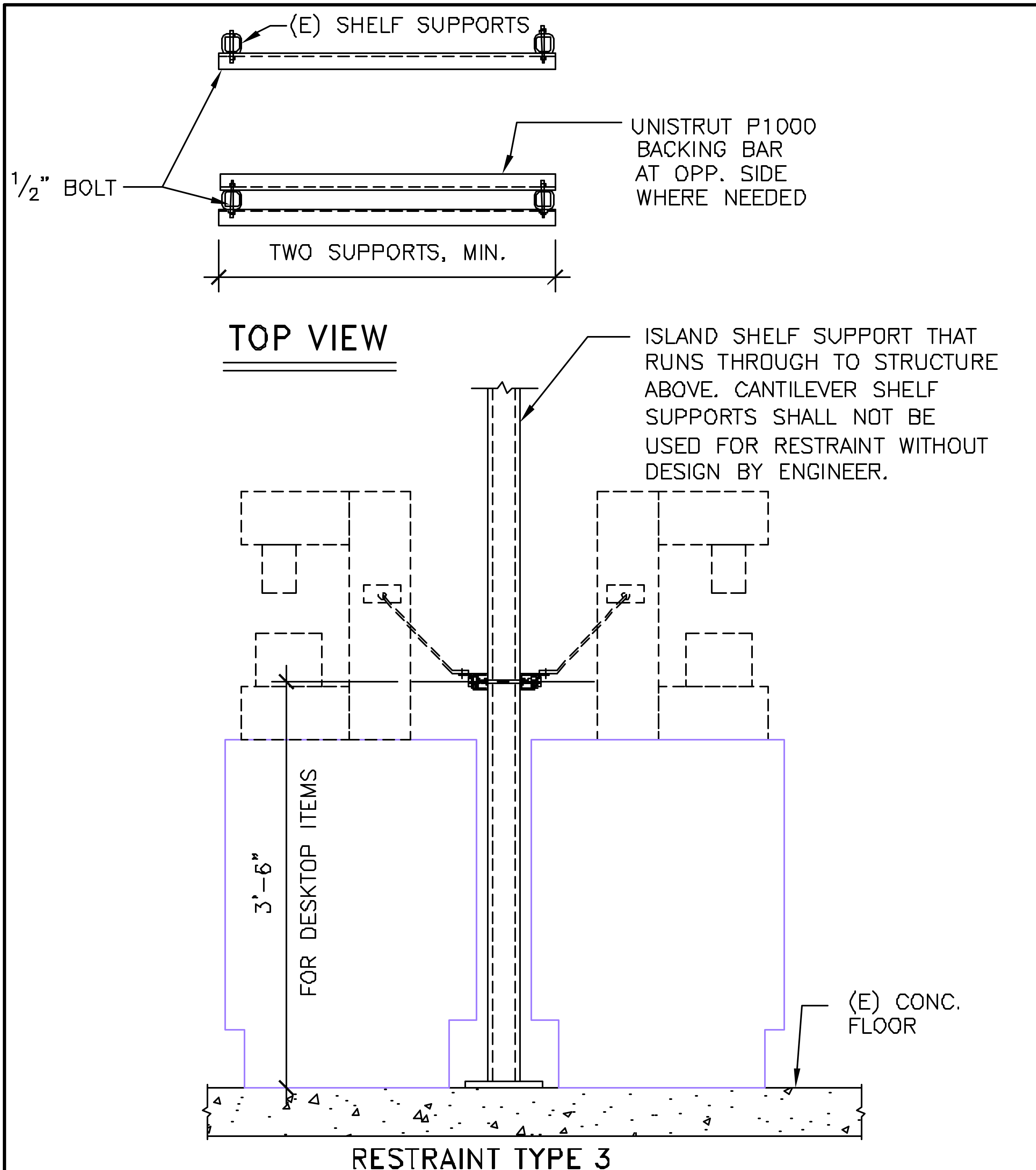


RESTRAINT TYPE 1

EXTERIOR BACKING BAR AT METAL STUD PARTITION WALLS THAT RUN TO FLOOR ABOVE WALLS THAT STOP AT CEILING SHALL NOT BE USED FOR RESTRAINT WITHOUT DESIGN BY ENGINEER. DETAIL ALSO APPLIES AT FURRING OVER CONCRETE WALLS OR STEEL STRUCTURE.

DETAIL RT1

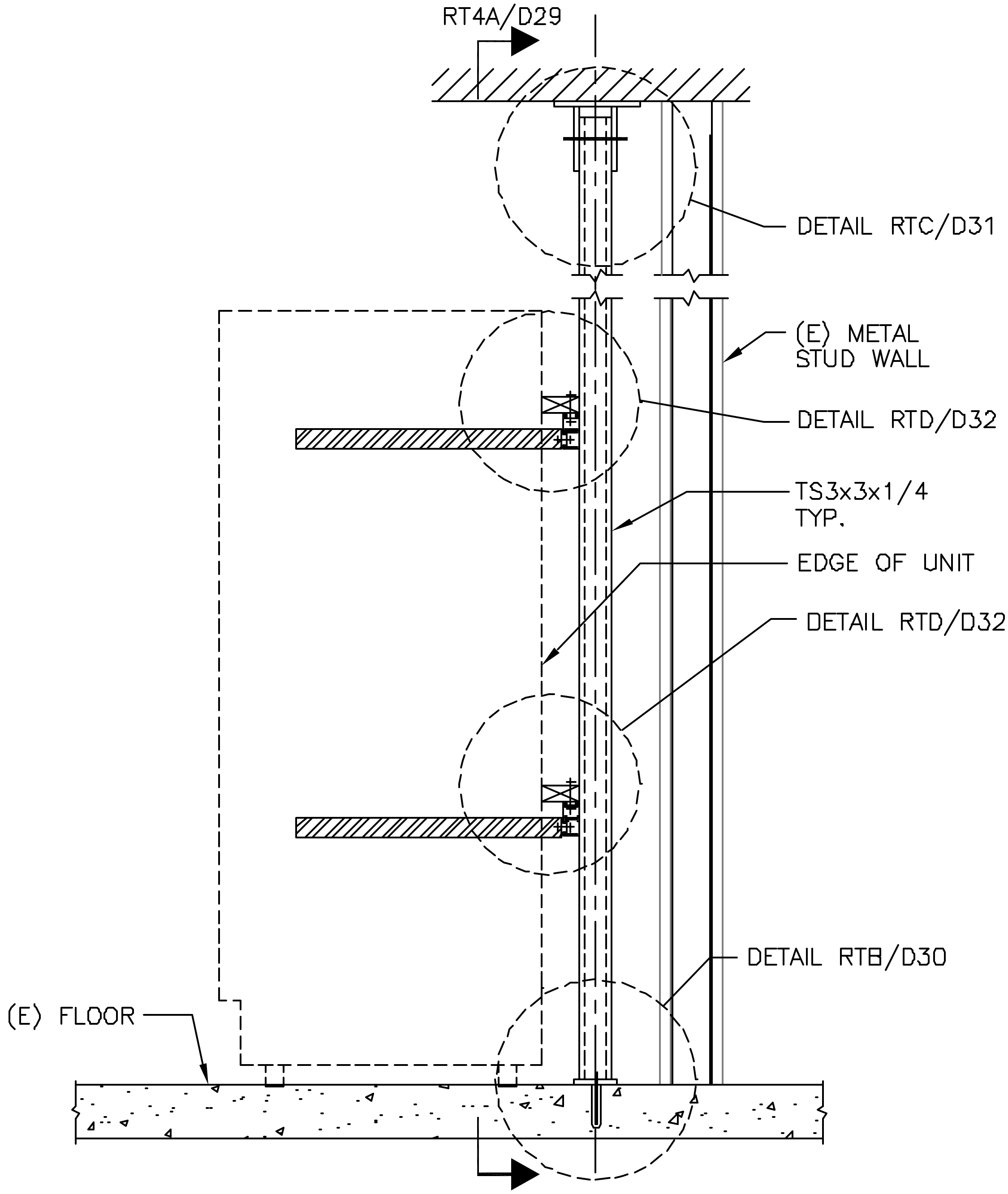
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL RESTRAINT TYPES AT PARTITIONS**	SCALE: NO SCALE SHEET: **D26**



EXTERIOR BACKING BAR @ EXISTING CABINET SUPPORTS

DETAIL RT3

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL RESTRAINT TYPES AT ISLAND**	SCALE: NO SCALE SHEET: **D27**

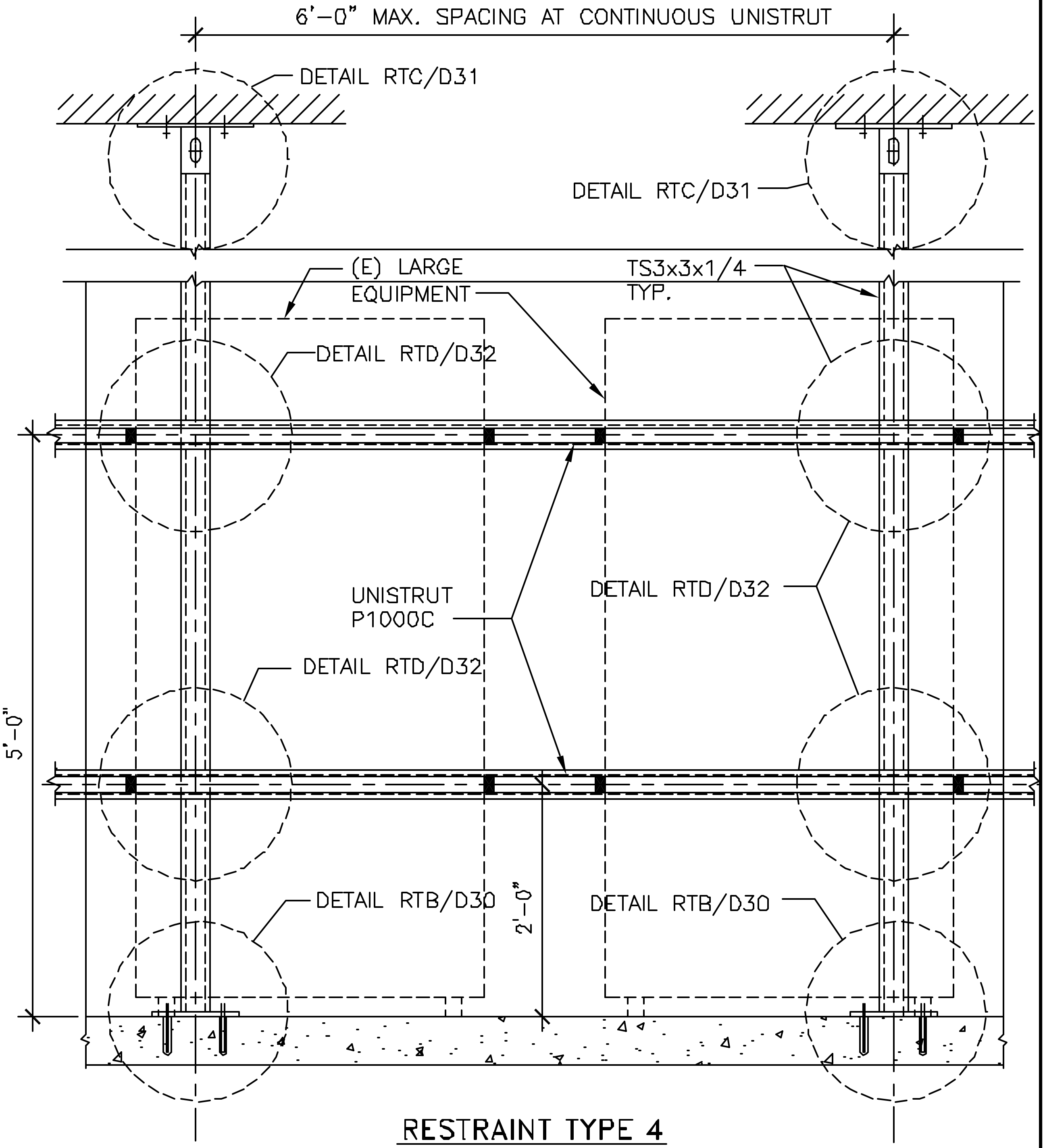


RESTRAINT TYPE 4

TYPICAL STRONGBACK DETAIL

DETAIL RT4

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL RESTRAINT TYPES AT WALLS**	SCALE: NO SCALE SHEET: **D28**

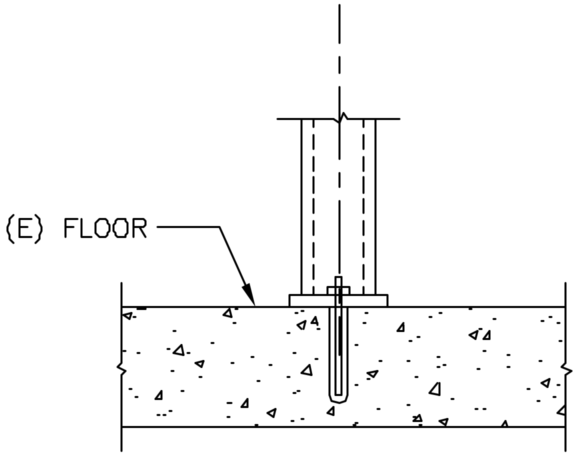


RESTRAINT TYPE 4

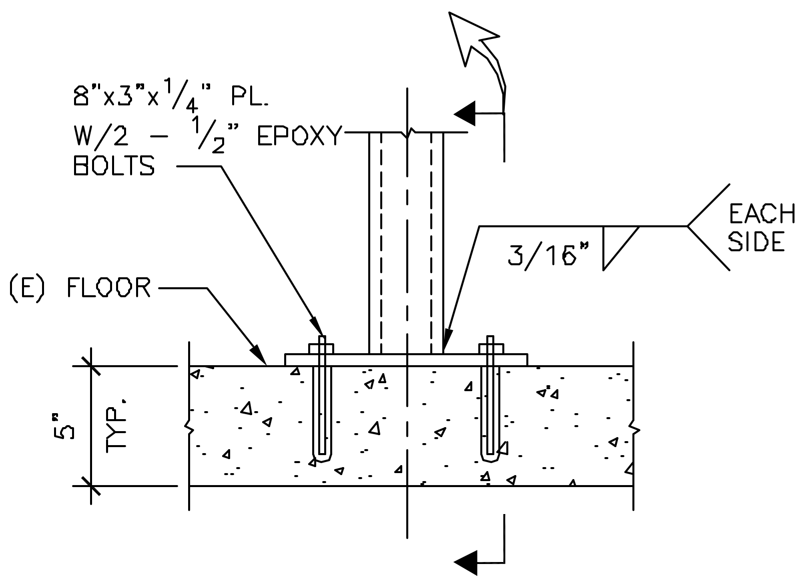
TYPICAL STRONGBACK DETAIL

ELEVATION RT4A

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL RESTRAINT TYPES AT WALLS**	SCALE: NO SCALE SHEET: **D29**



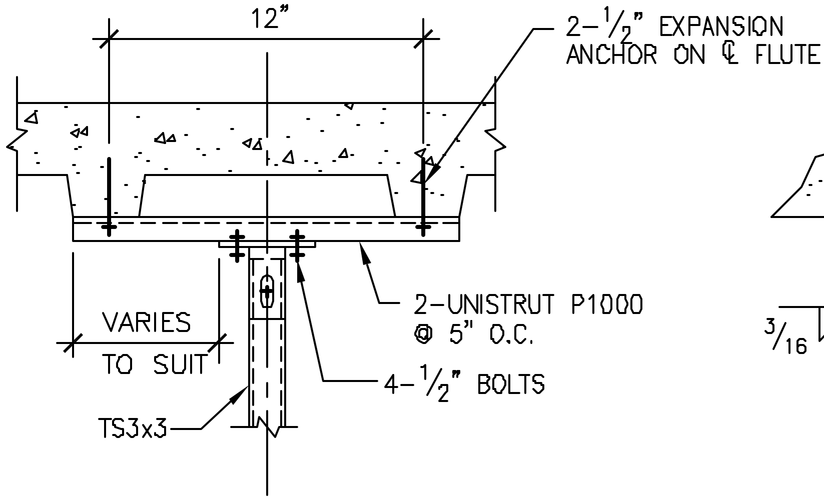
SECTION



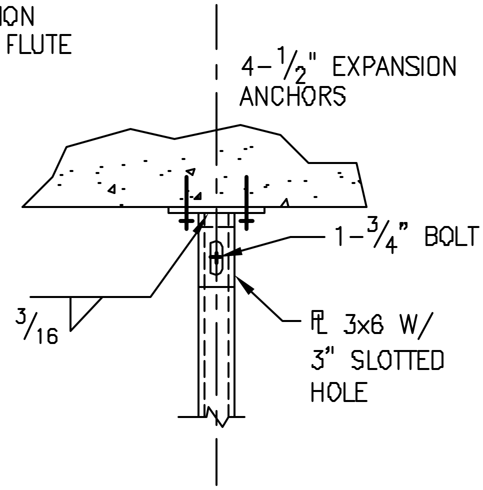
DETAIL RTB

STRONGBACK CONNECTION
TO FLOOR

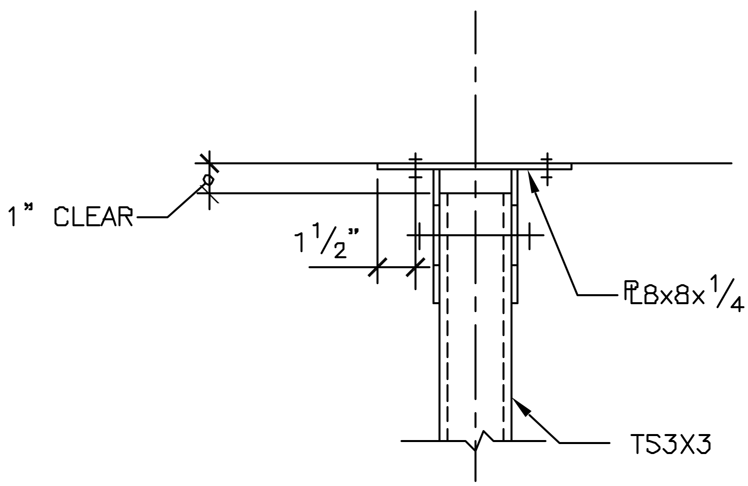
IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL DETAILS**	SCALE: NO SCALE SHEET: **D30**



SECTION AT METAL DECK



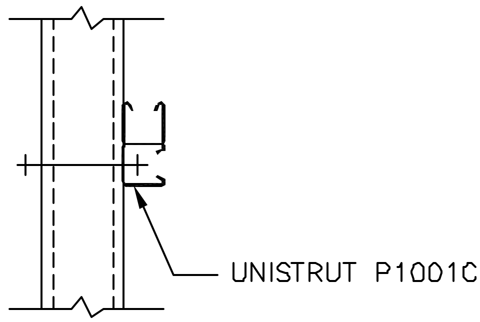
SECTION AT CONCRETE SLAB



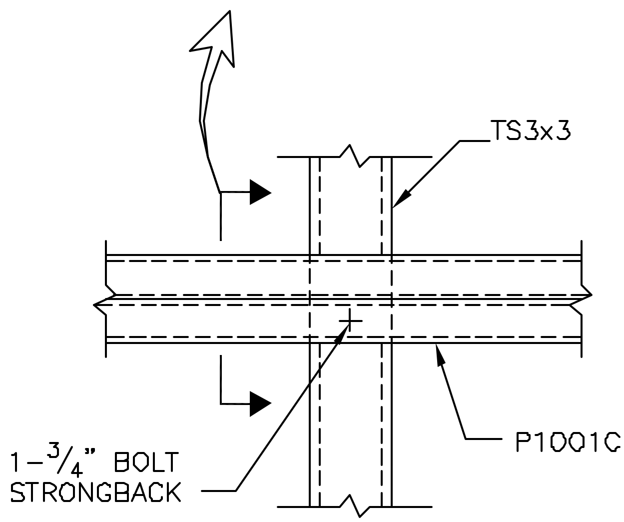
DETAIL RTC

STRONGBACK CONNECTION TO
CHANNEL AT CEILING CONNECTION

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: **TYPICAL DETAILS**	SCALE: NO SCALE SHEET: **D31**



SECTION



DETAIL RTD

STRONGBACK CONNECTION
AT INTERMEDIATE SUPPORT

IMPLEMENTATION MANUAL FOR THE SEISMIC PROTECTION OF LABORATORY CONTENTS CASE STUDY BUILDING 2	TITLE: TYPICAL DETAILS	SCALE: NO SCALE SHEET: D32

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