Resilience Against Natural Disasters

Restrain Your Services
Design for Seismic Zones

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ASHRAE TC 2.6 Sound & Vibration Control

Natural Disasters

Nepal Earthquake, April 2015

David Ramos - Getty Images

- **Earthquakes**
- **Storms**
- **Floods**
- **Avalanches**
- **Volcanic eruptions**
- **Wildfires**

Definitions and Goals

Seismic

It is a subject relating to, or caused by an earthquake;
also: relating to, an earth vibration caused by something else

Restraint

A device that restricts movement

Brace

Something that transmits, directs, resists, or supports weight or pressure

- What are non-structural components?
- How does seismic apply to non-structural?
- Which codes and standards should be followed?
- Who is responsible?
- How seismic restraint and bracing accomplished?

Outline

1. Earthquakes and Non-Structural Building Components

- Earthquakes
- Non-structural Components
- The Importance of Non-structural Components
- Past Earthquakes: Non-structural Component Failure and Damage
- Non-structural Seismic Design Process

2. Seismic Restraint and Bracing Requirements

- Seismic Codes and Guides
- Building Performance Levels
- IBC /ASCE Seismic Design Requirements
- Seismic Force Equations
- Mounting System
- Support Attachment - Anchorage
- Quality Control
- What's Required for Designing a New Project?

3. Seismic Restraint and Bracing Installation Examples

- Floor, Wall Mounted and Suspended Equipment
- Suspended Services

Section 1.

Earthquakes and Non-Structural Building Components

Earthquakes

The Science

1. **Earthquake science is faced with difficult task.**

2. **There is not enough data to improve the accuracy of prediction.**

3. **We need 1000 & 1000 of years of data to get confidence in the science.**

4. **There are many variables and the dynamic nature of the earth's core is one of them.**

Earthquakes

The Science

Science Books are Rewritten After Major Earthquakes

<u>Christchurch, NZ, 2011</u>

*** The *vertical acceleration* was <u>far greater</u> than the horizontal acceleration**
*** The <u>unknown</u> fault that caught out Christchurch**

<u>Tohoku, Japan, 2011</u>

Powerful tsunami created waves that reached <u>heights of up to 40.5</u> metres

Earthquakes

Tohoku, Japan, 2011

NUCLEAR DISASTER

Cause

- **Diesel generators flooded**
- **Reactors could not be cooled down causing catastrophic damage**

Most important lesson learned

- **Ensure power supply**
- **Diesel generators could have been located on a higher ground**

Structure survives the earthquake but luck of **detailed attention** to **Non-Structural** components proves to be fatal.

Non-structural Components

MEP Systems

- **Mechanical Systems**
  - HVAC equipment, air handling units, cooling towers, water heaters, boilers, pumps, chillers, compressors, etc.
- **Electrical Power Systems**
  - Transformers, panel boards, Motor Control Centers (MCCs), control panels, conduit & cable trays
- **Piping & Plumbing**

Non-structural Components

Life Safety Systems

- **Fire Protection Systems**

  - Piping, pumps, tanks, etc.

- **Safety Systems**

  - Alarm, smoke detection, emergency lighting

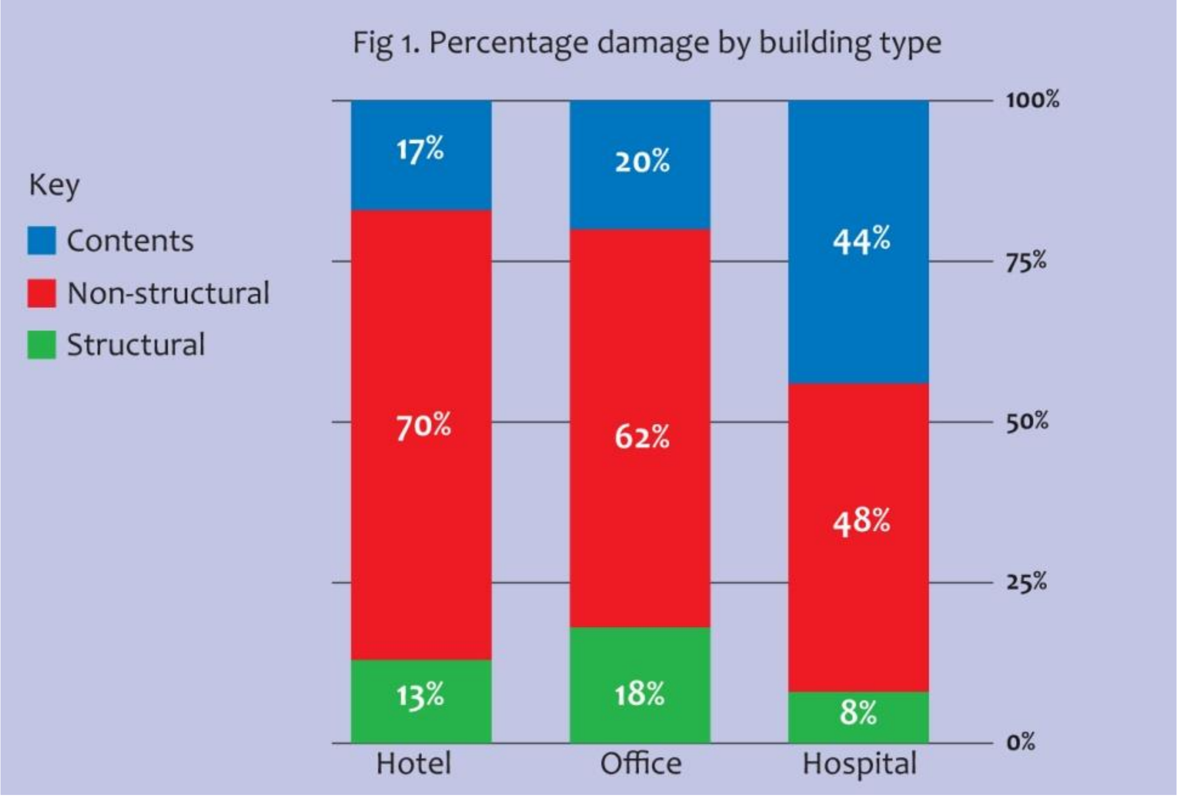
- **Emergency Power Systems**

  - Engine generators, start batteries, fuel oil systems, fuel oil storage tanks, control equipment, disconnect switches, etc.

- **Security/Communication Systems**

Non-structural Components

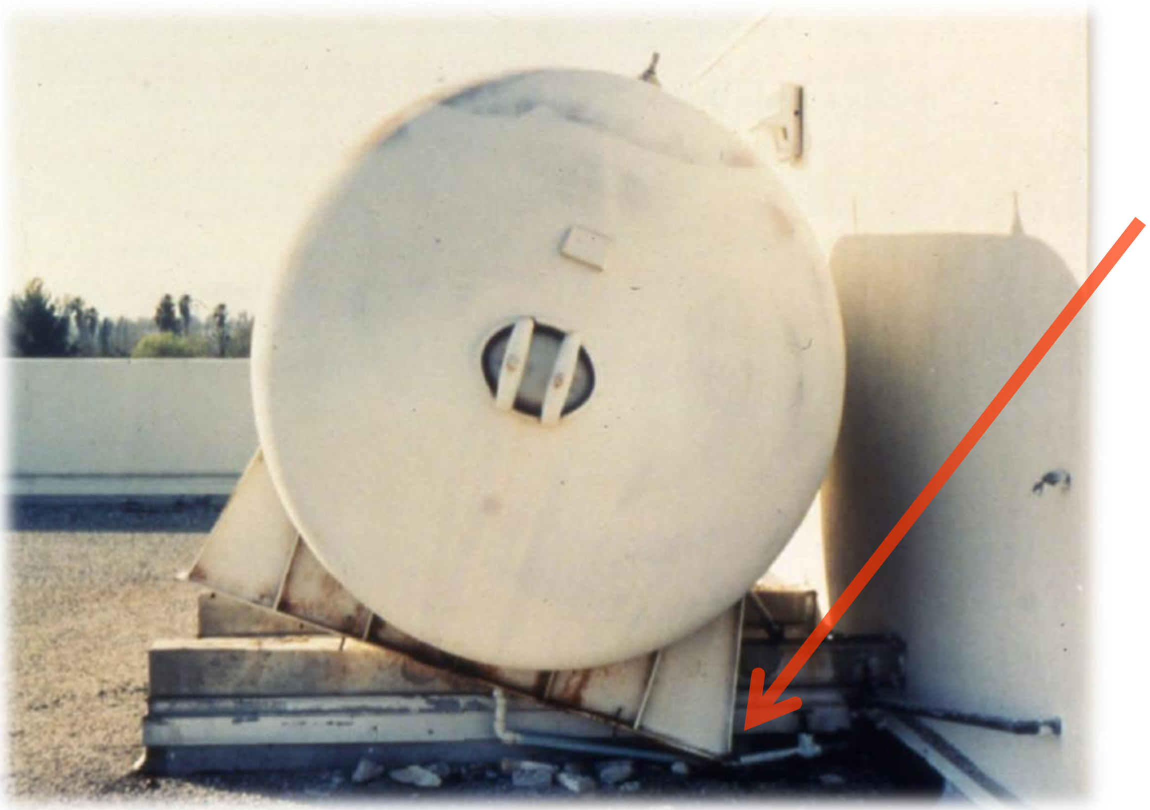
Nonstructural building components are critical for the proper functioning of a buildings.



Data from Northridge, CA Earthquake - 1994

Past Earthquakes

Northridge, CA, USA ,1994



Damage:
Horizontal tank shifted of support damaging attached pipe work

Reason:
Not anchored at all!!!

Solution:
Anchors should have been installed as per engineer's seismic calculations.

Example of rigid (no vibration isolation) equipment failure - Granada Hills Hospital
(Photo courtesy of OSHPD)

Past Earthquakes

Northridge, CA, USA ,1994

Damage:

Vertical tank at hospital overturned damaging attached pipe work.

Reason:

Not anchored at all!!!

Solution:

Anchors should have been installed as per engineer's seismic calculations.

Example of rigid (no vibration isolation) equipment failure

(Photo courtesy of OSHPD)

Past Earthquakes

Bio-Bio, Chile, 2010

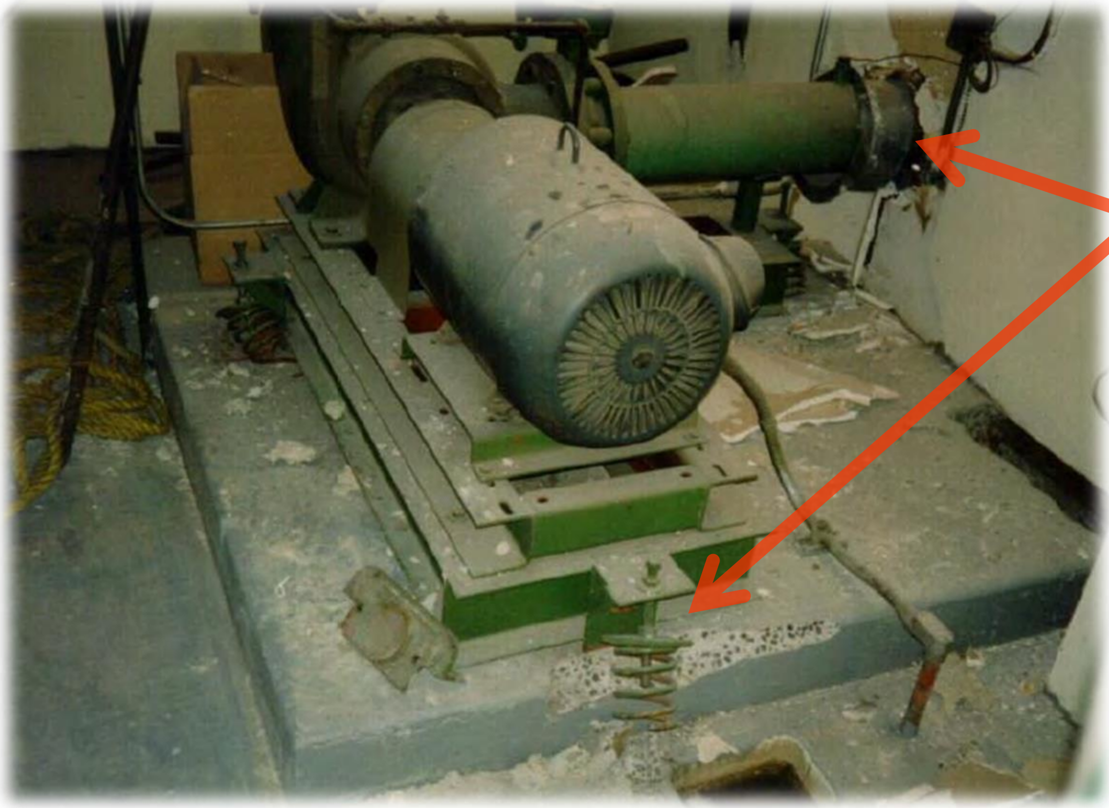
Damage:
Numerous rooftop units toppled over.

Reason:
Poorly anchored!!!

Solution:
Anchors should have been installed as per engineer's seismic calculations.

Example of rigid (no vibration isolation) equipment failure
(Photos courtesy of Rodrigo Retamales, Rubn Boroschek & Associates)

Past Earthquakes



Damage:
Failure of pump mounted on three vibration isolators and damage at wall penetration.

Reason:
Wrong type of isolators used!!!

Solution:
Restrained (housed) isolators should have been installed and properly anchored as per engineer's seismic calculations.

Example of resiliently (vibration isolated) mounted equipment failure

(Photo courtesy of Mason Industries)

Past Earthquakes

Damage:
Complete failure of vibration isolators .

Reason:
Correct type of isolators but with wrong housing (NON-DUCTILE) material !!!

Solution:
Isolators housing should have been manufactured from DUCTILE materials.

Example of resiliently (vibration isolated) mounted equipment failure

Past Earthquakes

Damage:
Complete failure of vibration isolators .

Reason:
Poorly anchored!!!

Solution:
Anchors should have been installed as per engineer's seismic calculations.

Example of resiliently (vibration isolated) mounted equipment failure

Past Earthquakes

Damage:
Complete failure of supporting structure (I-Beam).

Reason:
Supporting structure not able to carry the loads !!!

Solution:
Supporting structures should have been designed to resist earthquake loads as well.

Example of resiliently (vibration isolated) mounted equipment failure

(Photo courtesy of Mason Industries)

Past Earthquakes

Bio-Bio, Chile, 2010

Damage:
Suspended HVAC equipment drops down from the ceiling.

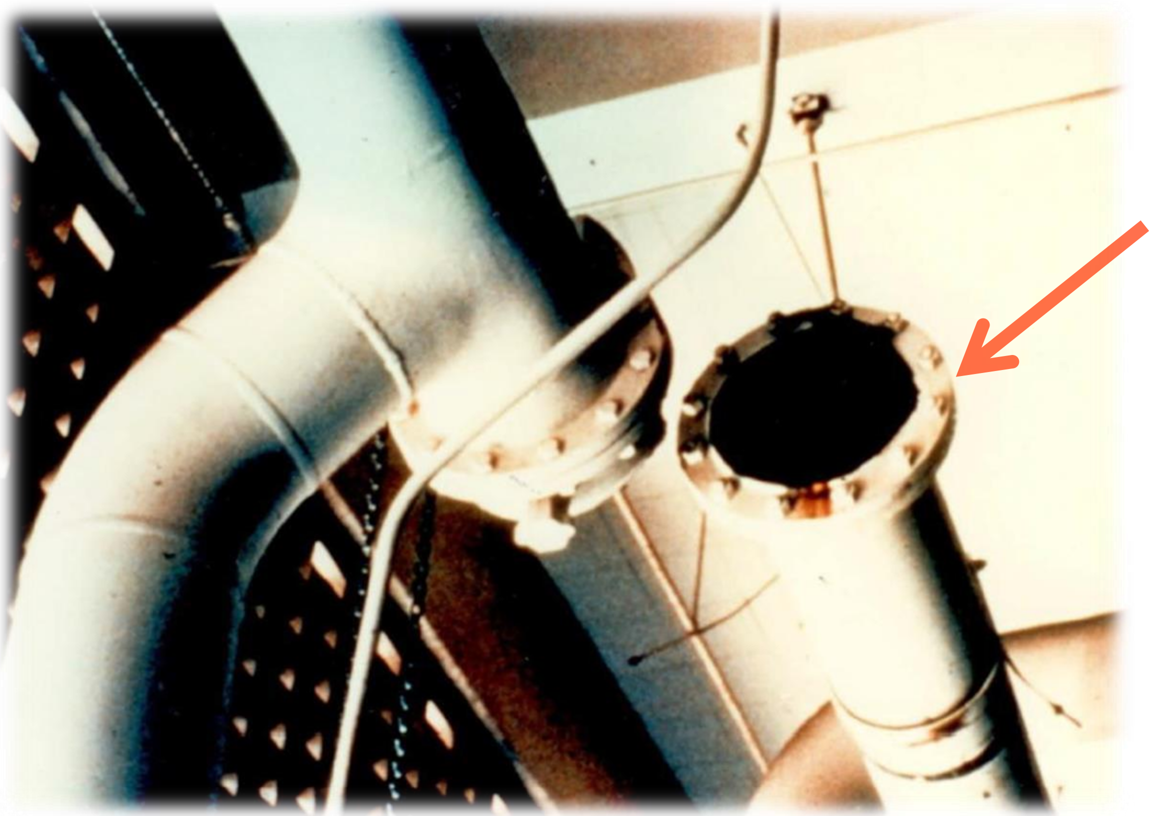
Reasons:
No bracing !!!
Threaded rod failure!!!

Solution:
Bracing and rod stiffens should have been installed as per engineer's seismic calculations.

Example of suspended HVAC equipment failure – Santiago Airport Terminal
(Photo courtesy of Gokhan Pekcan)

Past Earthquakes

San Fernando, CA, USA ,1971



Damage:
Complete failure of pipe joint.

Reasons:
No bracing !!!

Solution:
Bracing should have been installed as per engineer's seismic calculations.

Example of suspended piping failure
(Photo courtesy of John F. Meehan)

Past Earthquakes

Damage:
Complete failure of pipe joint.

Reasons:
NON-DUCTILE material used !!!

Solution:
Piping which has been manufactured from DUCTILE material should have been used.

Example of ground piping failure

Non-structural Seismic Design Process

OWNER / DEVELOPER — **ARCHITECT**

Program Manager

Design Team

Civil

Structural

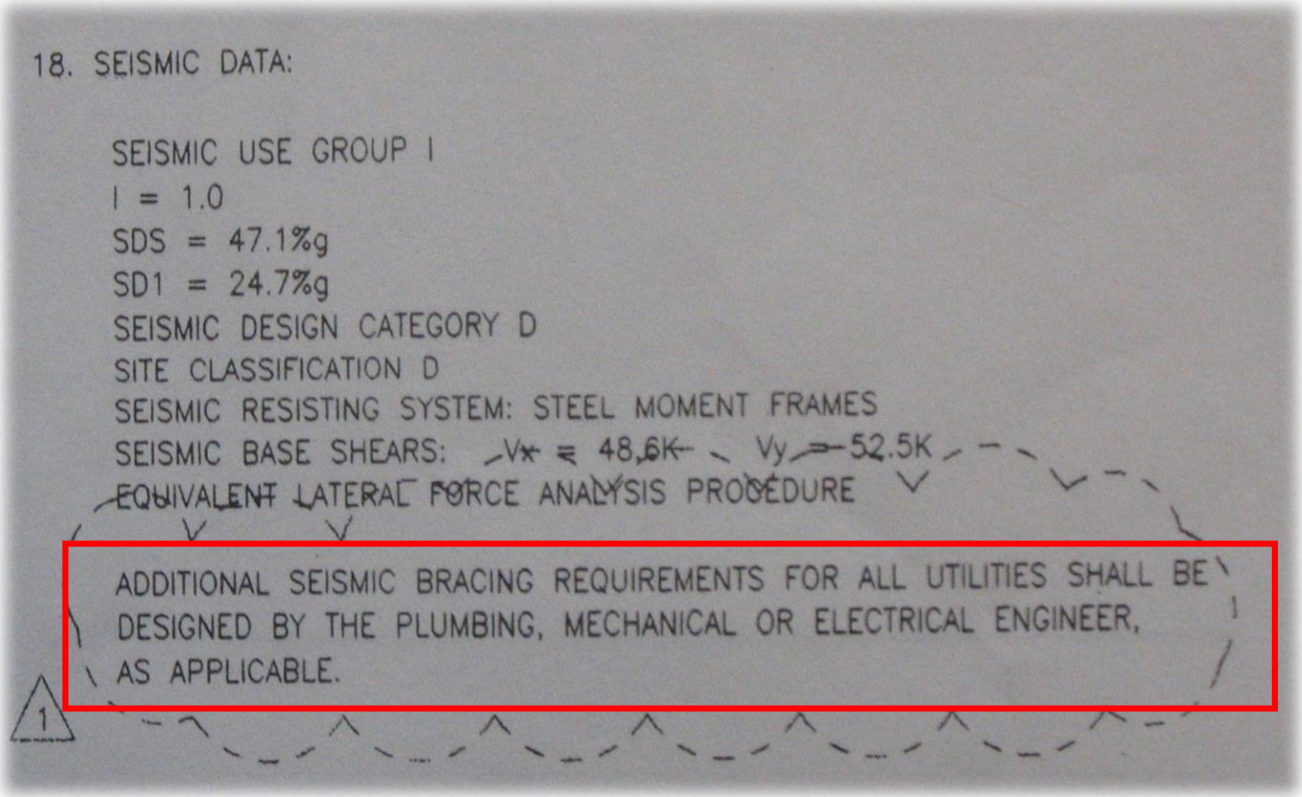
MEP Systems

IT Systems

Communications

Fire Protection

Non-structural Seismic Design Process


18. SEISMIC DATA:

SEISMIC USE GROUP I
I = 1.0
SDS = 47.1%g
SD1 = 24.7%g
SEISMIC DESIGN CATEGORY D
SITE CLASSIFICATION D
SEISMIC RESISTING SYSTEM: STEEL MOMENT FRAMES
SEISMIC BASE SHEARS: Vx = 48.6K Vy = 52.5K
EQUIVALENT LATERAL FORCE ANALYSIS PROCEDURE

ADDITIONAL SEISMIC BRACING REQUIREMENTS FOR ALL UTILITIES SHALL BE DESIGNED BY THE PLUMBING, MECHANICAL OR ELECTRICAL ENGINEER, AS APPLICABLE.

1

Structural engineer's approach to non-structural component design

Section 2.

Seismic Restraint and Bracing Requirements

Seismic Codes and Guides

International Code Council (ICC)

- **IBC -2018 "***International Building Code"*

American Society of Civil Engineers (ASCE)

- **ASCE/SEI 7-16** *"Minimum Design Loads and Associated Criteria for Buildings and Other Structures "*

Federal Emergency Management Agency (FEMA)

- **FEMA 412-2002** *"Installing Seismic Restraints for Mechanical Equipment"*
- **FEMA 413-2004** *"Installing Seismic Restraints for Electrical Equipment"*
- **FEMA 414-2004** *"Installing Seismic Restraints for Duct and Pipe"*
- **FEMA 460-2005** *"Seismic Considerations for Steel Storage Racks"*

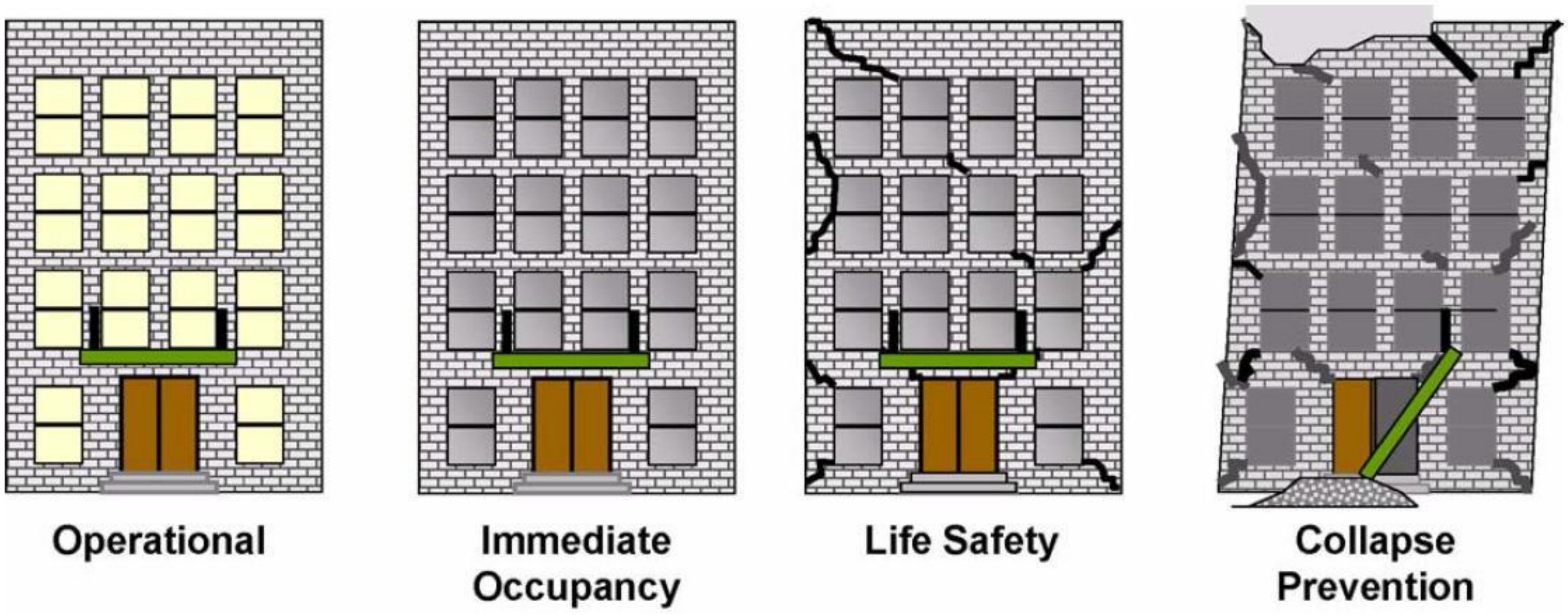
Seismic Codes and Guides

- **American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)**
  - *A Practical Guide to Seismic Restraint, 2012*

- **Sheet Metal & Air-Conditioning Contractors' National Association (SMACNA)**
  - *The Seismic Restraint Manual: Guidelines for Mechanical Systems, 3rd edition 2008, ANSI/SMACNA 001-2008*
  - *Seismic Restraint Manual, OSHPD Edition, 1st edition 2009*

- **National Fire Protection Association (NFPA)**
  - NFPA 13-2019: *Standard for the Installation of Sprinkler Systems*

Building Performance Levels



Essential facilities such as:
Hospitals
Police and Fire Stations
Military Facilities
Embassies, Consulates
City Halls ....

Buildings accommodating large number of people such as:
Airports
Schools and Universities
Large Supermarkets
Hotels, Jails ....

Most other buildings that are not classified as essential or for immediate use, such as:
Office Buildings, Hotels
Shopping malls,
Convention centres ....

Low occupancy structures such as:
Farm / Agricultural buildings, Warehouses
....

Seismic Design Requirements

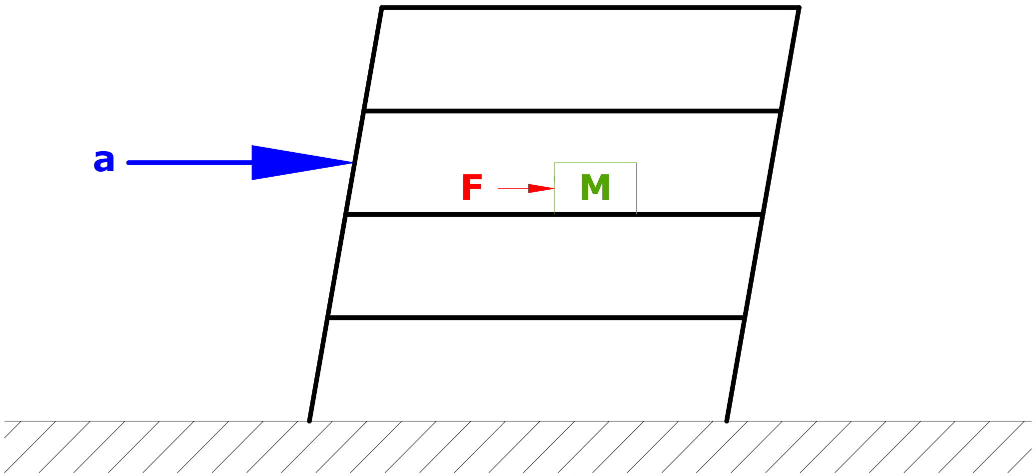
- **IBC Section 1613.1**
  "Every structure and portion thereof, including nonstructural components ….. shall be designed ….. for earthquake motions in accordance with ASCE 7."

- **ASCE/SEI 7-16 Chapter 13**
  Seismic Design Requirements for Nonstructural Components

Seismic Force Equations

Seismic loads are calculated according to the basic formula of:

Force (F) = Mass (m) x Acceleration (a)



F : Seismic load

M : Mass of equipment or pipe

a : Acceleration

Seismic Force Design Equations

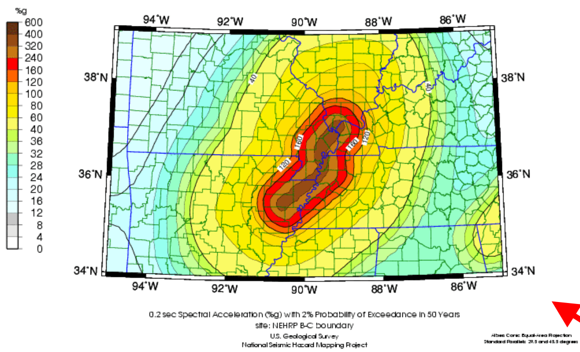
Design Equations: (ASCE 7-10, Section 13.3)

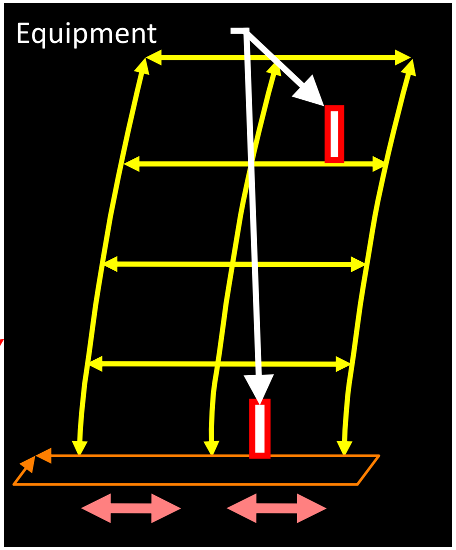
- Seismic Design Force → $$F_p = \frac{0.4 a_p S_{DS} W_p}{\left[\frac{R_p}{I_p}\right]}\left[1 + 2\frac{z}{h}\right]$$

- Seismic Force **not greater** → $$F_p = 1.6 S_{DS} I_p W_p$$

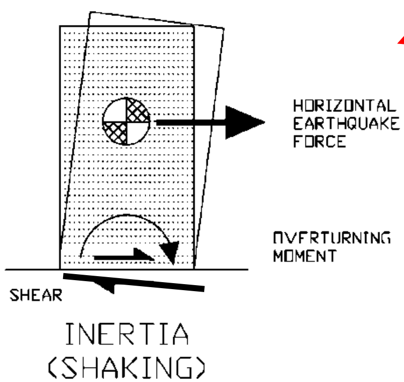
- Seismic Force **not less** → $$F_p = 0.3 S_{DS} I_p W_p$$

Seismic Force Design Equation





$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left[\frac{R_p}{I_p}\right]}\left[1 + 2\frac{z}{h}\right]$$



Mounting Systems

Floor Mounted

Mounting systems should be designed, manufactured and constructed to carry the seismic loads to the main supporting structure safely. Seismic loads can not be resisted by friction forces only.

MEP Equipment

Mounting (Equipment) Base
(Structural steel...)

Mounting Component
(Restrained Vibration Isolators, Snubbers...)

Mounting Support
(Steel structure, Housekeeping pads...)

Main Structural Support
(Concrete, Steel...)

Mounting Systems

Suspended

Mounting systems should be designed, manufactured and constructed to carry the seismic loads to the main supporting structure safely. Seismic loads can not be resisted by friction forces only.

Main Structural Support
(Concrete, Steel...)

Mounting Component
(Vibration Isolation Hangers...)

Mounting Support
(Steel structure...)

Piping

Seismic Bracing
(Steel wire rope, rigid brace ...)

Mounting Systems

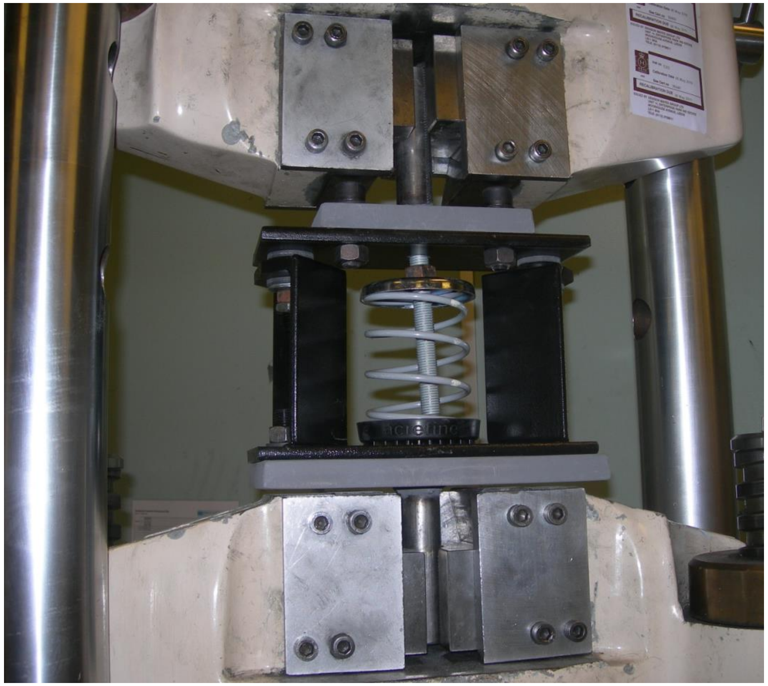
Load Capacity

1. Mounting Base (Structural Steel...)
   Engineering calculations based on well established design principles.

2. **Mounting Components (Restrained Vibration Isolators, Snubbers...)**
3. **Seismic Bracing (Steel wire rope, rigid brace ...) - Engineering calculations are not adequate. Independent testing per recognised standards should be performed to verify load capacity.**

3. Mounting Supports (Steel Bases, Housekeeping pads...) - **Engineering calculations based on well established design principles.**

4. Main Structural Support (Steel, Concrete) **- Should be checked and verified by structural engineers.**



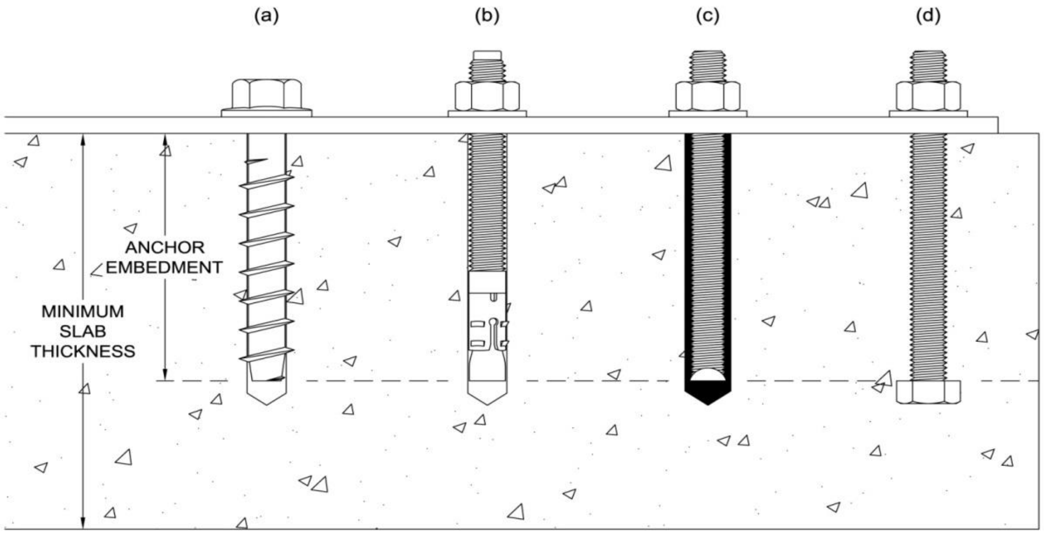
Testing of Mounting Component per ANSI/ASHRAE STANDARD 171-2008:
Method of Test of Seismic Restraint Devices for HVAC&R Equipment

Support Attachment - Anchorage

- Steel Supports: **Weld, Bolts, Screws**

- Concrete supports:
  - Cast-in-place anchors
  - Post-installed anchors

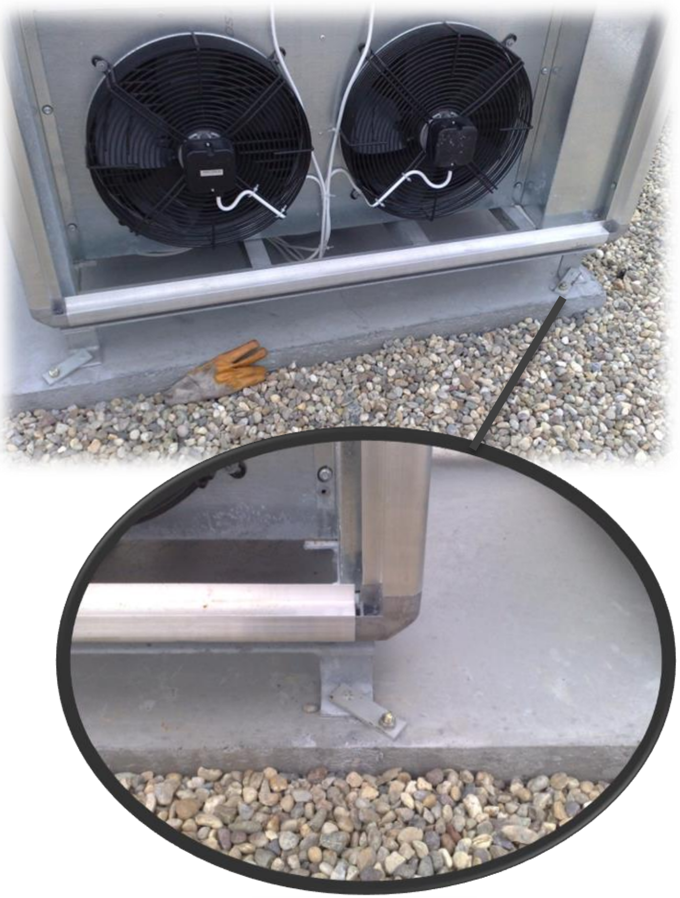
a) Screw anchor
b) Expansion anchor
c) Adhesive anchor
d) Cast-in-place bolt



Quality Control

Why is proper construction important? Because it ensures:

- Expected earthquake design performance objectives will be met.
- Reduction in life-safety risk to building occupants.
- Reduction in risk or damage to the component itself.
- Reduction in risk or damage to adjacent or closely located items – falling, overturning, swinging and impacting, leaking, etc.
- For critical facilities the needed operability assurances necessary for Immediate Occupancy (e.g., hospitals, fire stations, police stations, other critical facilities, etc.)



Designing New Project

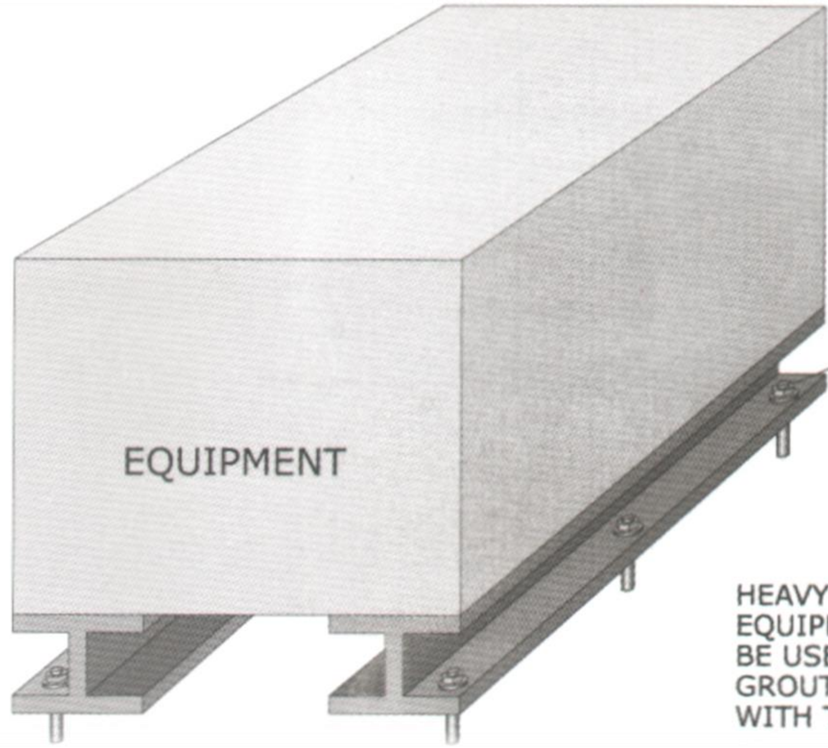
What is Required?

- ❑ Building Code & Edition
- ❑ MEP Design Project Drawings
- ❑ Seismic specification *and* the component specification
- ❑ Design Parameters:
  - Occupancy Type (II, III, IV)
  - Building Importance Factor – I
  - Spectral Acceleration - S_{DS}
  - Component Importance Factor – I_p
  - Seismic Design Category – SDC (C, D, E, F)
- ❑ Structural Drawings for attachment design

Section 3.

Seismic Restraint and Bracing Installation Examples

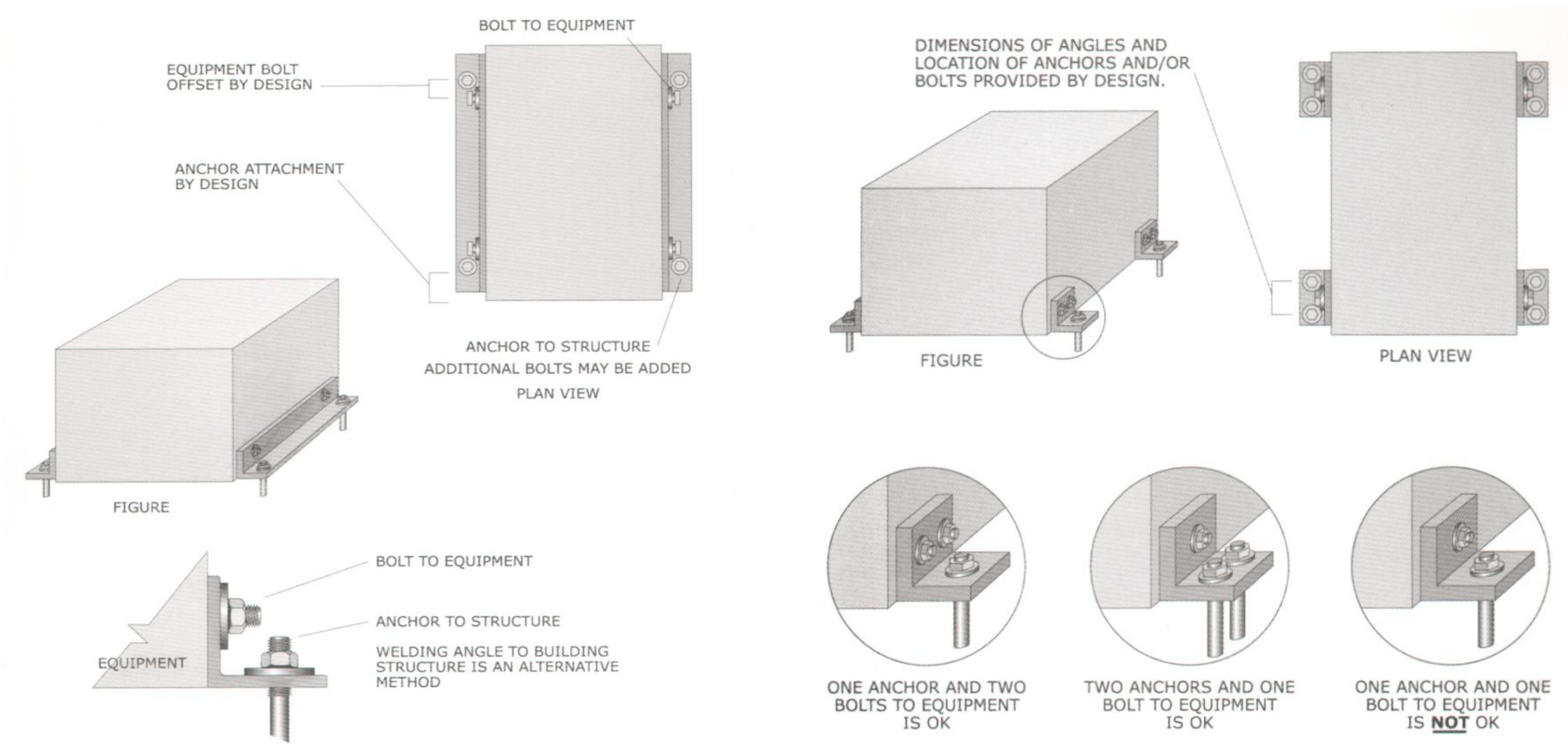
Floor Mounted Equipment



Rigid Mounting

Typical attachment of equipment with structural steel to a supporting structure

Floor Mounted Equipment



Rigid Mounting Details

Typical attachment details of equipment with angle steels to a supporting structure

Floor Mounted Equipment

Rigid Mounting Example

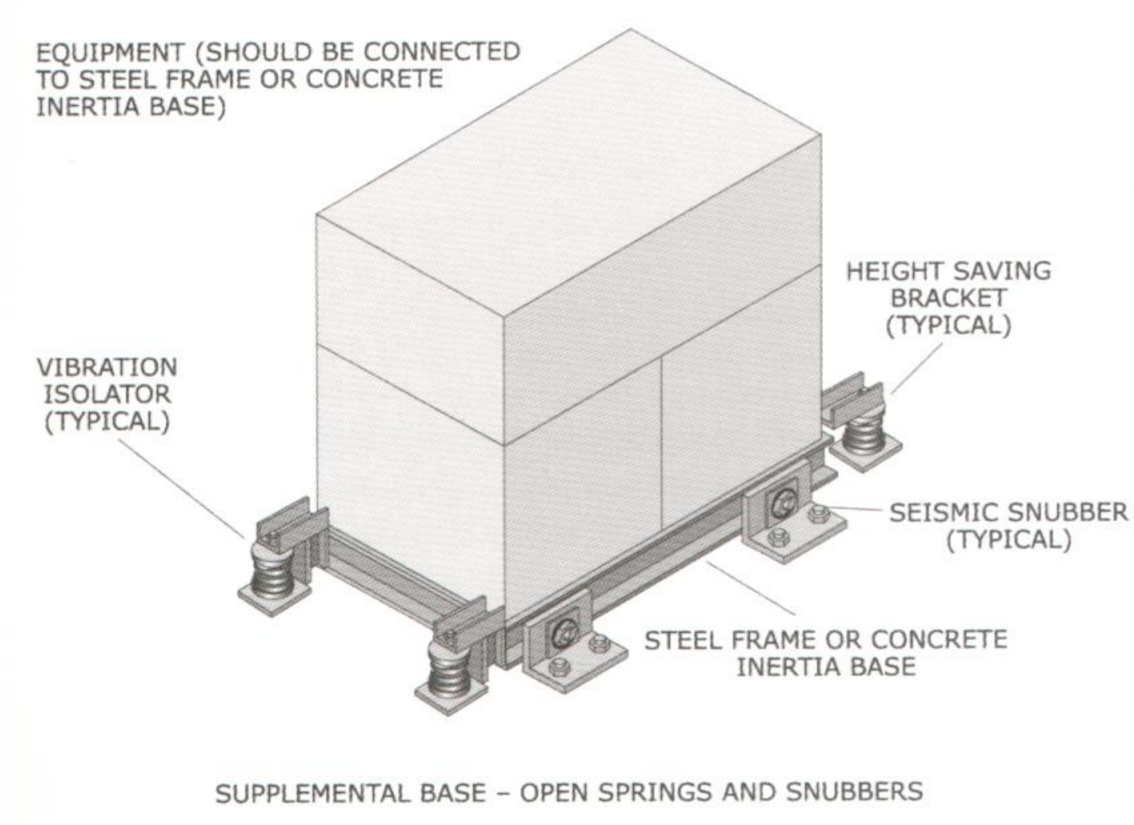
Direct attachment of equipment with custom manufactured bracket to a supporting structure *(Photo courtesy of Eduardo Fierro, BFP Engineers)*

Floor Mounted Equipment

Rigid Mounting Example

Direct attachment of equipment with the addition of snubbers to increase lateral capacity *(Photo courtesy of Eduardo Fierro, BFP Engineers)*

Floor Mounted Equipment



Resilient Mounting

Typical installation with open springs and snubbers

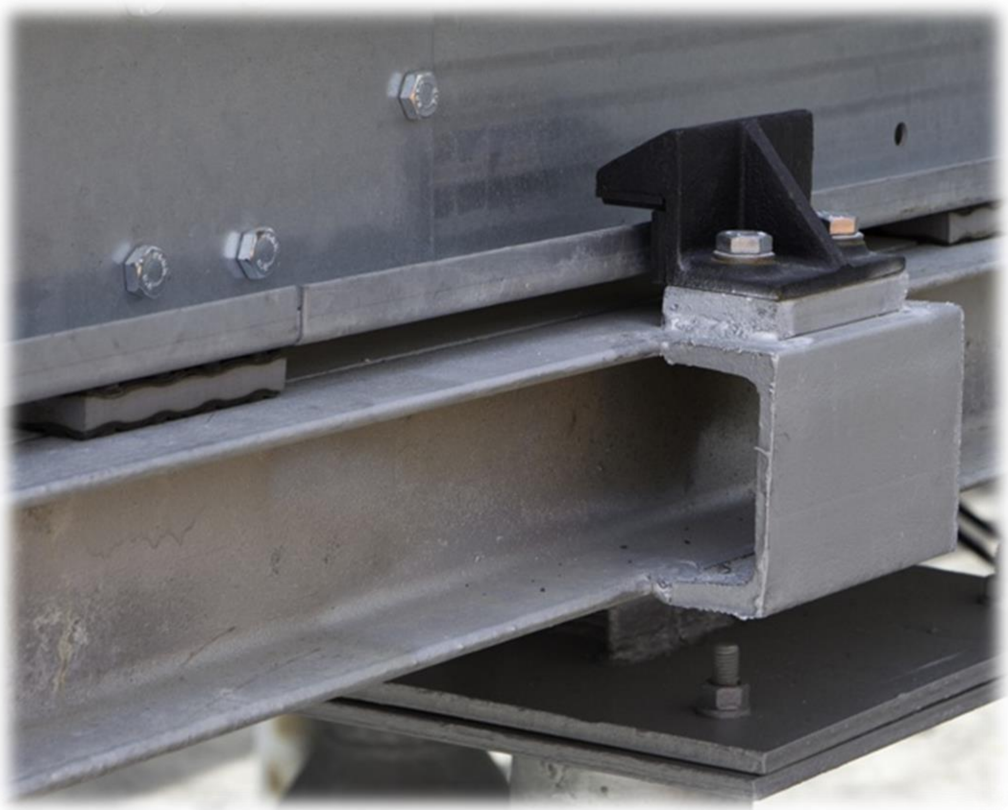
Floor Mounted Equipment

Resilient Mounting Example

Open springs and snubbers used to support equipment

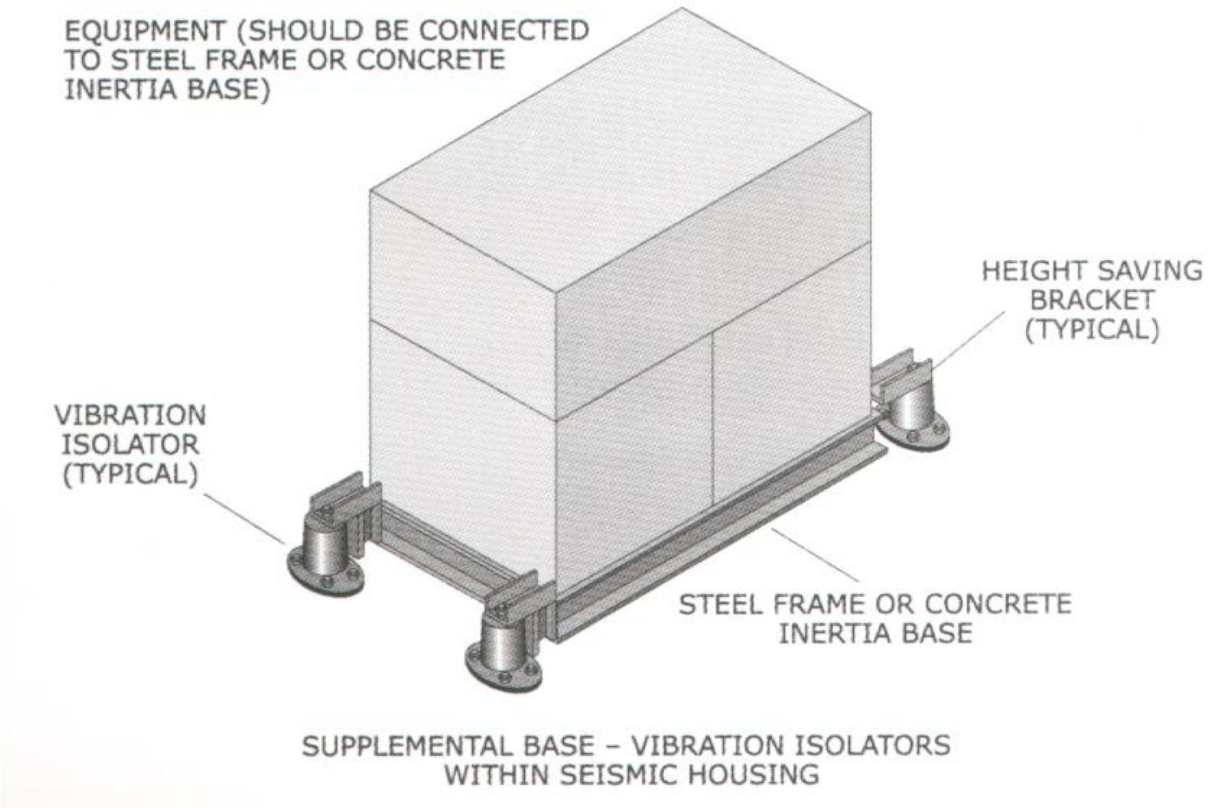
(Photo courtesy of Mason Industries)

Floor Mounted Equipment



Resilient Mounting Example
Rubber pads and snubbers used to install equipment
(Photo courtesy of Acrefine Engineering)

Floor Mounted Equipment



Resilient Mounting

(Typical installation with restrained vibration isolators)

Floor Mounted Equipment

Resilient Mounting Example

Pumps with inertia bases installed with restrained vibration isolators

(Photo courtesy of Ulus Yapi)

Floor Mounted Equipment

Resilient Mounting Example

Cooling towers with custom structural base installed on restrained vibration isolators

(Photo courtesy of Acrefine Engineering)

Floor Mounted Equipment

Resilient Mounting Example

Cooling towers with custom structural base installed on restrained vibration isolators

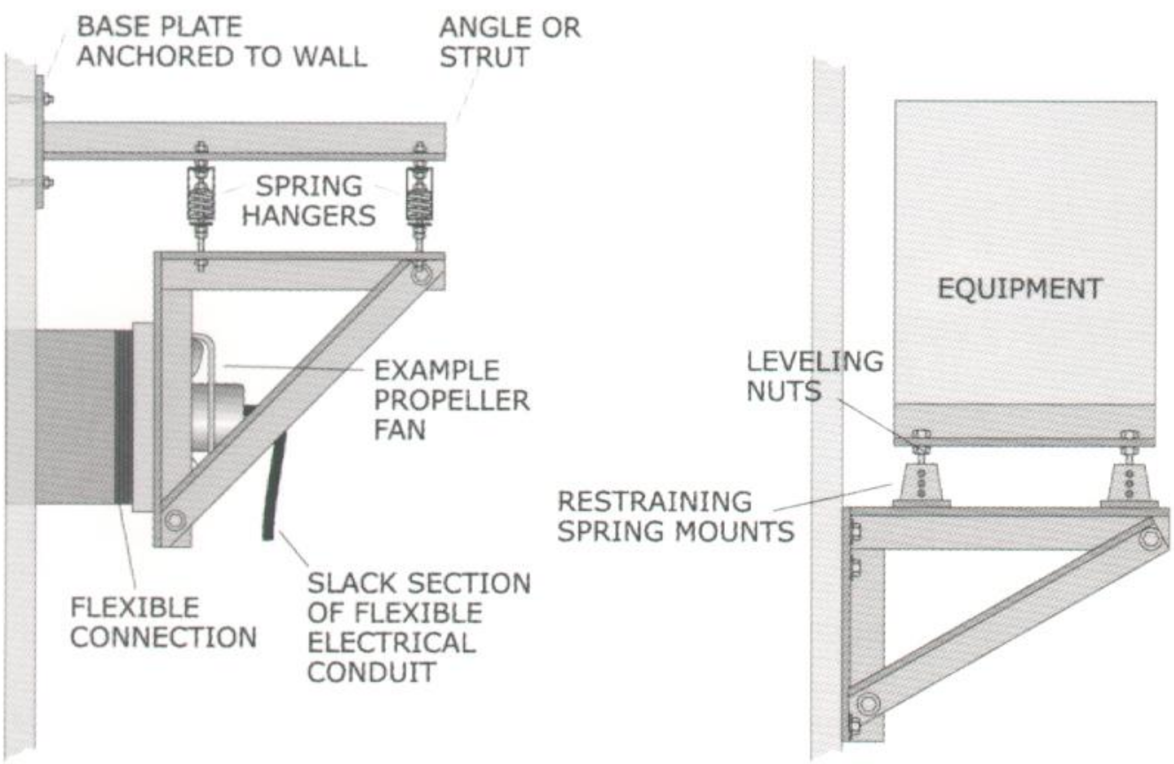
(Photo courtesy of Acrefine Engineering)

Floor Mounted Equipment

Resilient Mounting Example

Diesel generators with custom structural base installed on restrained vibration isolators *(Photo courtesy of Acrefine Engineering)*

Wall Mounted Equipment



Resilient Mounting Using Vibration Isolators

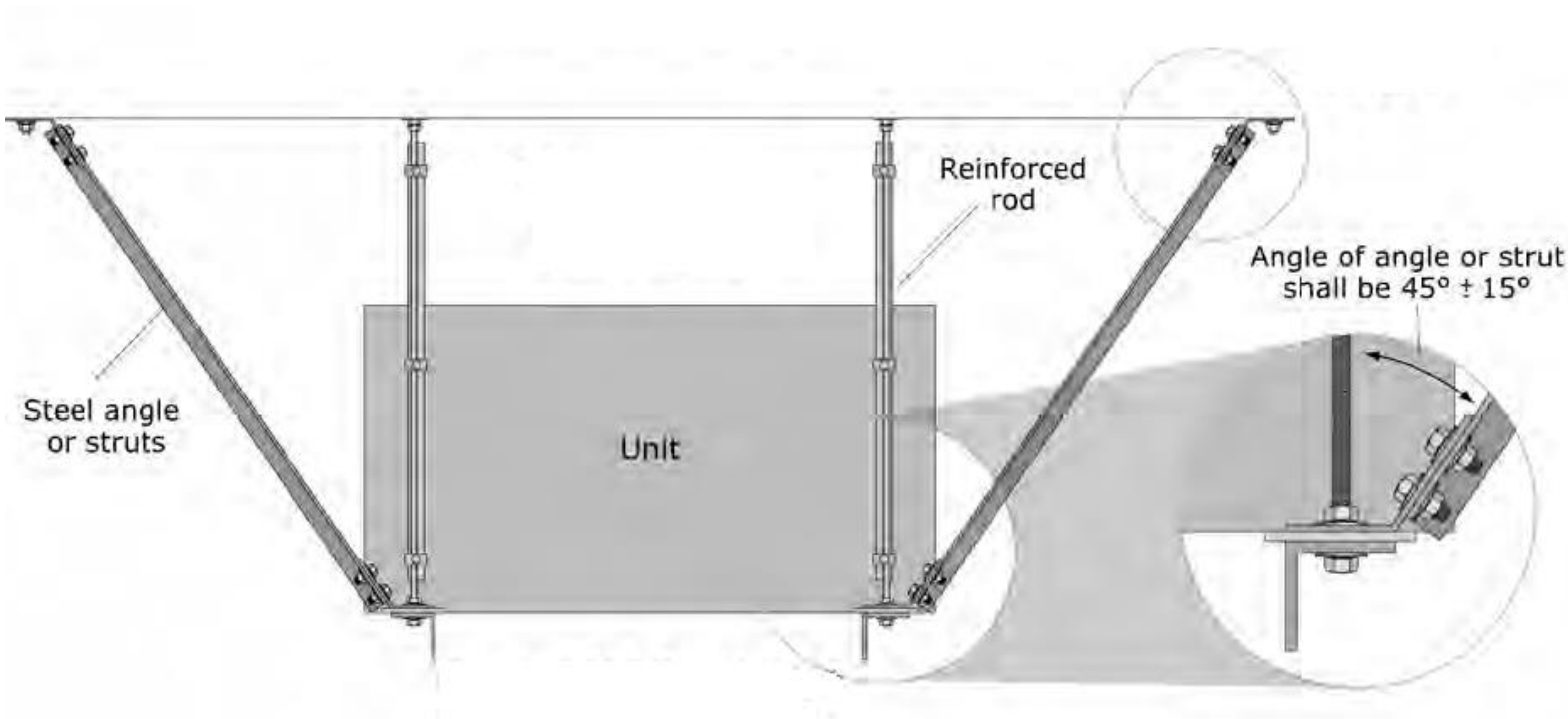
(Typical installation with isolation hangers and restrained vibration isolators)

Wall Mounted Equipment

Resilient Mounting Example

Condensing units on pads and suspended fan installed with restrained vibration isolators *(Photo courtesy of Acrefine Engineering)*

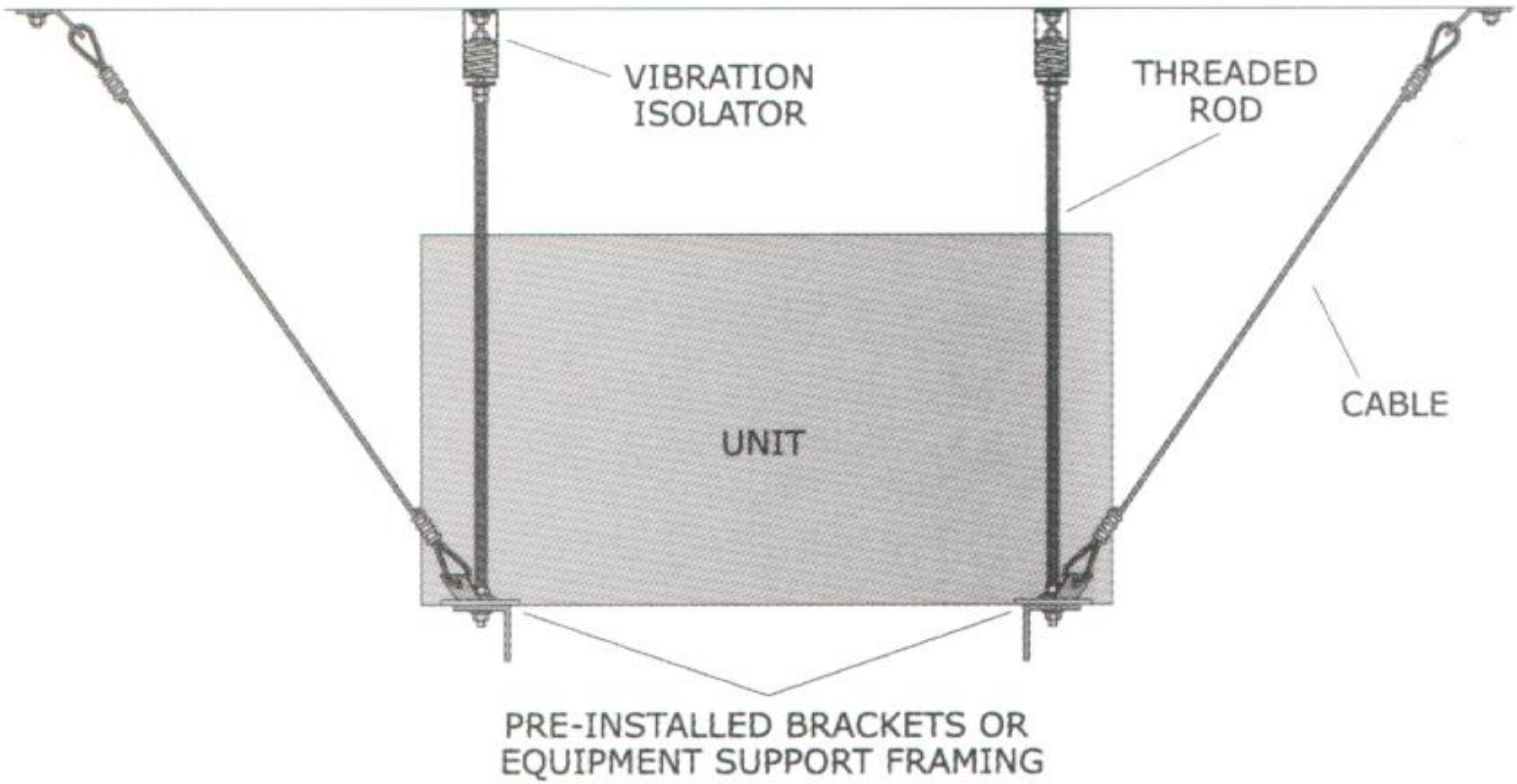
Suspended Equipment



Suspended Equipment

(Typical installation with threaded rods, rod stiffeners and rigid bracing)

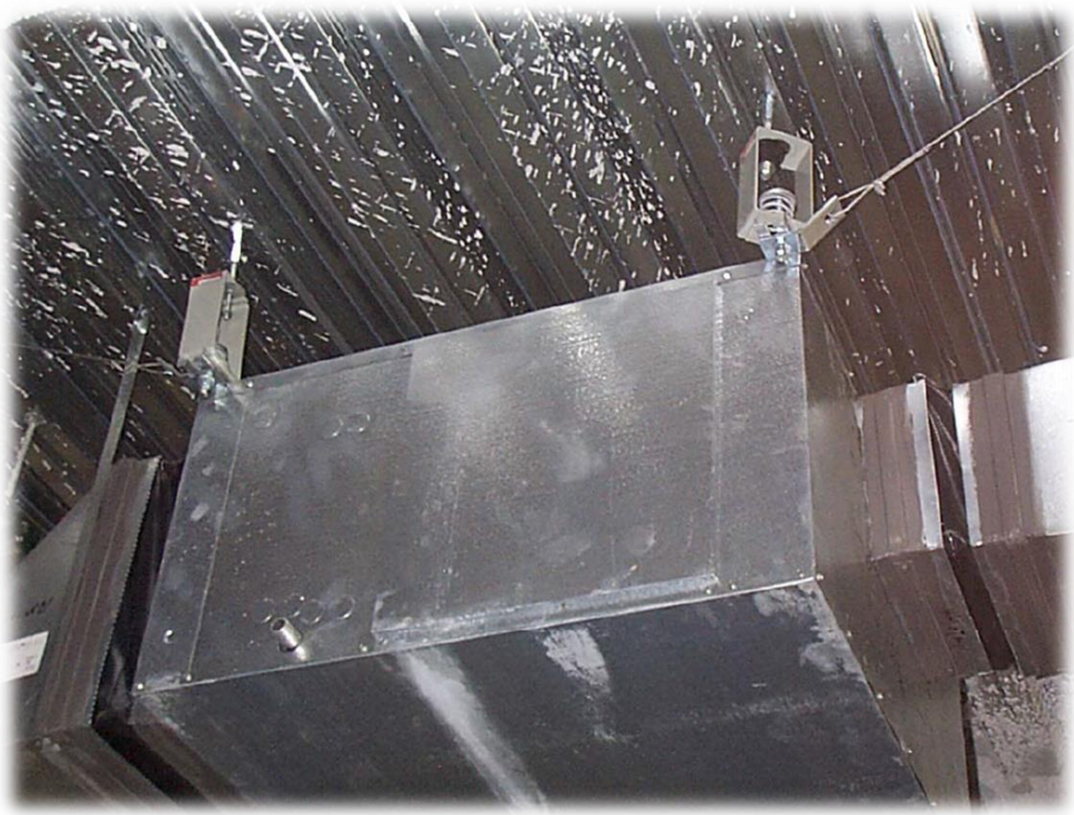
Suspended Equipment



Suspended Equipment with Isolation Hangers

(Typical installation with threaded rods, vibration isolation hangers and wire rope bracing)

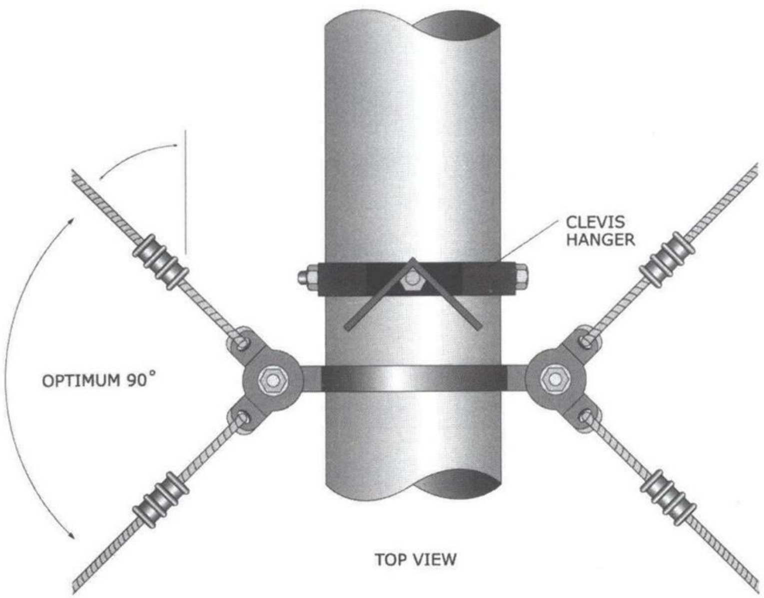
Suspended Equipment

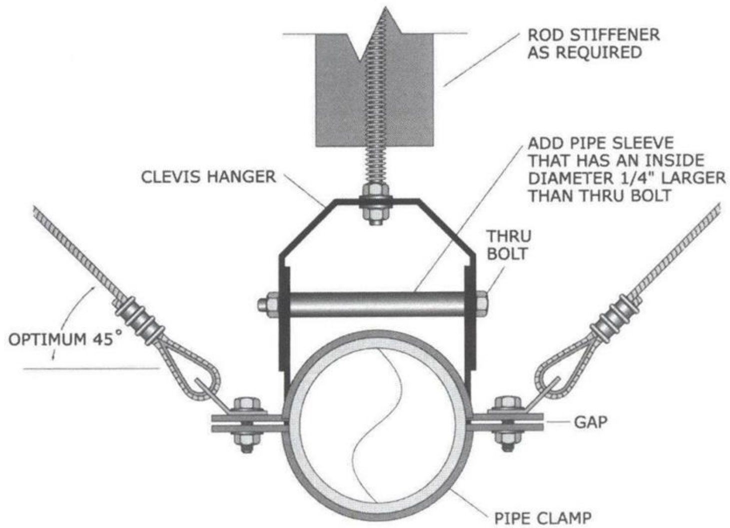


Suspended Equipment

Inline fan installation with vibration isolation hangers and wire rope bracing

Suspended Services

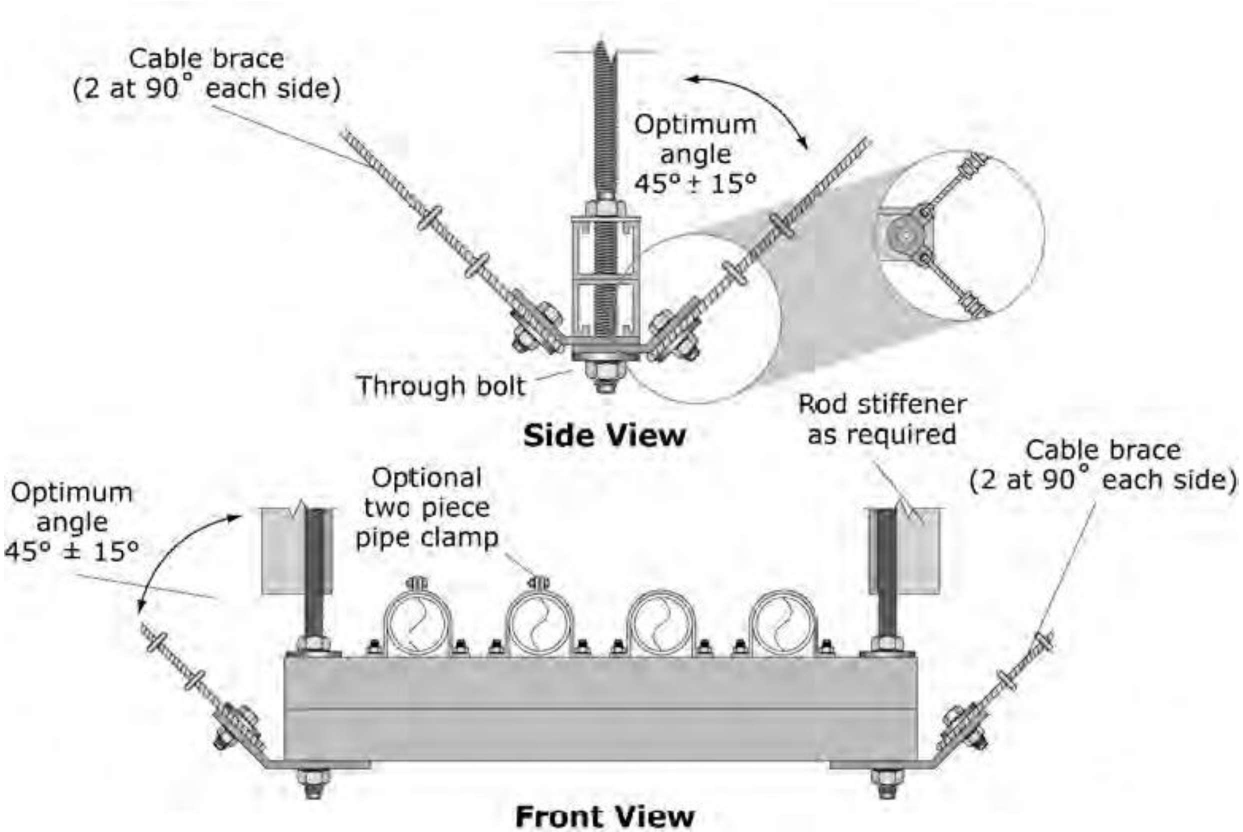




Single Line Installation

(Typical pipe installation with all directional wire rope bracing)

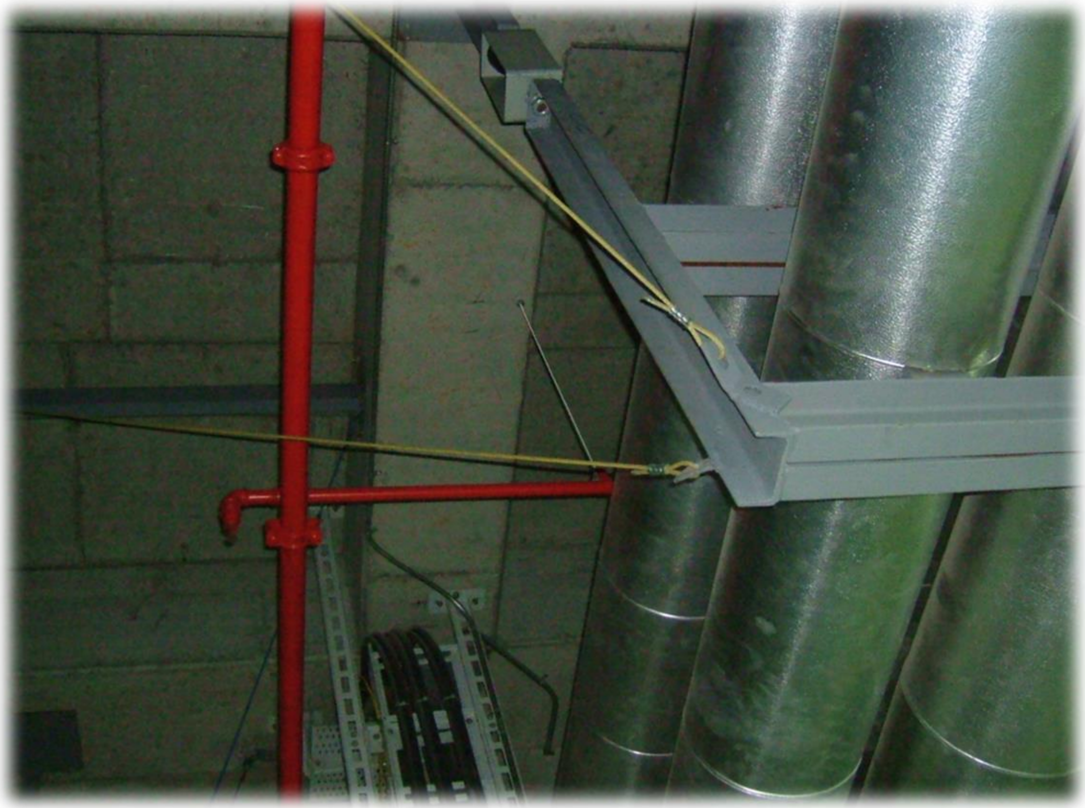
Suspended Services



Trapeze Pipe Support Installation

(Typical pipe installation with all directional wire rope bracing)

Suspended Services



Pipe Line Installation Example

Steel wire rope bracing *(Photo courtesy of Ulus Yapi)*

Suspended Services

Pipe Line Installation Example

Rigid bracing of piping *(Photo courtesy of Maryann Phipps, Estructure)*

Suspended Services

Ductwork Installation Example

Cable bracing of suspended ductwork *(Photo courtesy of Acrefine Engineering)*

Why it should be done?

- ❑ To SAVE LIVES and maximize PUBLIC SAFETY
- ❑ To minimize DOWNTIME after an earthquake
- ❑ To COMPLY with local and /or international codes and standards

  (in USA; UBC-1997, IBC-2009, NFPA-13, SMACNA, FEMA …)
- ❑ To COMPLY with job specifications.
- ❑ To PROTECT the investment.
- ❑ To LOWER the insurance premiums.
- ❑ To CREATE competitive advantage.

Haiti Earthquake 2010

Haiti Government Palace

Suffered major damage that was beyond repair

Haiti Earthquake 2010

US Embassy

Suffered minimal damage and it was operational

The End

Thank you very much

Presented by:

Martin M. Deveci

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