PRACTICAL APPROACHES TO IMPLEMENTING FACILITY WIDE EQUIPMENT STRENGTHENING PROGRAMS

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ABSTRACT

Equipment strengthening programs typically focus on components required to ensure operability of safety related equipment or to prevent the release of toxic substances. Survival of non-safety related equipment may also be crucial to ensure rapid recovery and minimize business interruption losses. Implementing a strengthening program for non-safety related equipment can be difficult due to the large amounts of equipment involved and limited budget availability.

EQE has successfully implemented comprehensive equipment strengthening programs for a number of California corporations. Many of the lessons learned from these projects are applicable to DOE facilities. These include techniques for prioritizing equipment and three general methodologies for anchoring equipment. Pros and cons of each anchorage approach are presented along with typical equipment strengthening costs.

INTRODUCTION

Equipment seismic retrofit has historically focussed on strengthening of components essential to operability of safety related equipment or to prevent the release of radioactive materials. Usually these items comprise only a small percentage of the equipment contained within a facility. Survival of non-safety related equipment may also be essential for continued facility operation following a major earthquake. Often, inadequate attention has been paid to anchoring or bracing these components.

A previous report [1] entitled, "Practical Equipment Seismic Upgrade and Strengthening Guidelines", was developed for Lawrence Livermore National Laboratory to aid DOE facility engineers in addressing this issue. The purpose of this report was twofold: 1) to help facility engineers understand typical earthquake damage to equipment, and 2) present conceptual sketches showing approaches which can be used to help protect equipment systems against earthquake damage. It is primarily intended for non-safety related equipment at General Use or Important or Low Hazard facilities.

Strengthening of non-safety related equipment (e.g. switchgear, transformers, air handlers, unique production equipment, etc.) can significantly minimize losses and downtime following a major earthquake and reduce the risk of an extended business interruption. The major problem in implementing this type of a program is how to efficiently manage the large amounts of equipment which can be strengthened throughout a facility.

This paper addresses these issues and presents three different techniques for implementing a comprehensive facility wide strengthening program. It is based upon work EQE has performed for a number of California corporations. Many of these approaches are directly applicable to DOE facilities.

EQUIPMENT SUSCEPTIBILITY TO EARTHQUAKE DAMAGE

California normally comes to mind as the highest earthquake risk area in the United States. However, there are many other regions which are also at risk. These include Puget Sound, Salt Lake City, the New Madrid area in the Central United States, and Charleston, South Carolina. Many DOE sites are located in these areas of moderate to high seismic risk and are susceptible to earthquake damage.

Seismic experience data have shown that properly anchored and braced industrial-grade equipment generally has an inherent seismic ruggedness and demonstrated capability to withstand significant seismic motion without damage. However, in the normal manufacturing environment, equipment is usually unanchored and very susceptible to damage. Typical observed damage modes include:

Computer Facilities. Data centers and local networks often are very susceptible to earthquake damage. Losses include both direct damage as well as business interruption resulting from facility downtime. Computer equipment tends to be particularly vulnerable to damage since it is relatively tall and heavy and may tip over or slide during ground shaking. Large, raised computer floors may collapse due to a lack of lateral bracing.

Electrical Equipment. Properly braced and anchored electrical equipment has an excellent performance record. However, unanchored components are very vulnerable. Typical observed failure modes include tipping or sliding and tearing of attached cabling.

Piping. Damage normally occurs due to differential displacements imposed on the piping system by the support structure. Failure usually initiates at joints. Welded steel pipe lines generally perform well while threaded or PVC pipe is vulnerable to damage.

Tanks. Tanks can tip over or slide due to inadequate bracing or anchorage. Tank movement can fail attached piping resulting in release of toxic or flammable liquids.

Vibration Isolated Equipment. Simple vertical spring vibration isolators used on air handlers, pumps, emergency generators, etc. are very susceptible to failure. Equipment misalignment and damage to attached piping or cabling may result when the equipment falls off the vertical isolator.

Strengthening equipment to mitigate these earthquake damage modes is straightforward. Seismic retrofit usually involves adding additional anchorage or bracing and/or providing adequate flexibility in attached cabling or piping. Snubbers can be used to limit displacement of vibration isolated components. The trick is to do it cost effectively.

CONSIDERATIONS IN DEVELOPING AN EQUIPMENT STRENGTHENING PROGRAM

Practical difficulties in implementing a comprehensive equipment strengthening program can keep it from ever getting off the ground. Typical issues include: How do you handle the large volumes of equipment potentially requiring strengthening with only very limited funding? How do you increase awareness and interest in the subject of non-safety related equipment retrofit? How do you set objectives and prioritize equipment requiring strengthening? The potential list of issues to be addressed may be long and complex.

Objectives of strengthening will depend on organizational goals. Protecting the life and safety of employees and the public is usually of foremost importance. Minimizing direct losses and downtime may also be critical. In many cases, downtime and resulting business interruption losses may pose the greatest economic risk to a facility.

Not all equipment requires strengthening. Given the large amounts of equipment present in typical manufacturing environments, strengthening all or even most items may not be practical given limited resource availability. Key to determining the scope of the program is to perform a needs analysis and determine what is important to ongoing operations and will be needed immediately following a major earthquake. Comprehensive interviews with product, process, and operations management personnel are a good place to start. Facilities and maintenance staff should also be interviewed.

A thorough review of operational requirements assures that all bases are covered. Involvement of different organizational groups also insures key people are knowledgeable regarding the issue and generates internal support for the program.

Once overall program objectives have been established, equipment prioritization can begin. Typical steps include:

1. Walkdown each piece of equipment to determine seismic performance issues and assign a preliminary priority.

2. Gather critical data including overall dimensions, estimated weights, existence/adequacy of existing anchorage, installation interferences, etc. Photo document the item and key issues.

3. Assign preliminary priority.

4. Revise priorities based upon senior management review.

Priorities are assigned based upon a number of factors including hazard posed to nearby personnel, component value, importance to overall operations, and adequacy of existing anchorage and bracing. Summary tables (e.g. Table 1) can be used to organize key information for upper management review. Preliminary priorities assigned by the project engineer are either confirmed or modified (up or down) during senior management review by adjusting the priority assigned to the final priority column. Equipment is then strengthened according to priority as funding becomes available.

EQUIPMENT STRENGTHENING

Equipment strengthening measures are conceptually more straightforward than building seismic retrofit. The basic idea is to secure the item against earthquake forces through additional anchorage and/or bracing.

Equipment strengthening approaches usually can be grouped into one of three general categories. These include:

1. Generic Fixes

2. Specific Fixes

3. Specific/Generic Fixes

Each approach has significant advantages and disadvantages when compared to each other. The best approach for a facility will depend upon budget constraints, type and mix of prioritized equipment, whether internal personnel or a contractor will be used to install retrofit hardware, and experience of the engineering staff. A discussion of the pros and cons of each approach follows.

SPECIFIC EQUIPMENT STRENGTHENING

Specific equipment strengthening is just what it sounds like - specifically engineered anchorage for each individual piece of

Table 1
Equipment Prioritization

Location/Item	Photo ID #	Number of Similar Items	Preliminary Priority	Final Priority ( )	Comments
Welded Bellows Area					
Portable Welding Machines	18/10:47,48	12	2	(1)	A
Heat Treat Area					
Furnace	18/10:51,52,53	1	1	(1)	B
Horizontal Tank	18/10:52,56	1	2	(3)	C

Priority:

1. Life safety and/or business interruption concern; or high value equipment subject to damage. Proceed with anchorage/restraint upgrade.
2. Medium value equipment subject to damage or sliding. Anchorage of selected items may be desired to increase safety or reduce damage.
3. No further action required.

Comments:

A. Table-top mounted equipment; no anchorage/restraint provided.
B. Some anchorage/restraint provided; need to confirm adequacy.
C. Marginal or no anchorage/restraint evident, although provisions for anchorage appear to be available.

equipment requiring seismic retrofit. Typical steps include:

1. Review each item to specifically determine problem areas and required fixes.
2. Field measurement of key dimensions and estimate weight.
3. Perform necessary calculations and finalize design in accordance with design criteria.
4. Make final field check to assure constructibility.
5. Generate engineering sketches or drawings suitable for obtaining contractor bids.

This approach is the technique normally used to anchor equipment. It results in a well engineered and highly reliable seismic retrofit. However, it may not be cost effective when dealing with large volumes of equipment for the following reasons.

First, it requires engineering of the anchorage for every item without any consideration of component similarity. This may result in additional costs due to duplication of engineering and drafting efforts.

Second, because component similarity is not explicitly accounted for the design process, each fix will be unique. This may result in higher construction costs since special fabrication may be required for each anchorage detail. Application of the specific anchorage approach normally should be limited to unique, highly hazardous, or costly items.

GENERIC EQUIPMENT STRENGTHENING

The second approach is generic equipment strengthening. It is based upon the following hypotheses: 1) identical anchorage details can be used to retrofit many different types of equipment so long as the items are similar in size, weight, and have similar installation clearance requirements, and 2) equipment retrofits can be logically presented in an easy to read manual format. A good description of this approach is pre-engineered anchorage for major equipment categories contained in a tabular look-up format.

Basic steps involved with generic equipment strengthening include the following:

1. Review plant equipment and develop categories and subcategories which generally encompass the majority of plant equipment.

2. Walkdown a representative sample to determine typical issues and problems, and develop required retrofit concepts.

3. Take necessary measurements for each required category or subcategory.

4. Perform bounding calculations to size generic details and anchorage requirements.

5. Make spot checks to help assure constructibility.

6. Generate sketches showing generic anchorage details.

7. Organize information in manual format for use by personnel installing retrofits.

While conceptually easy to visualize, this approach can be quite difficult to implement in practice. The most difficult part is organizing data for presentation in manual format.

On one recent project, equipment was categorized according to major types or classes found throughout the facility. Major equipment classes included communications, electrical, emergency, mechanical, HVAC, office, piping and conduit, process, shop, storage rack and cabinets, and tanks and vessels. Within each category, equipment subclasses were defined to provide additional breakdown and refinement. Tables were developed for each subcategory showing required anchorage configurations, bolt sizes, and generic anchorage details.

To demonstrate this approach, suppose a small, floor mounted chiller requires seismic anchorage. It weighs 7,000 lbs., with dimensions of 8' long by 4' wide by 5' high. The steps required to determine anchorage requirements are:

1. Go to the appropriate equipment class (Table 2 - Mechanical Equipment).

2. Within this equipment class, available subcategories include skid mounted equipment without vibration isolators and skid mounted equipment with vibration isolators. For this item, the appropriate subcategory is skid mounted equipment without vibration isolators (Table 3).

3. Determine the Height/Width (1.25) and Height/Length (0.62) ratios.

4. Using Table 3 in conjunction with a review of potential installation interferences, the only allowable anchorage category is III (seismic stops on all four sides). Using the

appropriate weight, height/length, height/width, and anchorage configuration requirements, the only allowable anchorage configuration is C. (Two seismic stops along each side of the chiller).

5. Reviewing possible base anchorage details (7, 8 or 9), detail 7 (Figure 1) appears to be the best choice for this application. Therefore, use detail 7 with 5/8 inch expansion anchors.

If correctly implemented, this approach can yield significant savings in engineering time. In addition, installation costs can be reduced due to similarity of anchorage details resulting in lower fabrication costs.

Table 2
Mechanical Equipment Groups

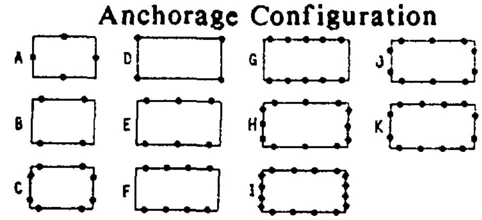
Item	Applicable Table
Skid Mounted Equipment Without Vibration Isolators o Chillers o Fans o Motors o Packaged A/C Units	3
Skid Mounted Equipment on Vibration Isolators o Boilers o Chillers o Compressors o Fans	N/A

Table 3
Skid Mounted Equipment Without Vibration Isolators

Applicable Details:

Category I (Existing Bolt Holes): 11
Category II (Seismic Stops at Corners): 5, 6
Category III (Seismic Stops Along Four Sides): 7-9
Category IV (Anchors Along Two Sides Only): 12-16
Category V (Anchors Along Four Sides): 12-16

Anchorage Configuration



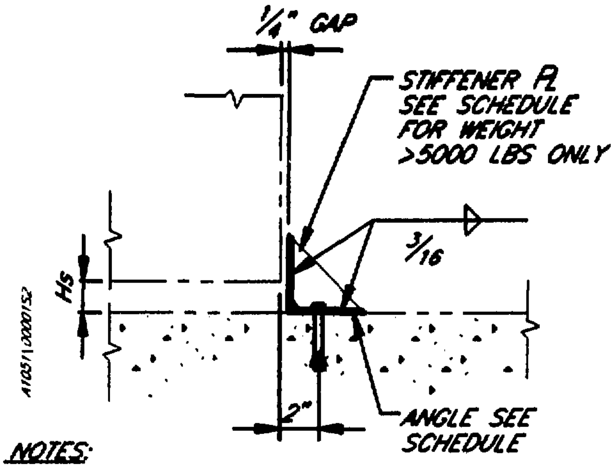
Weight (lbs.)	Height/ Width	Height/ Length	Anchorage Category	Base Configuration	Anchor Details	Expansion(1) Anchor Diameter
<5000	<4.0	<2.0	I	B or D	11	1/2
	<2.0	<2.0	II	D	5, 6	1/2
	<2.0	<2.0	III	C	7-9	1/2
	<4.0	<2.0	IV	B	12-16	1/2
	<4.0	<2.0	V	C	12-16	1/2
5001-10000	<2.0	<2.0	I	A, B, or D	11	1/2
	<2.0	<2.0	II	D	5,6	5/8
	<2.0	<2.0	III	C	7-9	5/8
	<2.0	<2.0	IV	B	12-16	1/2
	<4.0	<2.0	I	B or C	11	3/4
	<4.0	<2.0	V	C	12-16	5/8

Notes:
(1) Diameters are in inches. Bolt embedment is given in Appendix A under General Notes.
(2) Internal components on vibration isolators shall be anchored using Detail 69.

However, there are a number of potential disadvantages. First, the real world does not lend itself to generic approaches. Often, generic details can easily be installed at three places while the fourth location has an interference. Developing procedures to accommodate special anchorage requirements due to interferences is difficult.

Second, personnel installing the retrofits may misinterpret the manual and use improper anchorage in some cases.

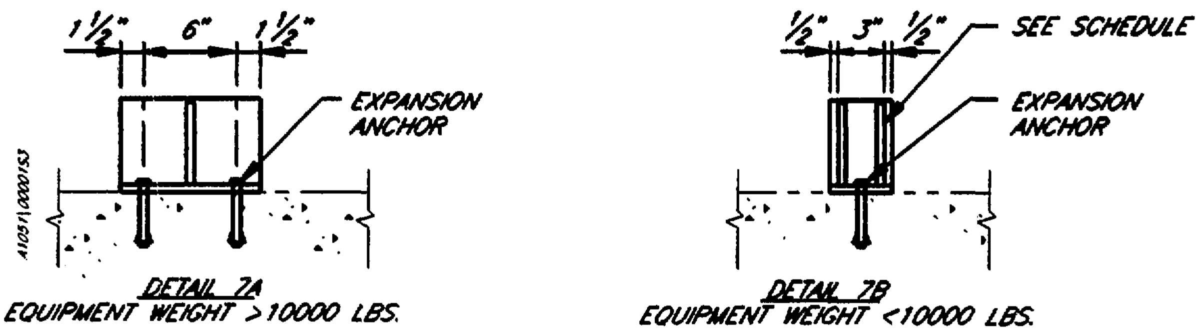
Finally, this approach will normally handle 70% to 80% of equipment requiring anchorage. Remaining items will require development of specific anchorage details as discussed previously.



NOTES:

1. Hs= HEIGHT OF EQUIPMENT ABOVE CONCRETE
2. Hs= 2" MAXIMUM FOR 1/2", 5/8", AND 3/4"φ BOLTS

Figure 1. Detail 7 - Seismic Stop



MEMBER SIZE SCHEDULE		
Hs (IN.)	ANGLE SIZE	STIFFENER THICKENESS (IN.)
0	L2 1/2x2 1/2x 1/4	1/4
<2	L6x4x 1/4	1/4
<4	L8x6x 3/8	3/8

Figure 1. (Cont.) Detail 7 - Seismic Stop

COMBINATION OF SPECIFIC AND GENERIC ANCHORAGE

This approach combines the best features of specific and generic anchorage approaches. It can be described as a specific call out of pre-engineered anchorage details. Basic steps include:

1. Walkdown each item to specifically determine the required retrofit.

2. Develop family of generic details based on component similarity.

3. Determine specific anchorage requirements at each location using generic details.

4. If required, design a specific fix for a particular anchorage location or piece of equipment.

5. Perform constructibility reviews.

6. Develop construction documents (drawings/sketches and tabulated data).

This approach is similar in concept to generic equipment strengthening. However, there are two major differences. First, all equipment has been reviewed rather than a representative sample. This insures retrofit approaches will be installable and require minimum field modification. Second, generic anchorage look-up tables such as Table 3 have been eliminated to avoid problems with installation personnel misinterpreting how to use them. Instead, a master call-out table is provided which fully defines the required anchorage for a particular item.

As an example, assume there are some chilled water pumps located in a mechanical equipment penthouse which require seismic restraint. The basic steps are as follows:

1. Using Table 4, locate the required equipment item (penthouse, chilled water pumps, 4 total, located in Chiller Room).

2. Use detail 1.3C (Figure 2) to anchor the base of the unit. Note that top anchorage is not required for this item.

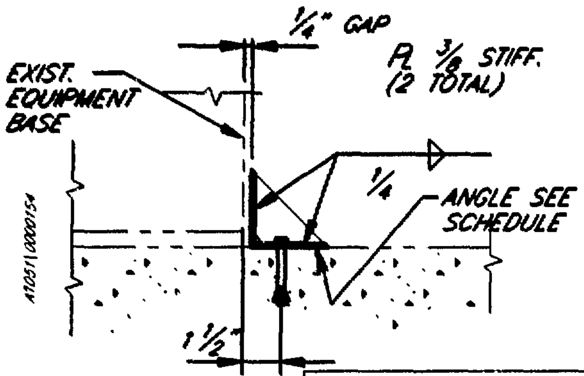
3. Install details per anchorage configuration F (Figure 3).

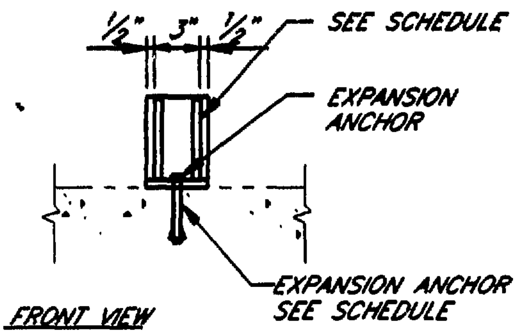
4. Review the comments column to note any special anchorage requirements or installation concerns.

Table 4
Equipment Anchorage Specification Table

Location/ Equipment Description	Quantity	Location	Base Anchor Detail	Top Anchor Detail	Anchor Config.	Comments
Penthouse						
Heat Exchanger	1	Chiller Room	5/8" Exp.(1) Anchor	----	----	3 anchors total.
Zinsco Switchgear Panel	3	Chiller Room	3/8" Exp.(2) Anchor	----	----	Install two exp. anchors per panel through front base channel.
Wayne Receiver Tank	1	Chiller Room	3/8" Exp. Anchor	----	H	----
Chilled Water Pumps	4	Chiller Room	1.3C	----	F	Place details on the inside of support channels with 1/4" gap.

Notes:
(1) Install anchors in existing holes in equipment base supports.
(2) Anchor configuration applies to each panel section.





DETAIL SCHEDULE		
DETAIL NO.	ANGLE SIZE	ANCHOR DIA. (IN.)
1.3A	3x3x3/8	1/2
1.3B	3x3x3/8	5/8
1.3C	6x6x3/8	5/8
1.3D	6x6x3/8	3/4

Figure 2. Detail 1.3 - Seismic Stop

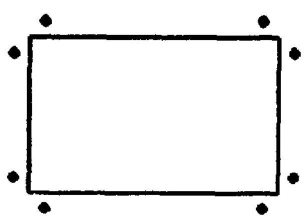


Figure 3. Anchorage Configuration "F"

This approach combines the best aspects of specific and generic anchorage. It takes full advantage of component similarity in generating anchorage details and specifically checks for interference problems prior to installation of retrofit hardware. Anchorage fabrication costs are minimized since the identical details are used for many similar items. However, more engineering time is required to develop equipment strengthening manuals than in the generic approach.

TYPICAL COSTS

Equipment strengthening based on a combination of generic and specific details can be carried out in an efficient and cost-effective manner. Though the cost of equipment strengthening is highly variable, costs often range from $1 to $5 per square foot for strengthening of high priority equipment in medium to large facilities.

Costs are on the order of $1 to $2 per square foot for facilities which require only nominal anchorage and bracing of building support equipment such as transformers, fans, and HVAC systems. For light assembly and manufacturing operations, equipment strengthening costs can range from about $1 to $3 per square foot. Raised computer floors can be retrofit for about $3 to $5 per square foot. Strengthening high technology equipment, such as those used in some electronics and aerospace environments, typically costs about $3 to $6 per square foot. Clean room environments can cost $5 per square foot or more due to the high cost of special preparation, installation procedures, and clean-up.

CONCLUSION

Risk of an extended business interruption due to earthquake damage to critical, non-safety related equipment can be as great if not greater than risks to buildings.

Equipment is often unanchored and can be vulnerable to tipping or sliding damage. Fortunately, it is often practical and cost-effective to survey facility equipment, select certain critical items to be seismically strengthened based on safety and operational criteria, and implement an equipment strengthening program.

Three general approaches for implementing an equipment strengthening program have been discussed. Each approach has advantages and disadvantages. Based upon recent experience, a combination of generic and specific equipment strengthening is recommended as generally being the most cost effective technique for implementing a facility wide strengthening program. However, the best approach for your facility will depend upon staff experience, type and number of items being retrofit, budget and schedule.

Strengthening equipment is cost-effective when savings and benefits realized from increased safety, reduced potential damage and downtimes, and reduced risk of an extended business interruption are considered. Coupled with a building strengthening program, equipment retrofit can play a vital part in assuring an organization's ability to survive and quickly return to business following a major earthquake.

REFERENCES

[1] EQE Engineering, Inc., "Practical Equipment Seismic Upgrade and Strengthening Guidelines," prepared for Lawrence Livermore National Laboratory, Livermore, California, November 1985

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