STRUCTURAL INTEGRITY
NYC Building Codes
Ramon Gilsanz, PE,SE
DOB Presentation
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Team Members

- **Ramon Gilsanz, PE, SE**
  Gilsanz Murray Steficek

- **Kenneth A. Hiller, PE**
  Bovis Lend Lease

- **John Steven McDonald**
  Battalion Chief, FDNY

- **Andrew D. Mueller-Lust, PE**
  Severud Associates

- **Robert Smilowitz, PE, PhD**
  Weidlinger Associates, Inc.

- **Bernard Yostpille, PE**
  Port Authority of New York & New Jersey
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Structural Integrity Provisions

- The new NYC building code is the first to specifically address the issue of structural integrity.
- There are no comparable provisions in the IBC code.
Since “practice makes perfect”, we ask that you please send suggestions, comments, clarifications, and improvements to:

structural.integrity@gmsllp.com

and

constructioncodes@buildings.nyc.gov
Impact

- For some offices, these provisions represent nothing new. Others will need to change their procedures.

- These provisions are designed to promote a uniform level of engineering practice.
Impact

- Since many of these provisions are already present in today’s code, there will be no significant impact on the cost of construction.

- Where code-prescribed seismic or wind design regulations are more stringent than the structural integrity provisions, the seismic or wind regulations shall govern.
Defining Structural Integrity

Dictionary: *Structure*
Any large, man-made object permanently fixed to Earth's surface, as a result of construction.
Defining Structural Integrity

- **BC 1626.5:**
  Where a structure is divided by joints that allow for movement, each portion of the structure between joints shall be considered as a separate structure.
Definitions (cont’d)

- Dictionary: *Integrity*
  The quality of being whole, reliable and complete.
**Definitions (cont’d)**

- *Structural integrity* in ASCE-7 05:

  Buildings and other structures shall be designed to sustain local damage with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage.
“Structural Integrity” is the ability of a structure to reliably withstand service conditions throughout its predicted lifetime.

“Structural Integrity” is a structure’s ability to safely resist required loads.
Definitions (cont’d)

- **BC-1625.1:**
  “The intent of these provisions is to enhance structural performance under extreme event scenarios.”
Goal of Code

- For structures to be planned, designed, and built so that they reasonably resist:
  - accidents
  - misuse
  - fire
  - normal construction practices
Goal of Code

- To avoid situations where damage to small areas or failure of single elements can lead to collapse of major parts of the structure.
Application

- For most buildings, structural integrity requirements will be prescriptive material requirements that do not require analysis.

- For special buildings, there are additional, stricter requirements that will require analysis.
Application

- **BC-1626.3:**

Where a structure is used for two or more occupancies, the structures shall be assigned the classification of the highest category corresponding to the various occupancies.
BC-1625.3 Lateral Bracing

- Floor
- Roof diaphragms
- Other horizontal elements

} to be tied to the lateral resisting system
BC-1605.7
Factored Load Combinations

- Vehicular Impact and Gas Explosions:
  \[ 1.2D + A_k + (0.5L \text{ or } 0.2S) \]
  \[ 0.9D + A_k + 0.2W \]

\[ A_k = \text{load effect of the vehicular impact or gas explosion} \]
BC-1605.6
Factored Load Combinations

- Alternate Load Path Method:
  \[ D + f_1 L + f_2 W \]
  - \( f_1 = 0.25 \) for buildings in Category II
    = 0.5 for buildings in Category III or IV
  - \( f_2 = 0 \) for buildings in Category II
    = 0.33 for buildings in Category III or IV
<table>
<thead>
<tr>
<th>II</th>
<th>Buildings and other structures except those listed in Categories I, III and IV</th>
</tr>
</thead>
</table>
| III | Buildings and other structures that represent a substantial hazard to human life in the event of failure including, but not limited to:  
  • Buildings and other structures where more than 300 people congregate in one area  
  • Buildings and other structures with elementary school, secondary school or day care facilities with an occupant load greater than 250  
  • Buildings and other structures with an occupant load greater than 500 for colleges or adult education facilities  
  • Health care facilities with an occupant load of 50 or more resident patients but not having surgery or emergency treatment facilities  
  • Jails and detention facilities  
  • Power-generating stations, water treatment for potable water, waste water treatment facilities and other public utility facilities not included in Category IV  
  • Buildings and other structures not included in Category IV containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released |
<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>NATURE OF OCCUPANCY</th>
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</thead>
</table>
| IV       | Buildings and other structures designed as essential facilities including, but not limited to:  
            - Hospitals and other health care facilities having surgery or emergency treatment facilities  
            - Fire, rescue and police stations and emergency vehicle garages  
            - Designated earthquake, hurricane or other emergency shelters  
            - Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response  
            - Power-generating stations and other public utility facilities required as emergency backup facilities for Category IV structures  
            - Structures containing highly toxic materials as defined by Section 307 where the quantity of the material exceeds the maximum allowable quantities of Table 307.7(2)  
            - Aviation control towers, air traffic control centers and emergency aircraft hangars  
            - Buildings and other structures having critical national defense functions  
            - Water treatment facilities required to maintain water pressure for fire suppression |
BC-1605.8
Factored Load Combinations

Specific Local Resistance Method

See section BC-1626.7
### Structural Integrity Exception

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>NATURE OF OCCUPANCY</th>
</tr>
</thead>
</table>
| I        | Buildings and other structures that represent a low hazard to human life in the event of failure including, but not limited to:  
- Agricultural facilities  
- Certain temporary facilities  
- Minor storage facilities |

and occupancy group R3  
(one or two family dwellings)
Structural columns that are directly exposed to vehicular traffic shall be designed for impact (i.e. ones that are not protected by bollards, guard walls, vehicle arrest devices, etc.).
BC-1625.5 Vehicular Impact

- Exterior corner columns
  - a horizontal concentrated load of 40 kips at a height of 18 in. or 36 in. above the finished driving surface, whichever has the greater effect.

- Other exterior columns (including loading docks, parking garages, etc.)
  - a horizontal concentrated load of 20 kips at a height of 18 in. or 36 in. above the finished driving surface, whichever has the greater effect.
BC-1625.6 Gas Explosions

- All key elements and their connections that are within 15 ft. of gas piping operating at pressures greater than 15 psi-gage shall be designed to resist a potential gas explosion.
Structural Integrity
BC-1624

Load Combinations
BC-1605

All Buildings
BC-1625

Vehicular and Gas Designs

Prescriptive Requirements

Steel
BC-2213

Concrete
Bc-1917

Masonry
BC-2114

Special Buildings Key Element
BC-1626

Alternate Load Path

Specific Load Resistance

NYC BUILDINGS

SEA

GMS
Definitions (cont’d)

- **TIE:**
  - A connecting, strengthening, or supporting beam or rod.
  - A link used to prevent two other structural members from spreading apart or separating.
Note: The required External Column, External Wall, and Corner Column tie forces may be provided partly or wholly by the same elements that are used to meet the Peripheral or Internal tie requirement.
Figure R516.5.2 of ACI-318

T = Transverse
L = Longitudinal
V = Vertical
P = Perimeter
IMPACT OF TIES

- Minor changes in reinforcement detailing can be made to provide continuity, redundancy and increase the ductility of the structure limiting the effects of local damage.
BC-1625.2 Continuity and Ties

- All framing elements shall have a minimum degree of continuity.
- All framing elements shall be tied to the building both laterally and vertically.
- See specific material chapters.
Although provisions are different for each material, the logic behind the requirements is similar: all three construction materials require vertical, horizontal, and peripheral ties.
The following sections of ACI 318 apply:
- Section 7.13 – Reinforcement Details (2 Pages)
- Section 13.3.8.5 – Two-way slabs
- Section 16.5 – Precast (2 Pages)
Slab Reinforcement
BC-1917.2.1

Slab Reinforcement

- Consists of a bottom mat reinforcement, placed in two roughly perpendicular directions made continuous with lap, mechanical or welded tension splices.

- The bottom mat reinforcement should not be less than the steel required for temperature reinforcement.
BC-1917.2 Peripheral Ties

- **1917.2** Located within perimeter beams or walls

- **1917.2** Within 4 ft. of edge of slab if there are no perimeter beams or walls

- **1917.3** For two-way slabs, the minimum reinforcement is half of the bottom reinforcement within the edge or edge strip (but no less than 2 bars)
BC-1917.2.3 Horizontal Ties

- At each column provide beam reinforcement or slab bottom reinforcement at each level to resist the developed tension force:

  \[
  \text{Tension Force} = \max \begin{cases} 
  3(1.0 DL) \\
  1.5(1.2 DL + 1.6 LL) \\
  1.5(1.4 DL) 
  \end{cases}
  \]

  - Load entering the column

- Ties must be distributed around the column perimeter and extended on all sides of the column into the adjacent slab for at least 1/3 of the span length.
Fig. 22.19  Schematic side views of bottom reinforcement that is capable of developing full tension strength when continuous over or anchored into a support. (For clarity, debris from collapsed level and other details are not shown.)
Compute the area of bottom mat reinforcement, continuous over an interior column which supports a 20-ft square flat plate (8-in. thick) panel, required to prevent a progressive collapse. Assume sustained superimposed dead and live loads of 20 psf on both floor levels $N$ and $(N + 1)$. Assume that a construction mishap precipitates the collapse of level $(N + 1)$.

**Solution**

Compute the loads to be supported. Level $(N + 1)$ loads are

\[ 8\text{-in. slab} = 100 \text{ psf} + 20 \text{ psf} = 120 \text{ psf} \]

The load should be doubled for the impact effect; thus

\[
\begin{align*}
\text{level } N + 1, & \quad 2(120) = 240 \text{ psf} \\
\text{loads on level } N, & \quad = 120 \text{ psf} \\
\text{total} & \quad = 360 \text{ psf}
\end{align*}
\]

\[
A_s = \frac{0.36(20)^2}{0.90(60)(0.707)} = 3.8 \text{ sq in.}
\]
BC-1917.2.4 Vertical Ties

- Columns and walls carrying vertical loads shall be tied continuously from the lowest to highest level.

- Ties must resist a tension force equal to the maximum of design dead and live loads received by the column/wall from any one of the four floors below.
BC-1917.3 Precast Concrete

BC-1917.3.1
- BC-1917.2.4 Vertical ties
- BC-1917.2.2 Peripheral ties
- ACI 318 Section 16.5 Precast (2 Pages)
BC-1917.3 Precast Concrete

End Connections BC-1917.3.1.2

Slabs, beams, and girders shall have an axial tension capacity greater than or equal to the maximum of:

- The vertical shear capacity of the connection at either end
- 2% of the maximum factored vertical dead and live loads
- 20 kips
- 2500 lb/ft of slab
End Connections BC-1917.3.1.2, cont’d

Where more than one element frames in one direction, with axial tension capacity greater than or equal to the maximum of
  - 1% of the column load
  - 20 kips
Precast Concrete (cont’d)

- Side connections (BC-1917.3.1.2)
  Shall have an axial tension capacity not less than that of the steel required for temperature reinforcement of the larger element

- Connection forces (BC-1917.3.1.3)
  Transverse shear and axial tensile forces do not need to be considered to act simultaneously
Precast Concrete (cont’d)

- Joints (BC-1917.3.2)
  Should not rely on friction due to gravity to transfer load

- Bearings (BC-1917.3.3)
  Net bearing area should not be less than 2 in. wide and 3 in. long in the direction of the member
BC-2213.1 Exceptions to Integrity Provisions for Steel Structures

- One-story buildings, less than 5,000 sq. ft. and not exceeding 15 ft. in height

- Buildings in category I and/or in occupancy category R-3 not more than three stories in height (one or two family dwellings)
All bolted connections should have at least 2 bolts.
BC-2213.2  Continuity and Ties

- Bolted connections of elements that are part of the lateral load resisting system should be designed as bearing-type connections with pre-tensioned bolts or as slip critical connections.
End connections of beams and girders should have a design axial tensile strength equal to the larger of:
- the maximum provided vertical shear strength of the connections at either side
- 10 kips minimum
Single plate, single angle, and double angle shear connections shall be determined by bolt bearing where deformation is not a consideration.
BC-2213.2 Continuity and Ties

- Elements and their connections that brace compression members should have an available axial tensile strength equal to:
  - At least 2% of the required strength of the compression member being braced
  - 10 kips minimum
BC-2213.2 Continuity and Ties

- Shear force and axial tensile force do not need to be considered to act simultaneously.

- Where more than one element braces a compression member in one direction, axial tension strength greater than or equal to the maximum of:
  - 1% of the required strength of the compression member
  - 10 kips
BC-2213.2.1 Vertical Ties

- Vertical Ties
  - Column splices should have an available tension strength greater than or equal to the largest design gravity load reaction applied to the column at any floor level located within four floors below the splice.
BC-2213.3
Composite Construction

- Shear studs with minimum ½” diameter at 12” maximum spacing.
Connections at discontinuous edges of permanent metal decking should have a connection strength $\geq$ shear strength of a $\frac{3}{4}”$ puddle weld every 12” on center.

Side lap connections of permanent metal decking should have a connection strength $\geq$ strength of a button punch every 24” on center.
BC-2213.3
Composite Construction

- Welded wire fabric reinforcement in concrete slabs should be continuous over all supports and in all spans
  - Minimum area of continuous reinforcement = 0.0015 x (area of concrete)
  - Reinforcement should have tension splices and be anchored at discontinuous edges
BC-2114.2.1 Horizontal Ties

- Provided in all load-bearing masonry walls, and around the perimeter of the building
- Consist of no less than two No. 4 bars
- Located within the thickness of walls and beams. Within 1’ of edge of slab if there are no walls or beams
BC-2114.2.2 Horizontal Ties

- Terminate in a perpendicular horizontal tie
- Anchored at the end of the wall if no horizontal tie exists within 4' of the end of a wall
BC-2114.2.2 End Connections

End Connections
- Axial Tension Capacity, equal to the maximum of
  - The vertical shear capacity of the connected element at either end
  - 2% of the maximum factored vertical dead and live loads in the compression masonry element
- At least one No. 4 bar at a maximum spacing of 24” on center
- At columns or piers four no. 4 bars
- Vertical reinforcement
- Continuous from lowest to highest level of the wall
- Anchored at each end in a horizontal tie or foundation element
BC-2114.2.3 Vertical ties

- Where openings in bearing walls are greater than 24” in height, ties should be provided at each side of the opening that extend and are anchored in masonry above and below the opening.
- Minimum of four continuous No. 4 bars should be provided per masonry column or pier.
BC-2114.2.1.2
Vertical Reinforcement in Walls

- No less than the equivalent of one No. 4 bar at a maximum spacing of 48” on center
- Consists of no less then two No. 4 bars placed within 16” of the end of the wall
Special Buildings
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<th>Definition</th>
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<td>ALTERNATE LOAD PATH METHOD</td>
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<td>ASPECT RATIO</td>
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<td>4</td>
<td>COLLAPSE</td>
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<td>5</td>
<td>ELEMENT</td>
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<tr>
<td>6</td>
<td>KEY ELEMENT</td>
</tr>
<tr>
<td>7</td>
<td>LOCAL COLLAPSE</td>
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<tr>
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<td>RESPONSE RATIO</td>
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<td>ROTATION</td>
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<td>SPECIFIC LOCAL LOAD</td>
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<tr>
<td>11</td>
<td>SPECIFIC LOCAL RESISTANCE METHOD</td>
</tr>
</tbody>
</table>
**BC-1624 Definitions**

- **ROTATION:** The angle, measured at the ends of a member, whose tangent is equal to the deflection of the member at mid-span divided by half the length of the member.

\[
\delta = \theta_1 + \theta_2
\]
BC-1624 Definitions

- LOCAL COLLAPSE: Failure of a structural element that results in the collapse of areas being directly supported by that element and not extending vertically more than three stories.
Progressive Collapse
With loss of a primary structural element (column) chain reaction collapse may occur.

Local Collapse
With loss of a primary structural element (column) collapse is limited to a single bay and level.
BC-1624 Definitions

**KEY ELEMENT:**
- An element which when lost, results in more than local collapse.
- An element that braces a key element, the failure of which results in failure of the key element.*

*A secondary element that provides required bracing to a key element may also be considered a key element.*
Where key elements are present in a structure, the structure shall be designed to account for their potential loss at a time by the Alternate Load Path Method or by the Specific Local Resistance Method as specified in Section 1626.7.
Special Buildings Definition

Analysis should be performed for buildings:

- In Category IV and more than 50,000 sq. ft. of framed area
<table>
<thead>
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<td>IV</td>
<td>Buildings and other structures designed as essential facilities including, but not limited to:</td>
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<tr>
<td></td>
<td>- Hospitals and other health care facilities having surgery or emergency treatment facilities</td>
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<td>- Water treatment facilities required to maintain water pressure for fire suppression</td>
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</table>
With the aspect ratio of 7 or greater, where the aspect ratio is equal to the ratio between the height of any portion of a building and the least dimension at the elevation from which the height is being measured.
ASPECT RATIO: The height of any portion of a building divided by its least dimension at the elevation from which the height is being measured.

RESPONSE RATIO: The ratio of an ultimate response quantity (e.g., deflection) to its value at yield.
Special Buildings (cont’d)

- Greater than 600 ft. in height or more than 1,000,000 sq. ft. in gross floor area
- Taller than seven stories for any element which supports in aggregate more than 15% of the building area
- Designed using non-linear time history analysis or with special seismic dissipation systems
- Where a structural peer review is requested by the commissioner
BC-1624 Definitions

- **ALTERNATE LOAD PATH METHOD:**
  A design approach that accounts for an extreme event by providing alternate load paths for elements that are no longer able to carry load.
Analysis Procedure

- Static Elastic Analysis
  - Dynamic effects of member loss or of specific local loads do not need to be considered
  - Structure assumed to remain elastic
  - Response ratio of structural elements is limited to 1
Analysis Procedure (cont’d)

- Dynamic Inelastic Analysis
  - Dynamic effects of member loss or of specific local loads are to be considered
  - Structure does not need to remain elastic
  - Response ratio and rotation limits obtained from Table 1626.9.3 are not to be exceeded
Analysis Procedure (cont’d)

- Energy Method
  - Static inelastic analysis using energy equilibrium
  - Structure does not need to remain elastic
  - Response ratio and rotation limits obtained from Table 1626.9.3 are not to be exceeded
### TABLE 1626.9.3
RESPONSE RATIO AND ROTATION LIMITS

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>RESPONSE RATIO</th>
<th>ROTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Slabs</td>
<td>( u &lt; 10 )</td>
<td>( \theta &lt; 4^\circ )</td>
</tr>
<tr>
<td>Post-Tensioned Beams</td>
<td>( u &lt; 2 )</td>
<td>( \theta &lt; 1.5^\circ )</td>
</tr>
<tr>
<td>Concrete Beams</td>
<td>( u &lt; 20 )</td>
<td>( \theta &lt; 6^\circ )</td>
</tr>
<tr>
<td>Concrete Columns</td>
<td>( u &lt; 2 )</td>
<td>( \theta &lt; 6^\circ )</td>
</tr>
<tr>
<td>Long Span Acoustical Deck</td>
<td>( u &lt; 2 )</td>
<td>( \theta &lt; 3^\circ )</td>
</tr>
<tr>
<td>Open Web Steel Joists</td>
<td>( u &lt; 2 )</td>
<td>( \theta &lt; 6^\circ )</td>
</tr>
<tr>
<td>Steel Beams</td>
<td>( u &lt; 20 )</td>
<td>( \theta &lt; 10^\circ )</td>
</tr>
<tr>
<td>Steel Columns</td>
<td>( u &lt; 5 )</td>
<td>( \theta &lt; 6^\circ )</td>
</tr>
</tbody>
</table>
Additional Requirements

- Minimum Response
  - Structural response of elements determined using a dynamic inelastic analysis should not be less than 80% of that determined using a static elastic analysis

- Strength Reduction Factor
  - Structural design for:
    - Specific Local Loads
    - Key Elements
    \[ \text{Strength reduction factors} = 1 \]
SPECIFIC LOCAL RESISTANCE METHOD:
A design approach that accounts for extreme event loads by providing sufficient strength for elements that may fail.
- Key elements are designed for specific local loads
Specific Local Loads

- Compression element – in combination with the full dead load and 50% of the live load, a concentrated load equal to 2% of its axial load (but not less than 15 kips) is to be applied at mid-span in any direction and perpendicular to its longitudinal axis.
Specific Local Loads (cont’d)

- Bending element
  - Combination of the principal acting moments plus an additional moment, equal to 10% of the principal acting moment, is to be applied in the perpendicular plane
Specific Local Loads (cont’d)

- Connections of tension elements – should be designed to develop the smaller of the tension capacity of the member OR 3 times the force in the member.

- All structural elements – should be designed for a reversal of load, which is equal to 10% of the design load used in sizing the member.
Web Links

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