STRUCTURAL STABILITY in the NEW YORK CITY BUILDING CODE

presented by

Dan Eschenasy, P.E., F.SEI, SECB

Chief Structural Engineer

BUILD SAFE / LIVE SAFE CONFERENCE 2010

Credit(s) earned on completion of this course will be reported to AIA CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This course is registered with AIA CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

COPYRIGHT MATERIALS

The information in this document is only a summary and overview and is not intended to substitute for the full text and meaning of any law, rule or regulation. The City disclaims any liability for errors that may be contained in this document and shall not be responsible for any damages, consequential or actual, arising out of or in connection with the use of this document and/or the information contained herein. The City reserves the right to take action at variance with this document. This document shall not be construed to create a substantive or procedural right or benefit enforceable by any person. The information contained in this document is current only as of the publication date of this document.

COURSE DESCRIPTION

- The course reviews the definition and concepts of structural stability as they relate to issues faced by engineers during the design and construction process. Additionally, specific structural stability instructions intended to help contractors and special inspectors ensure safety at construction site are be discussed.

LEARNING OBJECTIVES

At the end of the this course, participants will be able to:

1. Participants will discuss the concept of structural stability and its various interpretations in order to understand how it is used in the NYC Building Code.

2. Participants will learn about the use of NYC Building Code sections 1604.4, 1605.1, 1704.20 , 3306 , etc. and will be able to describe how to appropriately apply inspection requirements to maintain structural stability.

3. Participants will review the different stability safety responsibilities of a contractor, designer and inspector and be able to describe these various job functions interact to mitigate risks of a construction site.

4. Participants will discuss and will be able to identify specific existing building conditions that require detailed specifications for structural stability monitoring.

IBC INTENT
101.3

The purpose of this code is to establish the minimum requirements to provide a reasonable level of safety, public health and general welfare through

- structural strength,
- means of egress facilities,
- stability,
- sanitation,
- adequate light and ventilation,
- energy conservation, and
- safety to life and property from fire and other hazards

*The two basic structural engineering concerns of any Building Code are **strength** and **stability***

WHAT IS STABILITY?

It is not necessary to be a structural engineer to have a sense of what it means for a structure to be stable. Most of us have an inherent understanding of the definition of instability…..

- Theodore V. Galambos

STABILITY
MERRIAM WEBSTER DEFINITION

a. the strength to stand or endure: firmness

b. the property of a body that causes it when disturbed from a condition of equilibrium or steady motion to develop forces or moments that restore the original condition

c. resistance to chemical change or to physical disintegration

The Building Code uses one or the other meaning without qualifying

NYC BUILDING CODE

Depending on context NYC BC may intend any of these meanings:

- Strength to stand, that is to not fall or become a mechanism.
- Capacity to recover original condition, that is to not buckle.
- Capacity to endure, to resist disintegration (somewhat related to maintaining integrity)

NYC BUILDING CODE
1604.4 ANALYSIS

Load effects on structural members and their connections shall be determined by methods of structural analysis that take into account

- *equilibrium,*
- *general stability,*
- *geometric compatibility and*
- *both short- and long-term material properties.*

NYC BUILDING CODE

1605.1.1 STABILITY

*Regardless of which load combinations are used to design for strength, where overall structure stability (such as **stability against overturning, sliding, or buoyancy**) is being verified, use of the load combinations specified in Section 1605.2 or 1605.3 shall be permitted.*

ASCE 7-2016
BASIC REQUIREMENTS

*1.3.1 Strength and Stiffness'. Buildings and other structures, and all parts thereof, shall be designed and constructed with adequate strength and stiffness to provide **structural stability**, protect ….*

*C1.3.1 Strength and Stiffness. Buildings and other structures must satisfy strength limit states in which members and components are proportioned to safely carry the design loads specified in this standard to resist **buckling**, yielding, fracture, and other unacceptable performance*

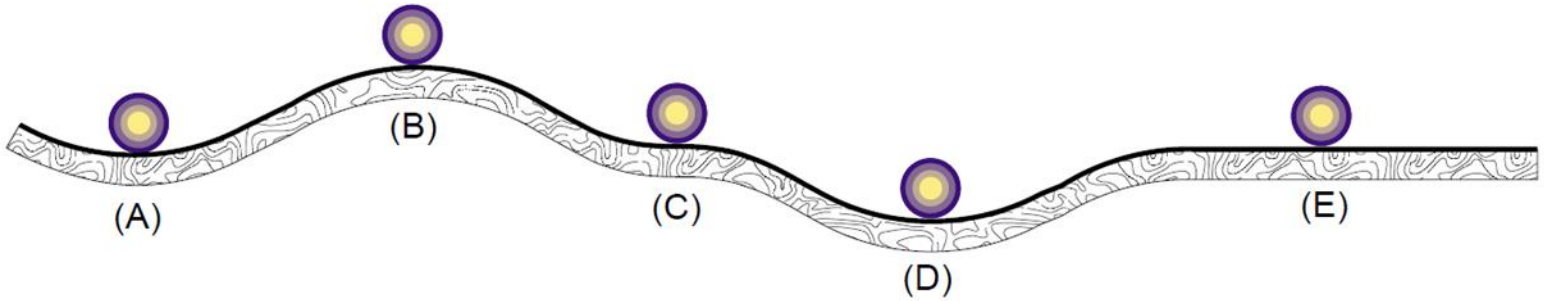
STABILITY VS. INSTABILITY

- **Stability** The ability of a system to recover an equilibrium state upon being disturbed by **any** of the allowed perturbations.

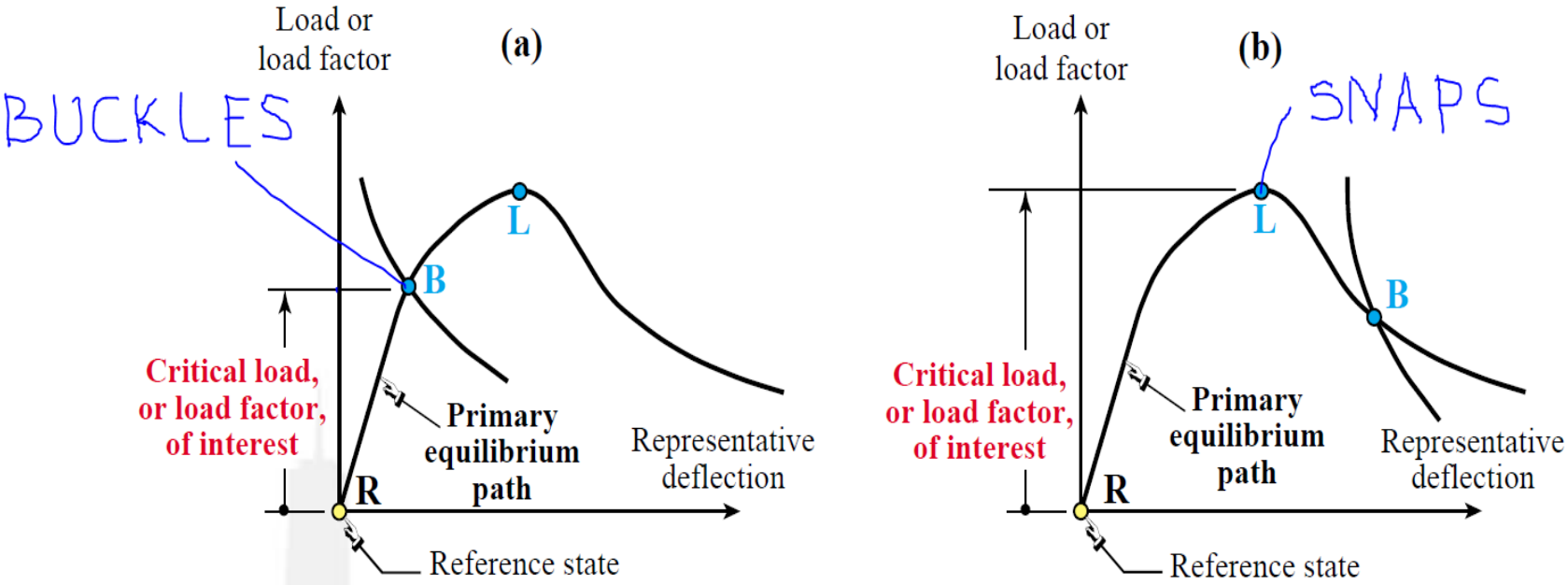
- **Instability** The inability of a system to recover an equilibrium state upon being disturbed by **at least one** allowed perturbation.

TYPES OF EQUILIBRIUM

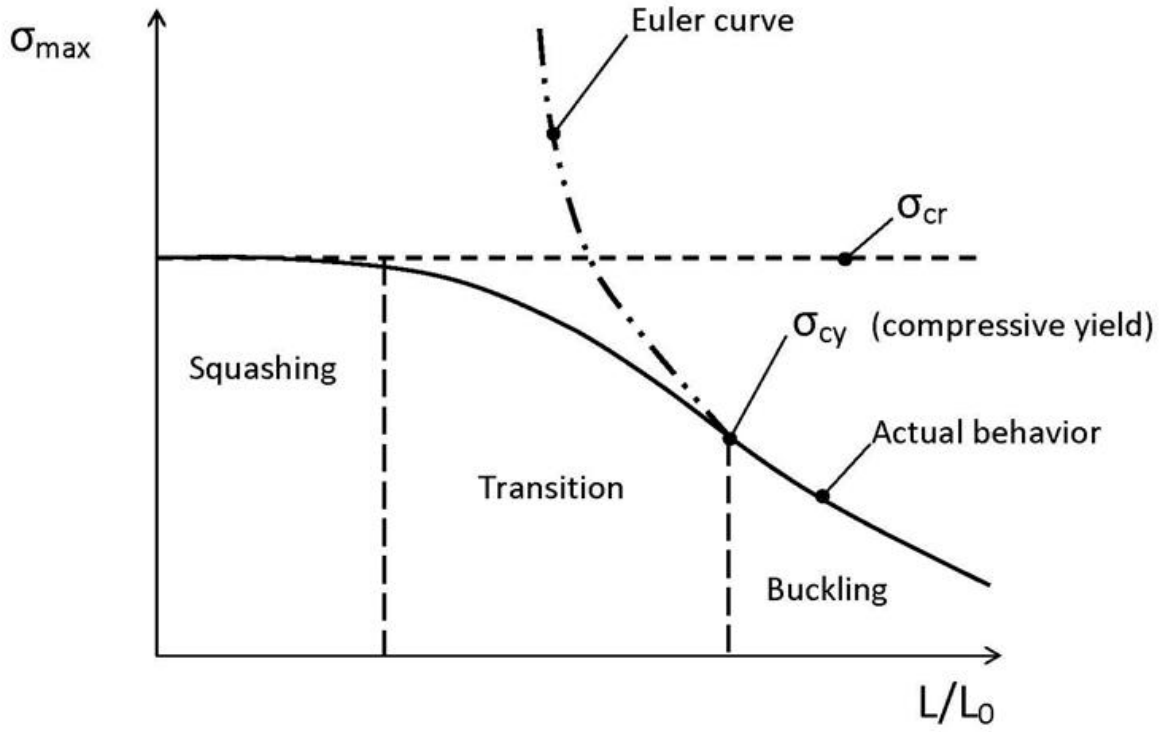
- ***Stable***
- ***Neutrally Stable***
- ***Unstable***



CRITICAL POINT ON EQUILIBRIUM PATH



BUCKLING VS. FRACTURE



MAXIMUM SPECIFIED LOADS

Under maximum specified loads a structure **must** resist collapse and deformation. Design to obtain:

- Equilibrium – all applied loads are balanced and carried to foundation.
- Sufficient Strength – stresses are acceptable
- Geometrically stable – maintain its geometry
- Adequate rigidity –

INTERNALLY STABLE

Maintains its shape if all the reactions supports were removed. A structure that is internally unstable may still be stable if it has sufficient external support reactions.

CRITICAL LOAD

- **Critical (buckling) load** – the load when the system passes from stable to unstable state
- **Instability** occurs when a small change in load causes a large change in displacement
  - **Structural instability** is generally associated with the presence of compressive axial force or axial strain in a plate element that is part of a cross-section of a beam or a column.
  - **Local instability** occurs in a single portion of a member, such as local web buckling of a steel beam.
  - **Member instability** occurs when an isolated member becomes unstable, such as the buckling. Member instability may lead to system instability.
  - **System instabilities** are often catastrophic.

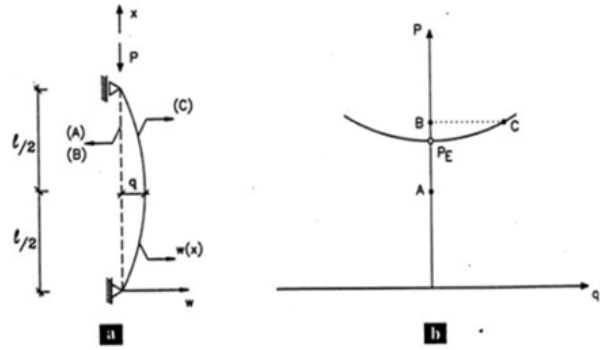
CRITICAL LOAD
HISTORY

Euler (1750s) developed the concept of critical load of an elastic column in the solution of the second degree differential equations.

Structural Stability

- Stability and Instability
  - Ex: Euler column
    - EI – Structural modulus

$$P_E = \frac{\pi^2 EI}{l^2} \qquad w(x) = q \cdot \sin\left(\frac{\pi x}{l}\right)$$



MAGNIFICATION FACTOR

Young (1807), realized importance of imperfections such as initial curvature, initial bending moments or load eccentricity

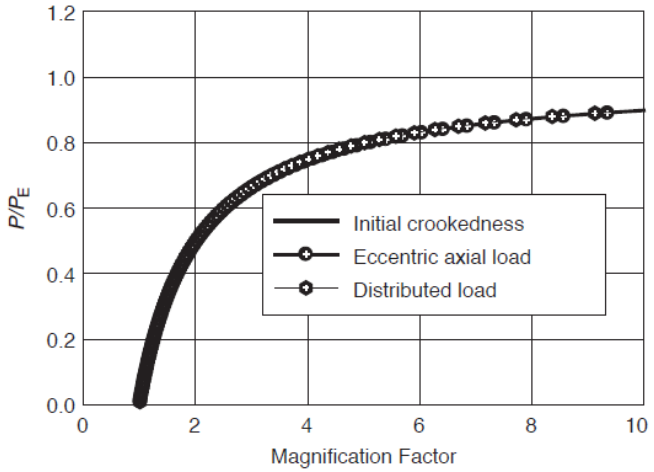


Fig. 2.11 Comparison of magnification factors.

plotted in Figure 2.11 against P/P_E. Also plotted is the magnification factor for the case of initial curvature (equations 2.24):

$$MF = \frac{1}{1 - P/P_E} \tag{2.34}$$

IMPERFECTIONS

Material Properties

- Inhomogeneous
- Residual stresses
- Plasticity

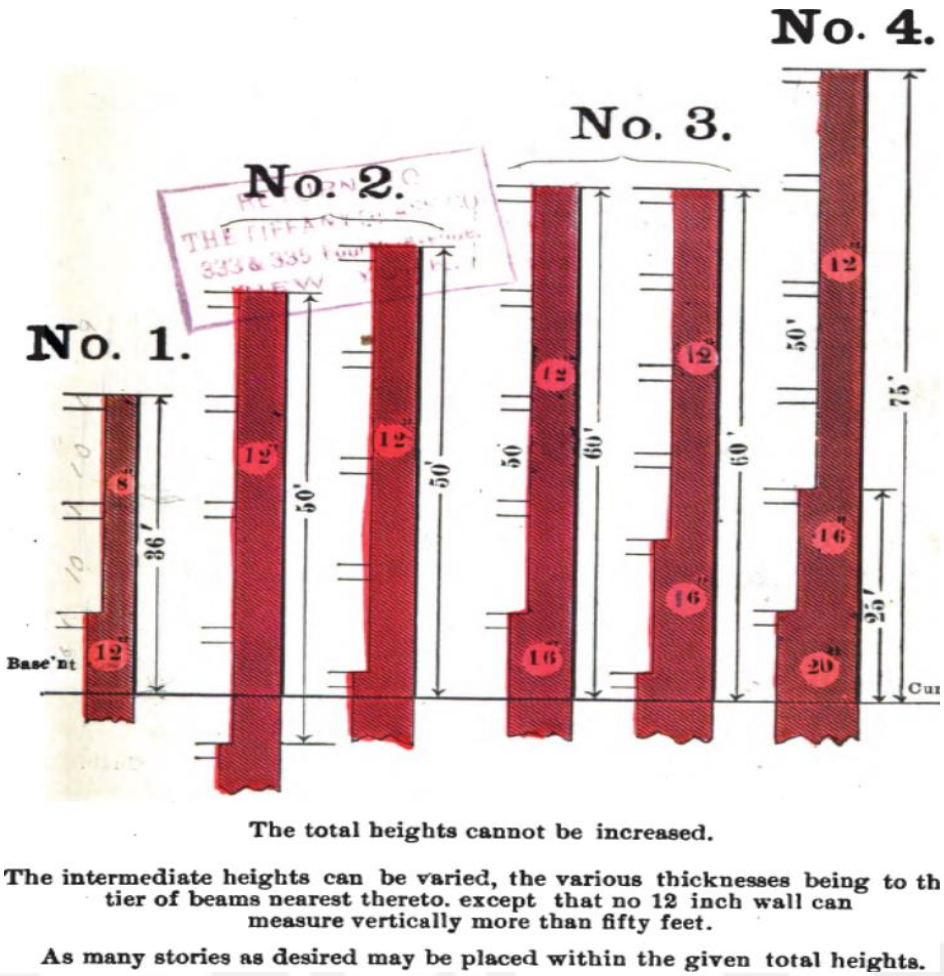
Disturbances

- Shape
- Load
- Boundary conditions (slippage, blocks)

WALL THICKNESS
1887 VS 2014

MSJC Slenderness Ratios

Type	Max l/t or h/t
Bearing Wall	20
Solid or Grouted	18
Exterior Non Bearing	18
Interior Non Bearing	36



The total heights cannot be increased.

The intermediate heights can be varied, the various thicknesses being to th tier of beams nearest thereto. except that no 12 inch wall can measure vertically more than fifty feet.

As many stories as desired may be placed within the given total heights.

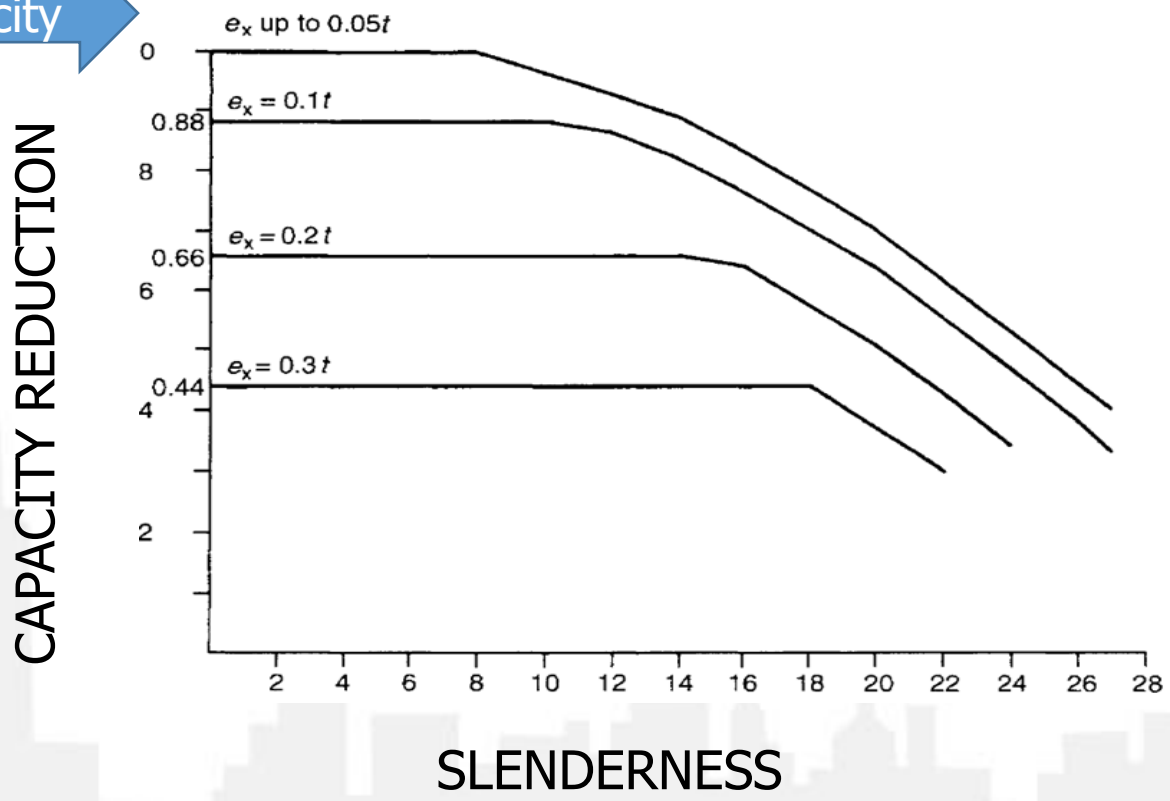
Masonry wall thickness was codified based on empirical data, not on Euler formula.

MASONRY
LOSING ITS BRACING

Bad demolition or decay lead to **unbraced masonry**

MASONRY
CAPACITY REDUCTION

Load eccentricity



MASONRY
2104.6 CONSTRUCTION BRACING

*In accordance with **TMS 602/ACI 530.1/ASCE 6 Section 3.3E**, the contractor shall design, provide, and install bracing that will assure **stability** of all masonry during construction. The contractor shall keep a bracing plan on site during all masonry construction. Bracing plans shall consider wind loads, initial and intermediate masonry strengths, and the contractor's ability to evacuate the site.*

COLLAPSE DUE TO WALL SLENDERNESS
BROOKLYN: MYRTLE AVENUE

STRUCTURAL STABILITY
PARTY WALLS

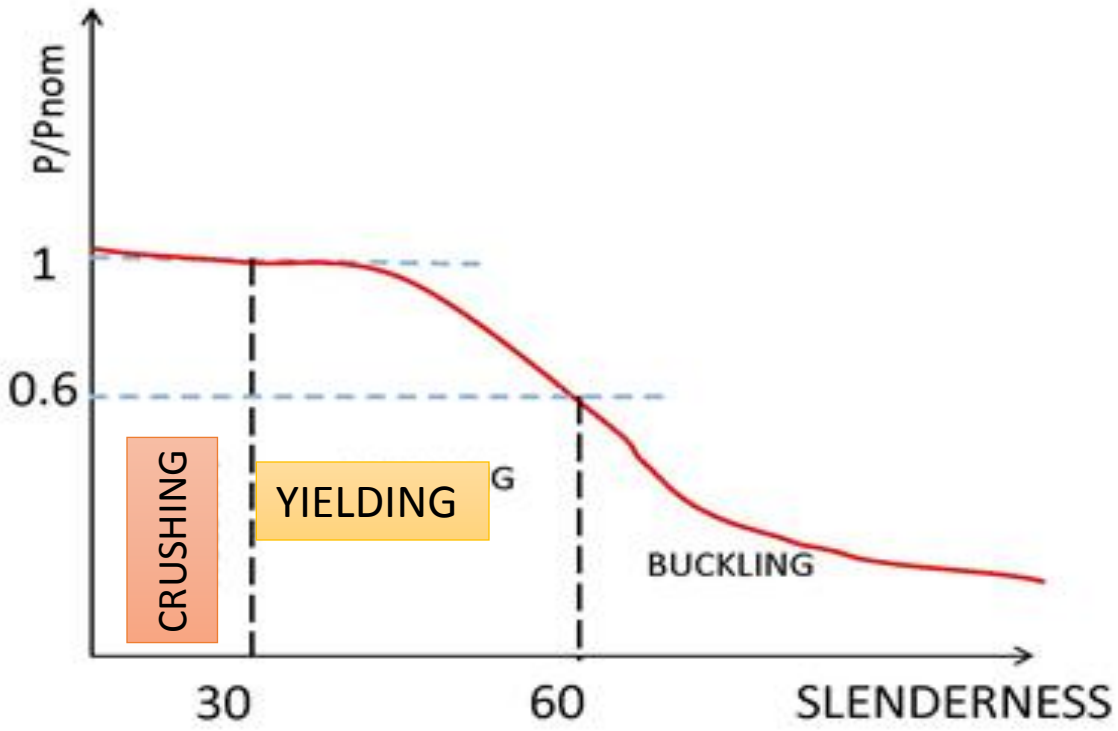
Stability and condition of remaining party walls shall be monitored and protected by the Owner of the demolished building.

ACI 318

Structural integrity *– ability of a structure through strength, redundancy, ductility, and detailing of reinforcement to redistribute stresses and maintain overall* ***stability*** *when localized damage or significant overstress occurs.*

The role of analysis is to estimate the internal forces and deformations of the structural system and to establish compliance with the strength, serviceability, and ***stability*** *requirements of the Code*.

CONCRETE COMPRESSION FAILURE



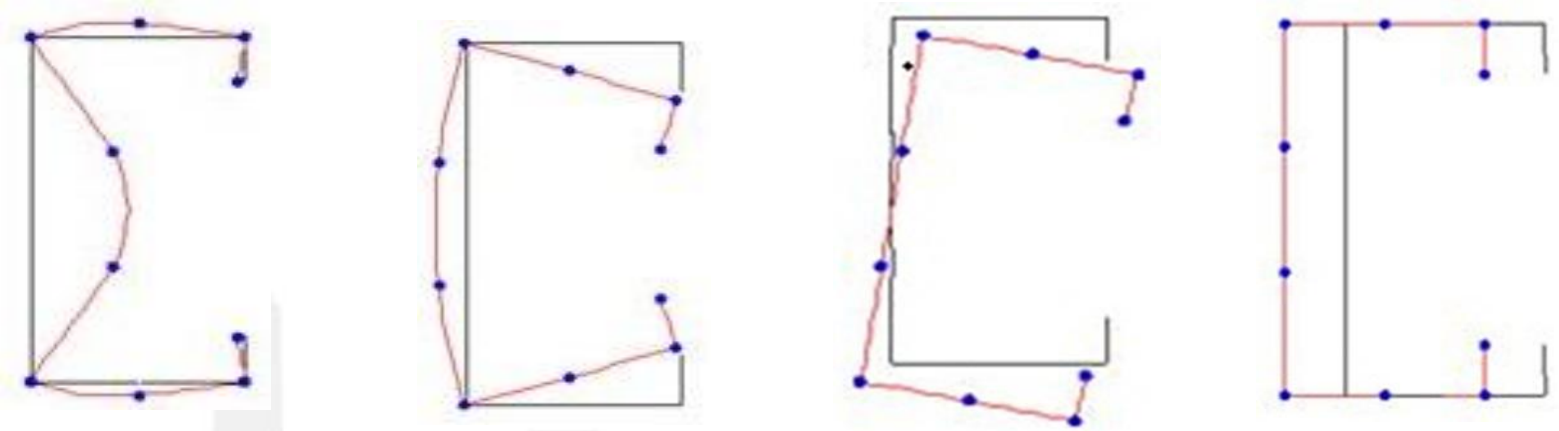
AISC 360-10

The increased use of engineered structural elements led to increased design concerns related to structural stability:

- Steel
- Aluminum

REQUIREMENT
STIFFENERS AND BRIDGING

- Local Buckling slender shape
- Torsion of web/flange juncture
- Torsion of cross section



The development of efficient members strength-wise increased stability problems

STRUCTURAL STABILITY
NB UNDER CONSTRUCTION

Overloaded Metal Deck

STRUCTURAL STABILITY & CONSTRUCTION

A. Building actually modified during the construction process

B. Building adjoining to construction

C. Damaged buildings/structures supported by temporary structural installations

CONSTRUCTION OPERATIONS
1704.20.1.1 INFLUENCING ADJACENT STRUCTURES

- *Where construction operations have the potential to affect structurally the condition or occupancy of the subject structure and/or an adjacent structure*

Together with

- **1704.20.1 Structural stability of existing buildings.** **...***where the stability or **integrity** of a structural system is to be temporarily diminished*

  (Maintaining INTEGRITY – preserving unaltered state)

STRUCTURAL STABILITY
BC 1704.20

- Requires Special Inspection for the following construction operations:
  - Existing Structures (BC 1704.20.1)
    - Construction operations influencing adjacent structures
  - Excavations (BC 1704.20.2)
    - Slurry (BC 1704.20.2.1)
  - Underpinning (BC 1704.20.3)
  - Demolition (BC 1704.20.4)
  - Raising and Moving of a Building (BC 1704.20.5)

STRUCTURAL STABILITY
MODIFICATIONS DURING CONSTRUCTION PROCESS

A. Demolition (1704.20.4)

B. Partial demolition (1704.20.1)

C. Lifting buildings/ building elements (1704.20.5)

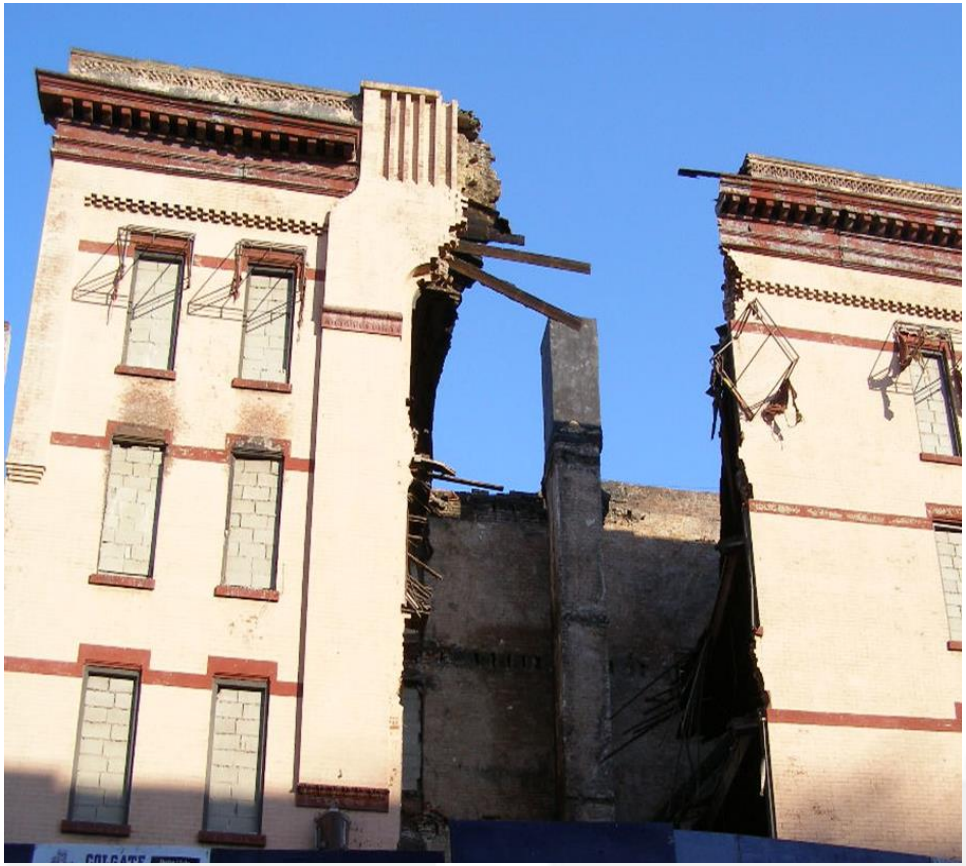
D. Underpinning (1704.20.3)

*****An ***intentional*** *modification of a structural system needs to be engineered.*

STRUCTURAL STABILITY

- Modifying or applying forces to a an existing structure shall be accomplished in conditions where the structure can recover its initial stable condition.
- The deformation or movement of the structure shall be limited to values close to original position of equilibrium.
- At all moments during construction a safe load path shall exist – temporary or permanent.

STRUCTURAL STABILITY
REMOVAL OF LATERAL SUPPORTS



DEMOLITION
BC 1704.20.4

Site-specific plans required prepared by licensed professional

Plans must indicate:

- Details of the building demolished clearly showing the extent and sequence of demolition
- Details of Bracing and shoring
- Listing and description of all mechanical equipment (other than handheld)
  - Scope of equipment work and positioning of equipment
  - Calculations showing the adequacy of the existing structure to support loads
- Description of protective methods
- Limiting allowances for deviation from horizontal or plumb lines

RAISING & MOVING A BUILDING

RAISING AND MOVING A BUILDING
BC 1704.20.5

Plans shall include:

- Written sequence of operations, a list of all items that need to be monitored during the operation, and an analysis investigating the possible need to protect adjoining construction.
- The capacity of the soil to temporarily support any installation used in the raising or moving operation.
- The maximum weight of the building to be raised or moved.
- The lateral loads that need to be resisted during the raising or moving operation per BC Chapter 16, or due to the maximum design permitted misalignment of the designed supporting system.

RAISING & MOVING A BUILDING
BC 1704.20.5

Plans shall include: *(continued)*

- Limiting allowances for deviation from horizontal or plumb lines.
- The type of machinery and installation to be used during the raising, lifting, elevating or moving operation and the rate/speed
- The construction or other work necessary to maintain the safety and integrity of the building when such building is in a weakened condition or becomes weakened in the process

Bulletin 2015-010

UNDERPINNING

Special Inspections

Special Inspection for **Underpinning** is required
Monitoring plan must be included (BC 1704.20.7.1)
New permanent installations installed with the underpinning require their own special inspection (e.g. **Steel**, **concrete**, etc.)

UNDERPINNING

Applicable Sections

- BC 1704.20.3 (Structural Stability - Underpinning)
- BC 1802 (Geotechnical Investigations & Material Classifications)
- BC 1814 (Underpinning And Support of Adjacent Property)
- BC 3309.4 (Soil or Foundation Work Affecting Adjoining Property)
- BC 3309.5 (Underpinning)
- BC 3309.8 (Adjoining Walls)

CONSTRUCTION OPERATIONS
IMPAIRING ADJOINING BUILDINGS

- **Vibrations** - driving of piles or of sheeting , blasting, soil compactors, anchor or caisson drilling, etc.)
- **Changes in soil condition or capacity** - dewatering, excavation removing overburden, soil loss at caisson drilling, soil movement when sheeting, soil grouting, etc.)
- **Loss of lateral support** - demolition of party wall or demolition that initiates/allows lean of adjoining building

UNKNOWN LOADS

- In these cases the exact load or displacement potentially imposed on the existing building is not known nor can one calculate with precision the existing building response.
- One can set specific controls on the construction actions and establish parameters that guarantee movement of building elements will not constitute an impairment.
- Special Inspection is not dictated in all cases but it should be required when it becomes apparent that construction activities had affected….

EXCAVATIONS

Special Inspections

- Where sheeting, shoring, or bracing or other methods to protect sides of excavations (including slurry) are utilized, special inspection is required (BC 3304.4)
- Identify special inspections for:
  - **Excavations - Sheeting, Shoring, and Bracing** and
  - Other Special Inspections based on materials and methods used, including but not limited to:
    - Structural Steel – Welding
    - Deep Foundation Elements (would include rock anchors)
    - Concrete – Cast-In-Place

DAMAGED BUILDINGS
SUPPORTED BY TEMPORARY INSTALLATIONS

- Buildings that for one reason or another have lost their integrity and have reached a state of potential danger to the public - *where the stability or integrity of a structural system is to be temporarily diminished.*
- Stability refers to **avoidance of total or partial collapse**.
- Because support is of a temporary nature and the condition of the building might be degrading, repeated inspection is necessary.

STRUCTURAL STABILITY
SHIMS MAY MOVE

STRUCTURAL STABILITY

Structural Stability Control Inspection needs to be based on clear instructions. The instructions shall be based on:

- Evaluation of the present condition of the structure.
- Engineered evaluation of the response of this structure to the proposed work.
- The instructions need specify the controls that need to be observed to insure that the structure maintains its integrity.

Structural Stability Control Inspection *is not just about avoiding collapse, but also about maintaining the integrity and stable equilibrium of the existing structure*.

REQUIRED ENGINEERING STEPS

- Condition Assessment. Identify capacity and weak points of the structure
- Control/understand the forces developed during the procedure
- Understand the stresses existing in the structure and the additional effect of construction imposed forces and displacement
- Mitigate/Shore to reduce stresses
- Monitoring of building movement
- Develop action plan

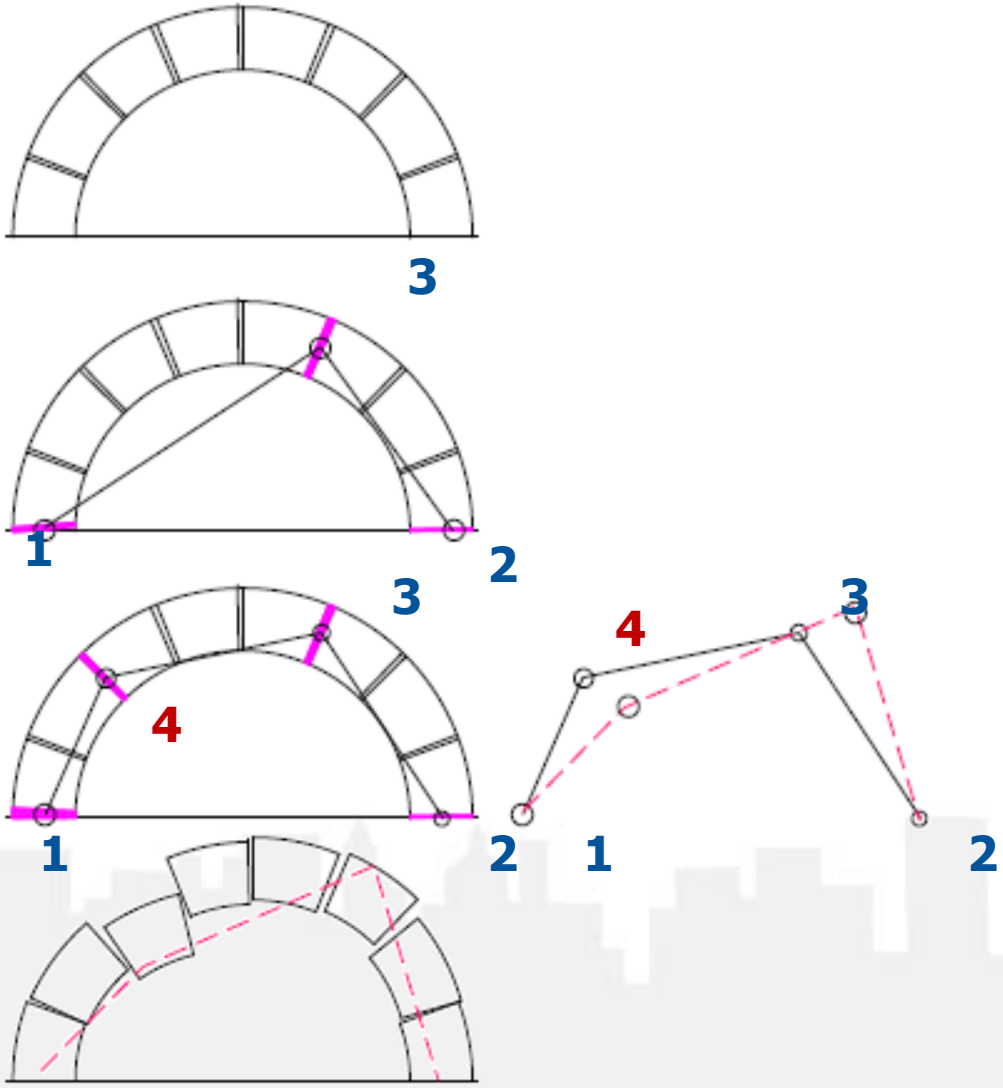
STRUCTURAL STABILITY
EXISTING CRACKS

Is there still an existing load path?

STABLE CRACKS & WEAKENED STRUCTURES

3 Cracks (joints) - system is stable

Development of one additional crack (joint) leads to an unstable system



CONDITION ASSESSMENT

CONDITION ASSESSMENT

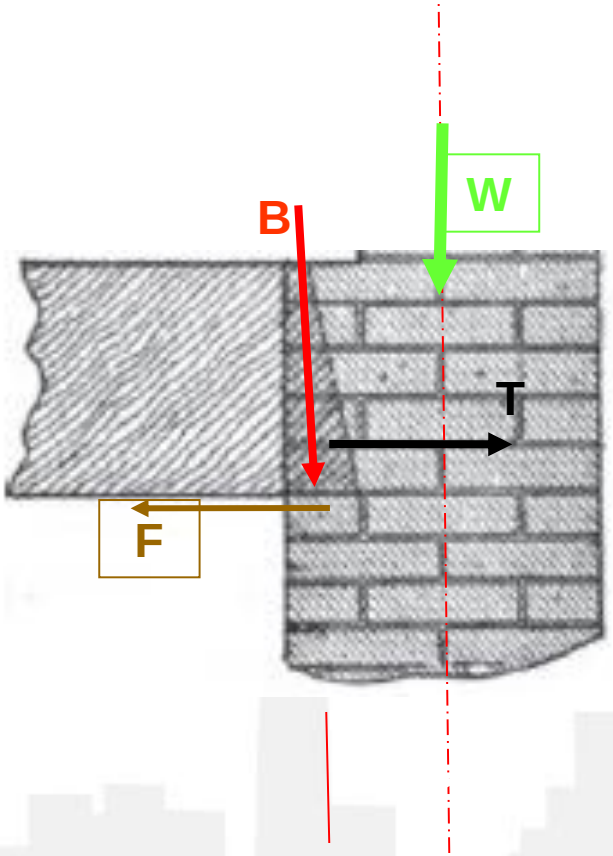
- Based on physical observations, probes and calculations determines how far the structure is from instability point.
- Based on such analysis parameters are established that assure the equilibrium condition is maintained stable.
- We observe the building to insure that it is still in a condition of stable equilibrium.

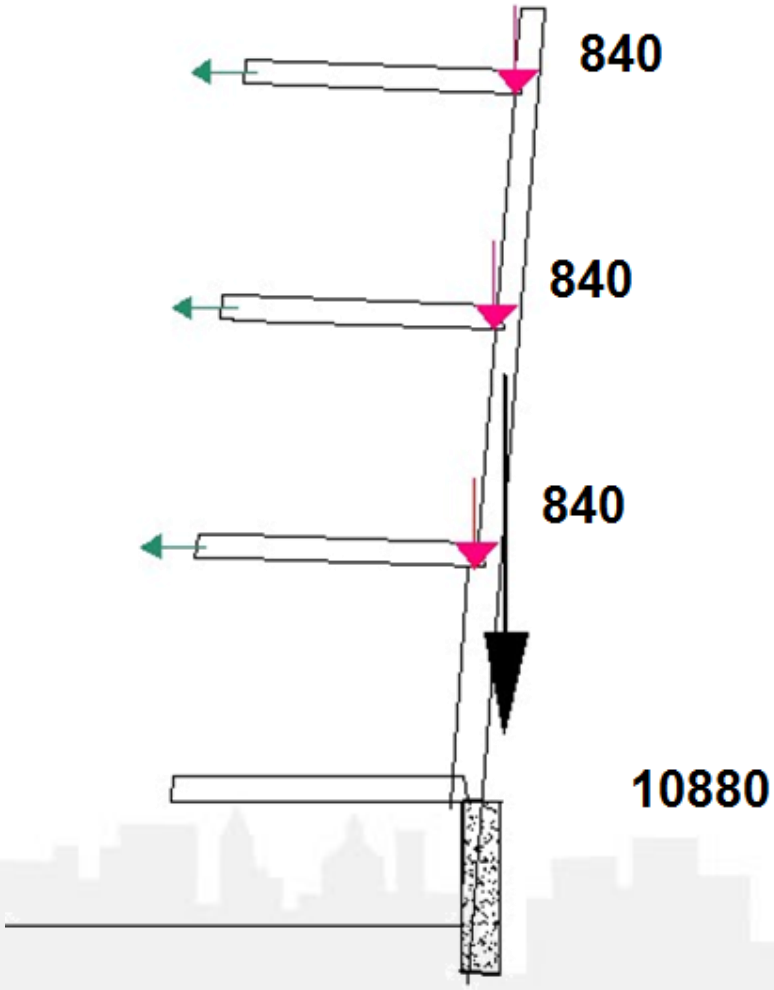
CONDITION ASSESSMENT

Observe

- Building lean
- Wall cracks
- Wood deterioration
- Evidence of foundation settlement
- Eroded mortar joints

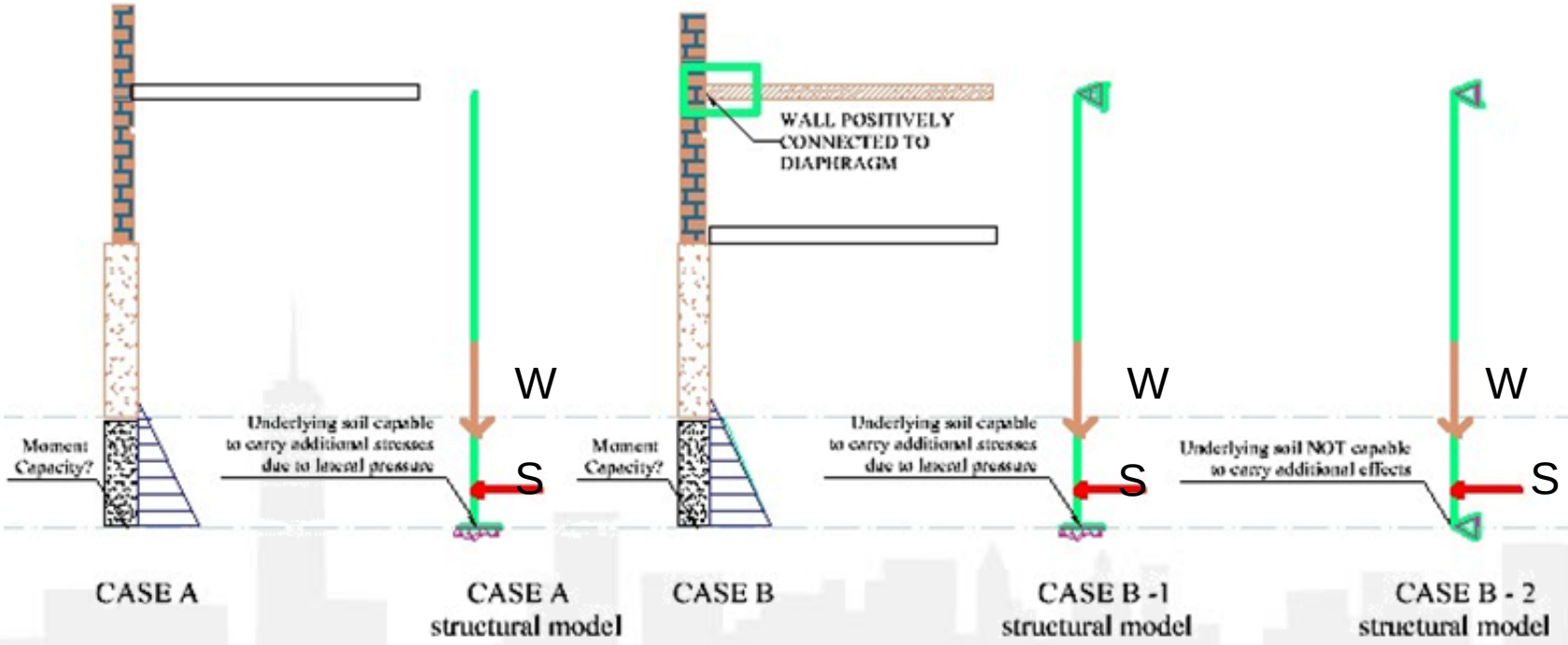
LEANING BUILDING



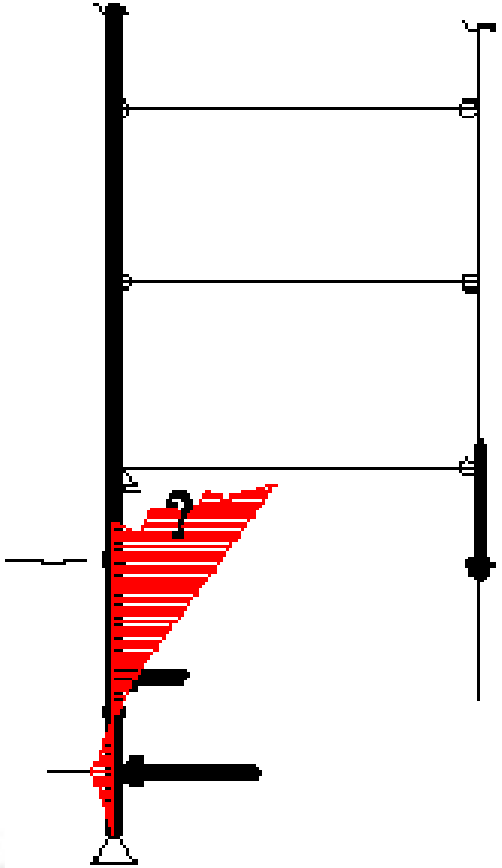


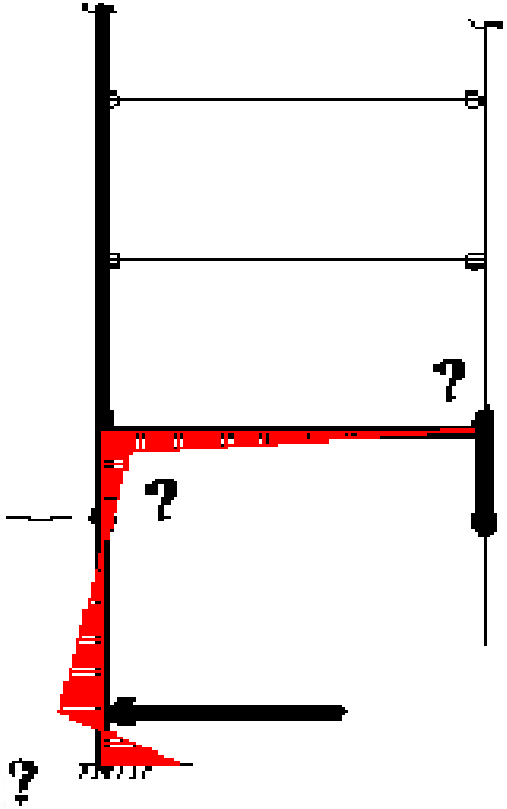
MODEL THE STRUCTURE

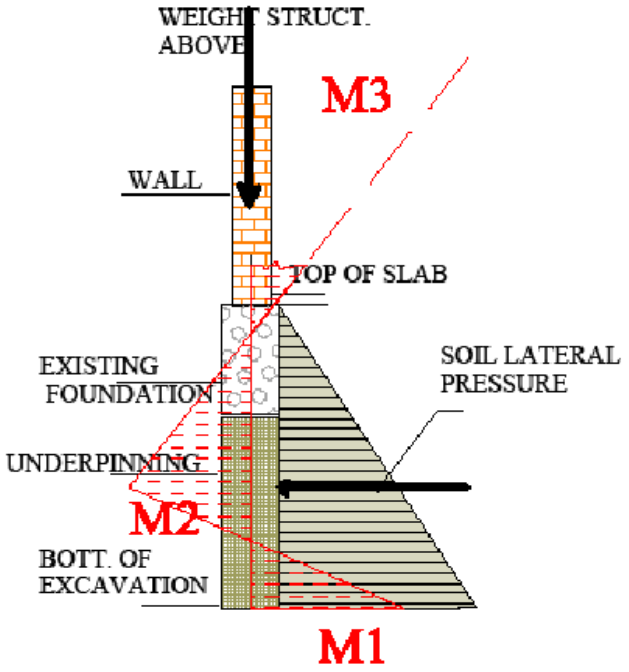
In all cases the soil shall be able to safely carry the applied vertical load



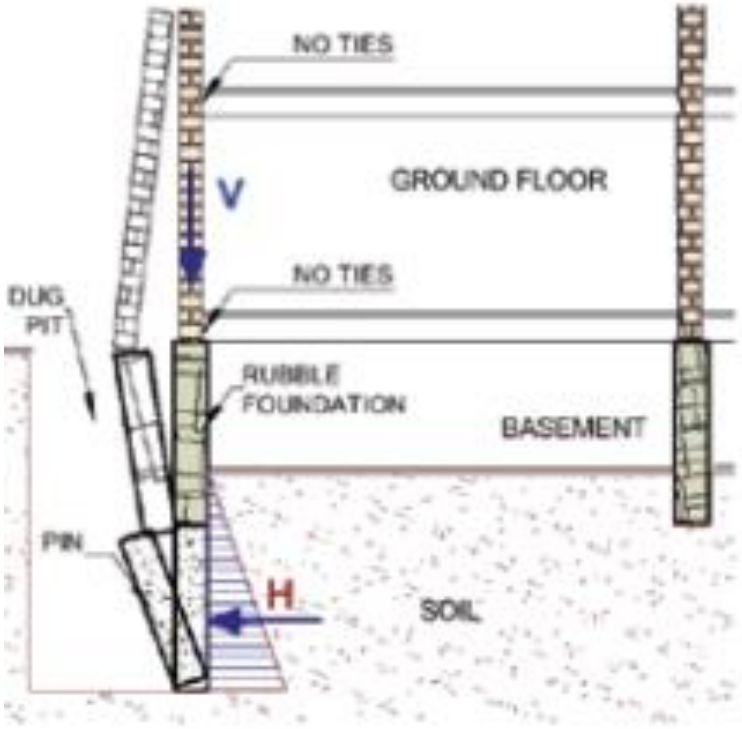
VARIOUS POSSIBLE STATIC SCHEMES



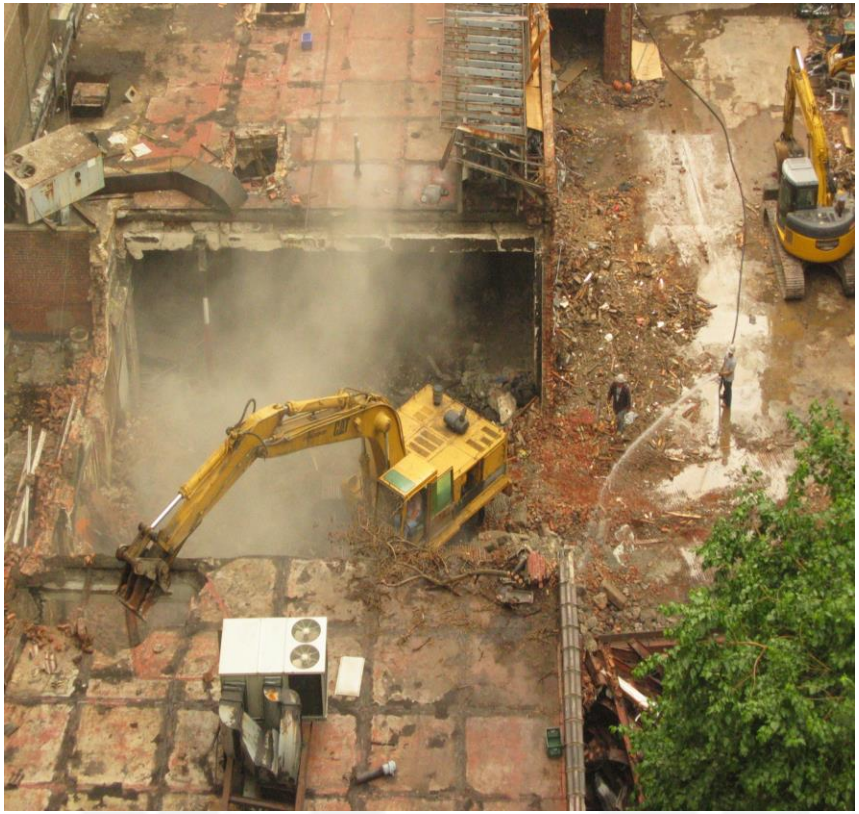


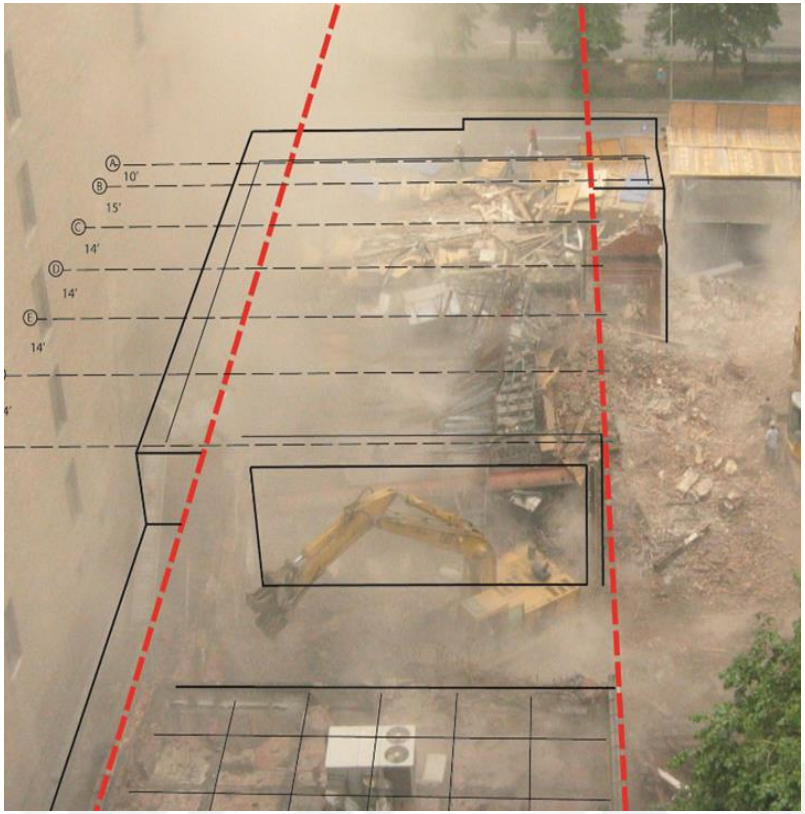


ESTABLISH LIMITS FOR STABILITY



LOADS IMPOSED DURING DEMO





DEMOLITION
SHORE AS YOU GO

REPAIR
BEFORE CONSTRUCTION STARTS

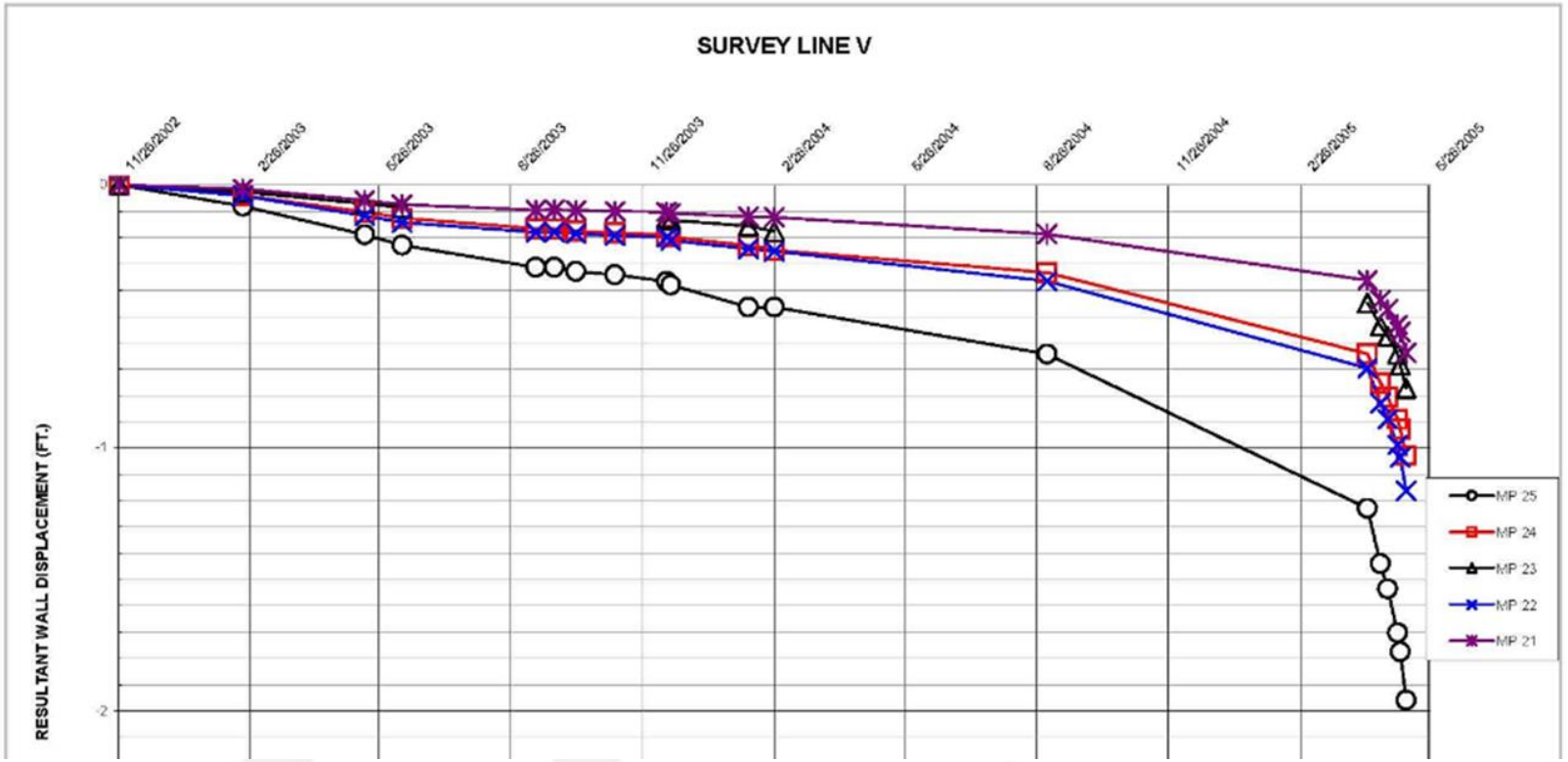
MONITORING REQUIRED

- Monitoring (BC 1704.20.7.1) - Structural stability design documents include monitoring requirements where applicable
  - Building specific
  - Operation specific
  - Specify monitoring frequency, tolerances, and reporting criteria
  - TPPN 10/88 may not be sufficient for your specific case

WHEN TO START?

- Monitoring should start from an **established baseline**
- Intraday and seasonal weather-related changes should be factored into the plan

DISPLACEMENT VS. TIME



MONITORING RESPONSE
CONSTRUCTION OPERATIONS CONTROL

EXCEEDS LIMITS

Monitor Response

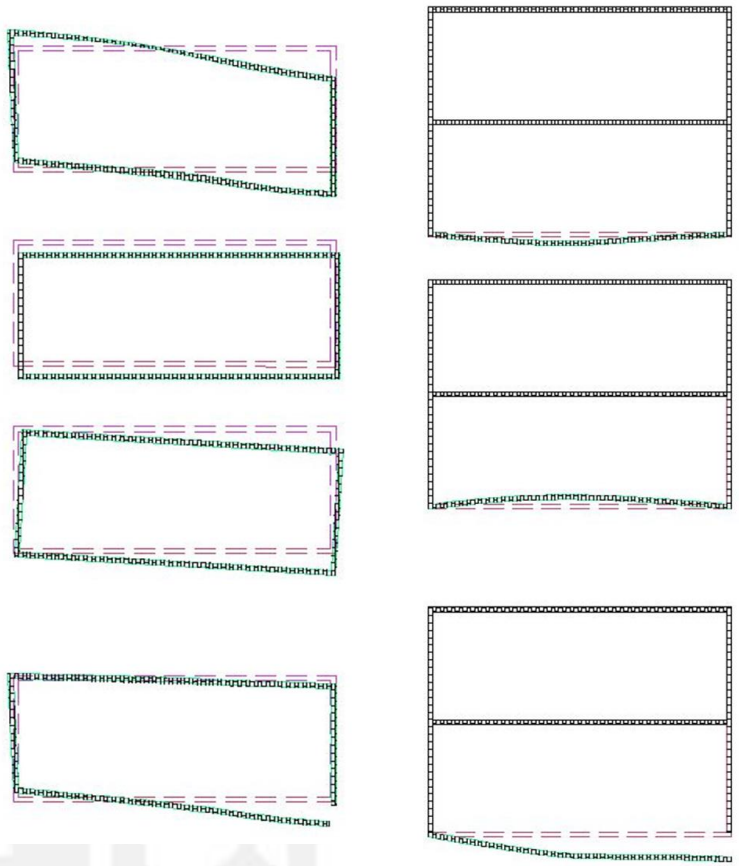
- Movement
  - Vertical
  - Out of Plumb
- Vibration
- Deterioration
  - Interior
  - Exterior
- Changes in Water Level

MODIFY ACTIVITY

Control Construction Activities

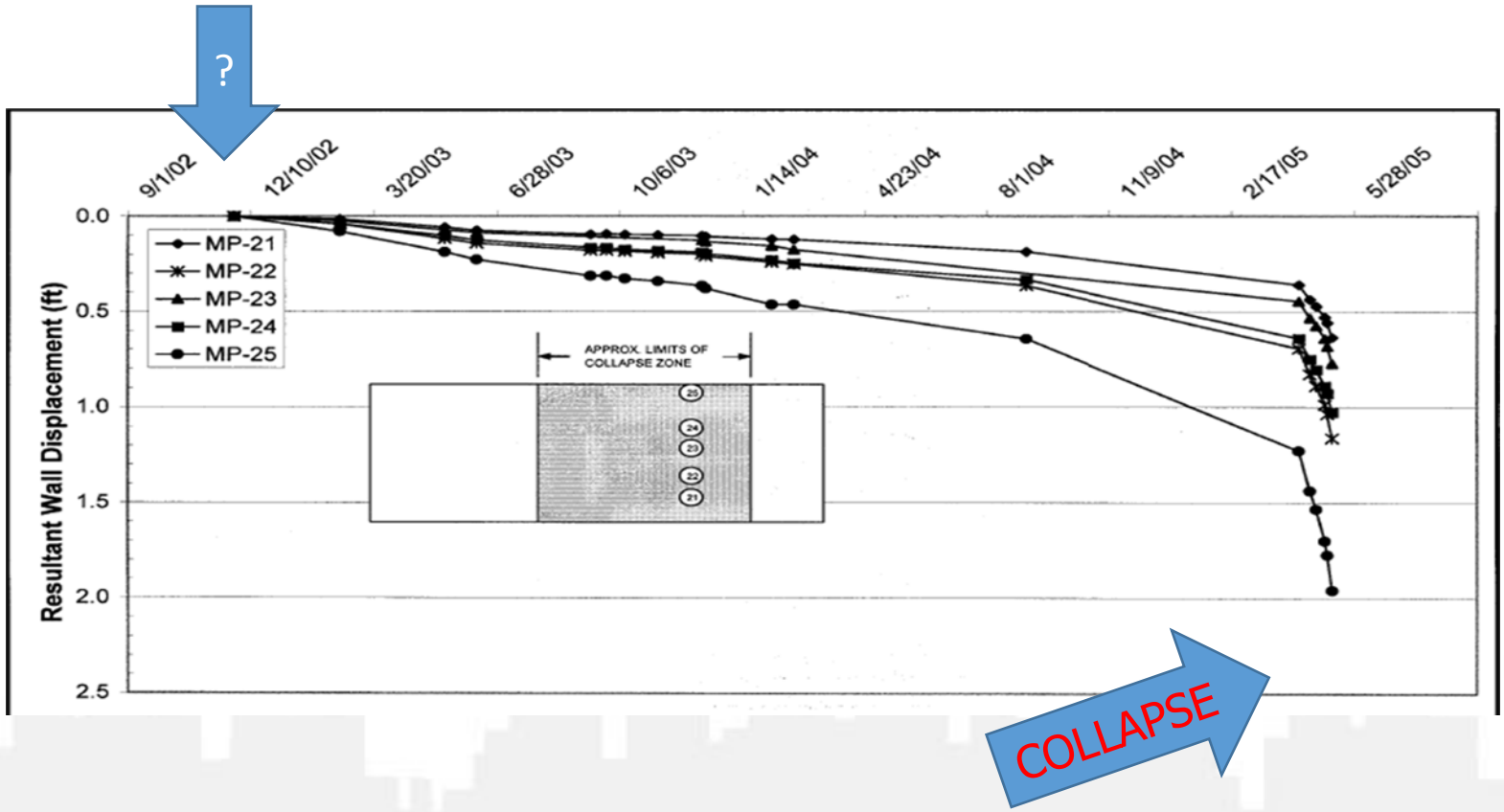
- Excavation
- Pile driving
- Lot Line Excavation
- Demolition
- Blasting

SURVEYING
POINT OF VIEW



Surveying and monitoring needs to be capable to register any possible movement.

MONITORING
NEEDS PLAN OF ACTION



BLASTING MONITORING CRITERIA

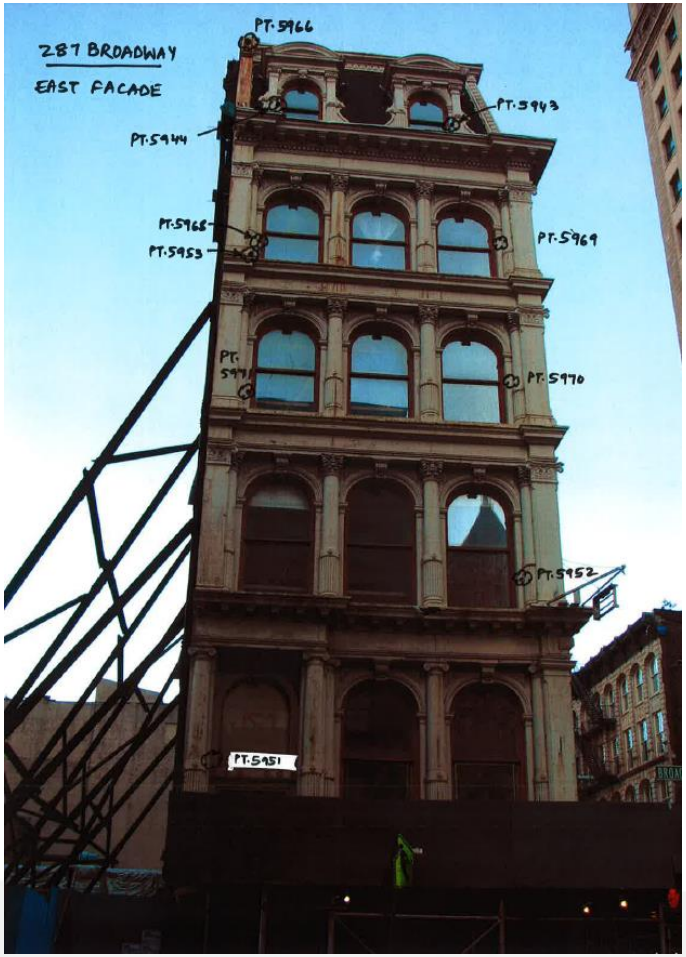
Building Address	DOB Classification per MOU	Contract Building Condition	Contract Response Values							
			Horizontal Movement (in)			Settlement (in)			Vibration (in/sec)	
			Threshold*	Limiting*	Current Maximum**	Threshold*	Limiting*	Current Maximum	Threshold	Limiting
94th to 95th St – West Side										
1831 2nd Ave	Group A	Not Fragile	0.5	0.7	0.40	0.3	0.5	0.36	N/A	N/A
94th to 95th St – East Side										
1838 2nd Ave	Group A	Not Fragile	0.5	0.8	0.35	0.7	1.0	0.21	N/A	N/A
95th to 96th St – West Side										
1849 2nd Ave	Group B	Not Fragile	0.5	0.7	0.47	0.3	0.5	0.32	1.5	1.92
95th to 96th St – East Side										
1840 2nd Ave	Group C	Fragile	0.6	0.9	0.75	1.3	2.0	1.42	0.3	0.5
1842 – 46 2nd Ave	Group A	Not Fragile	0.5	0.8	0.37	0.7	1.0	0.37	1.5	1.92

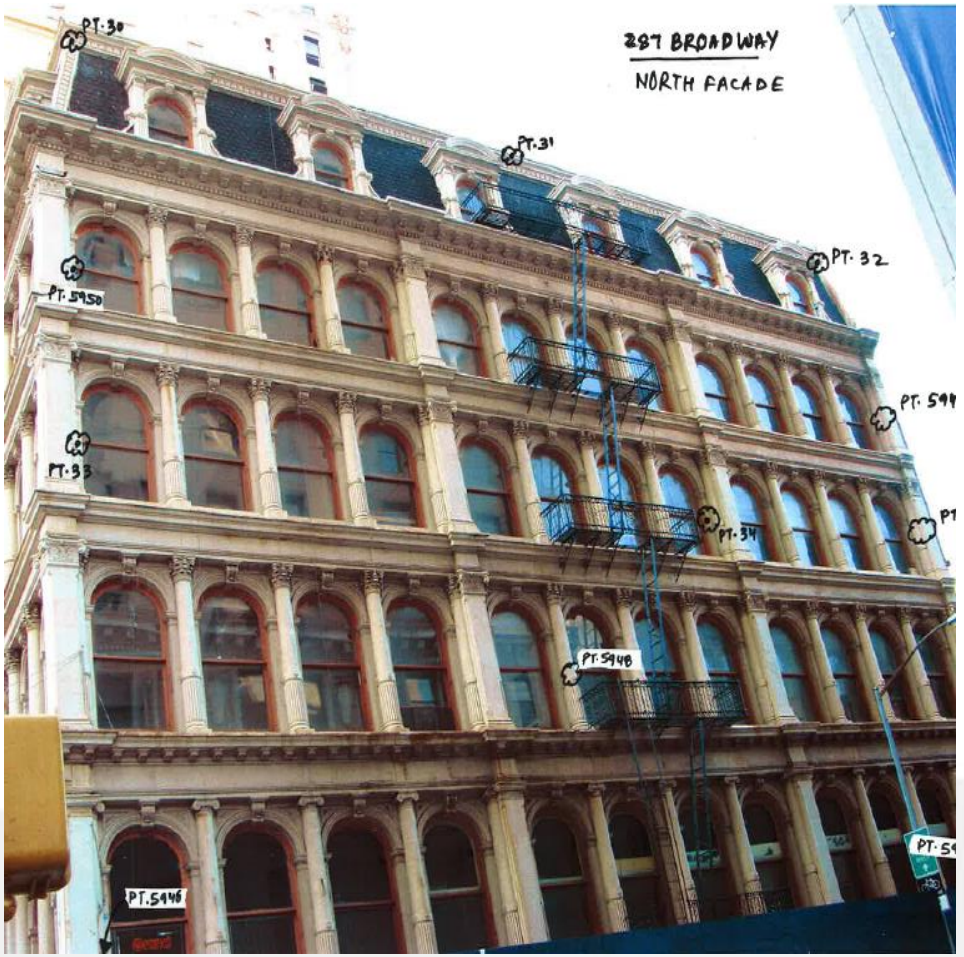
- *Where to place geophones?*
- *Are USBM criteria valid for NYC buildings?*
- *Tall Buildings?*

PLAN OF ACTION

	Type A	Type B	Type C w/shed	Type C	Type D
Vibration Limiting	1.9	0.5	0.5	0.5	TBD
One Time Reached Report by Engineer Next Day	3	1.5	1.5	0.75	same as TBD
Value reached more than three (3) times Same Day	2	0.75	0.75	0.5	
Displacement real-time notification and Report by Engineer					
	0.4	0.4	x	0.4	TBD
Cumulative Horizontal	0.4	0.5	x	0.5	same as TBD
One Time Horizontal or vertical	0.33	0.5	x	0.4	

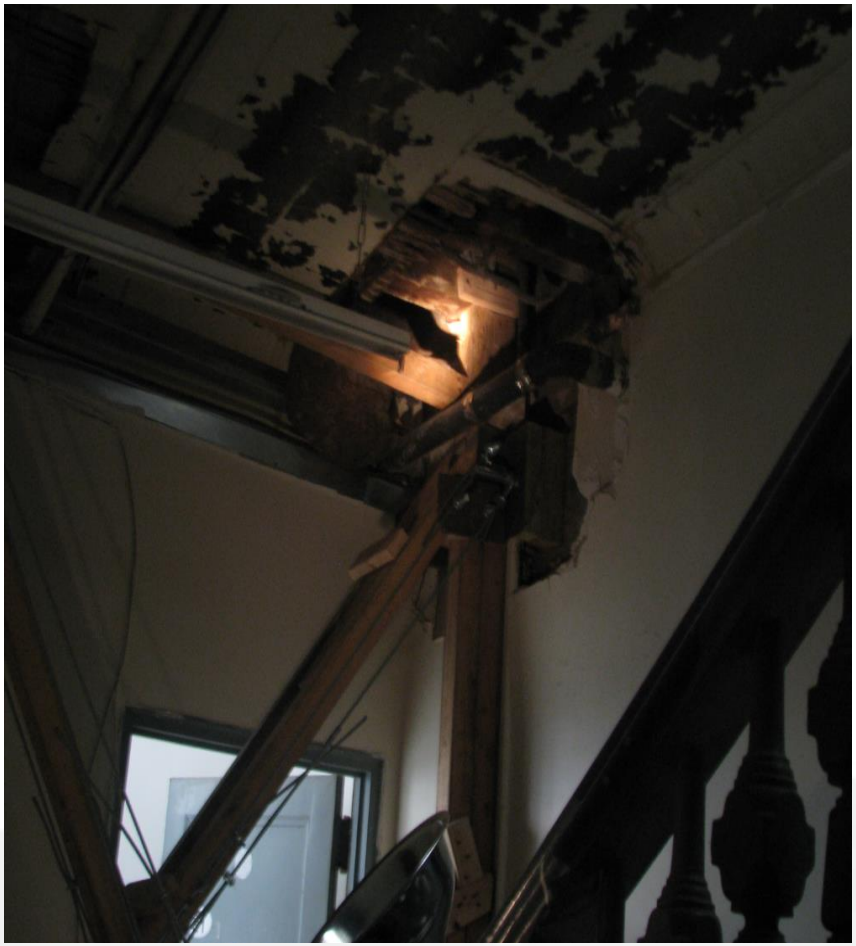
LEANING BUILDING
287 BROADWAY



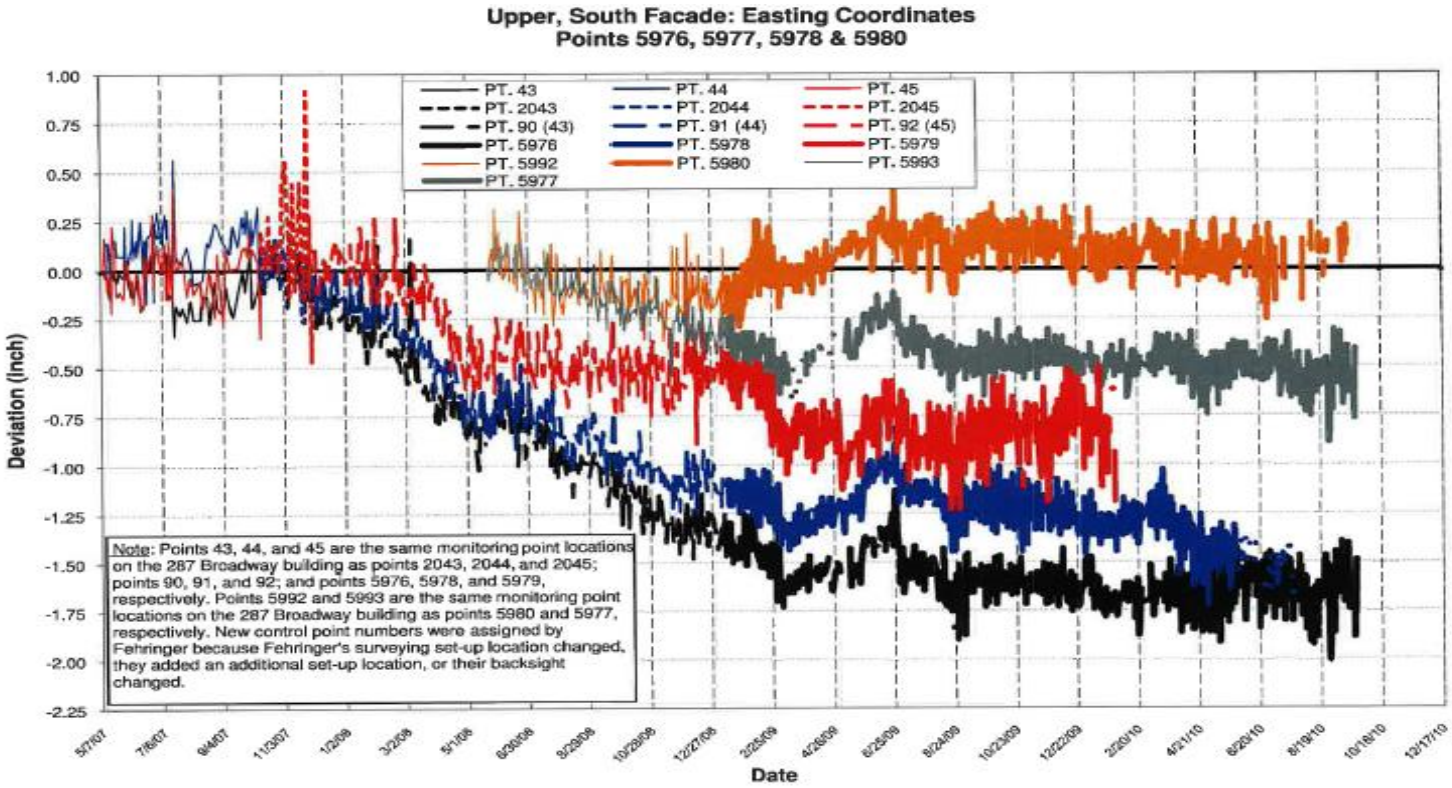


SHORING
287 BROADWAY

INTERIOR SHORING
287 BROADWAY

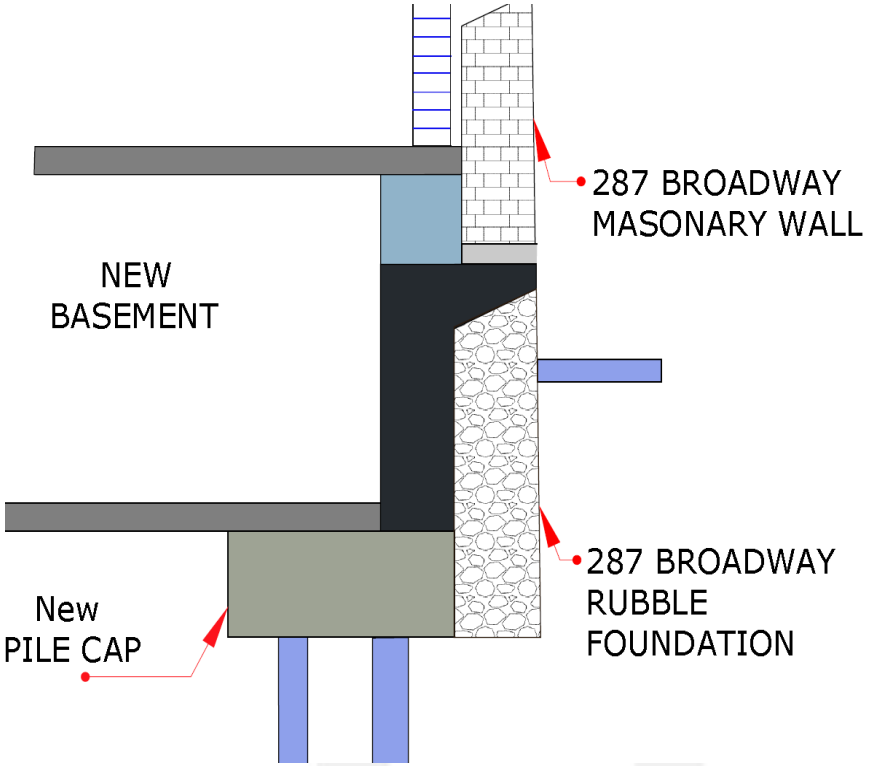


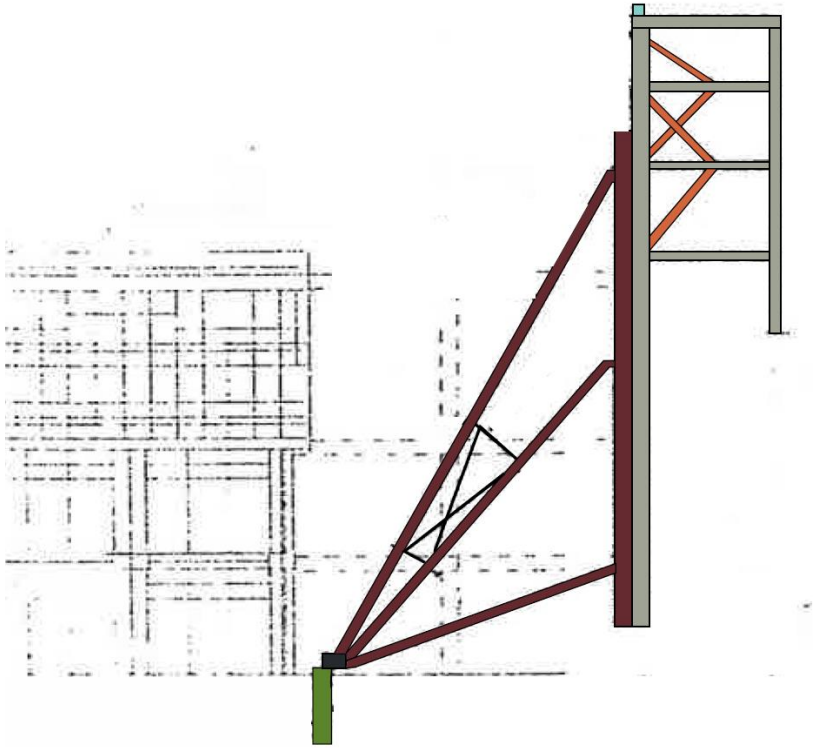
SURVEY REPORT
287 BROADWAY



Reevaluate the construction and need for additional shoring at every crossing of initial limits

SHORING & WALL SUPPORT

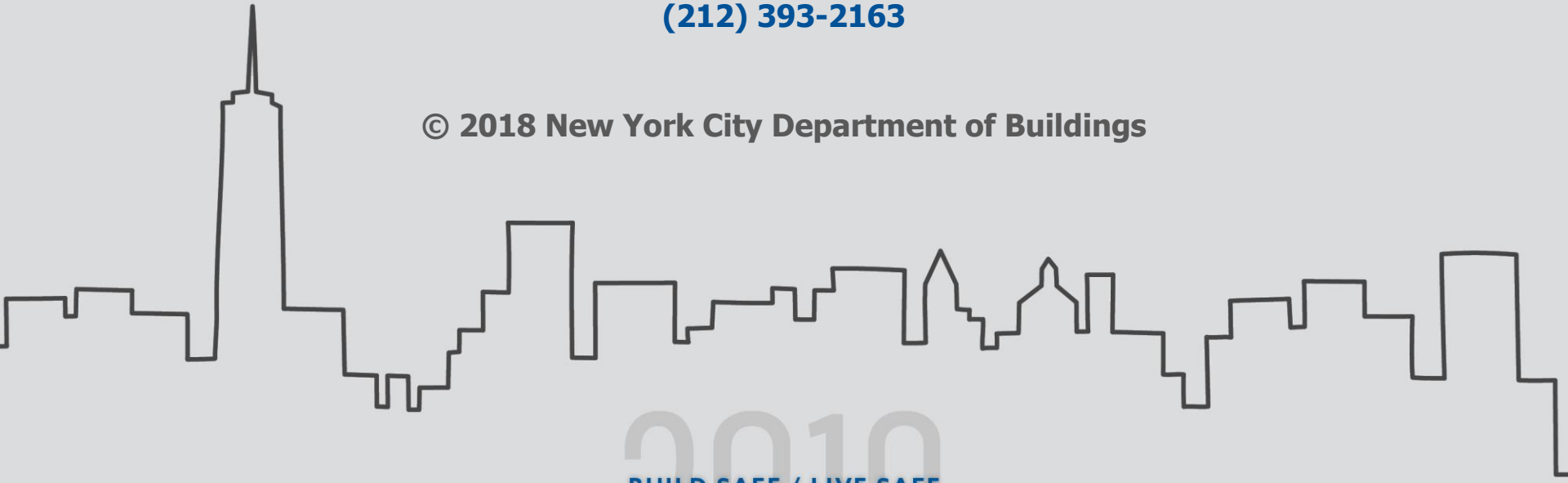




This concludes the
American Institute of Architects
Continuing Education Systems Course.

NYC Department of Buildings Contact for AIA:

Melanie Guzman
Melaguzman@buildings.nyc.gov
(212) 393-2163



BUILD SAFE / LIVE SAFE
CONFERENCE
2018