ENGINEERING 101:
A PRIMER ON BASIC STRUCTURAL ENGINEERING TERMS, CONCEPTS, AND ISSUES AS IT RELATES TO AGING BUILDINGS

INTRO

MELANIE K. RODBART, PE
melanie@jmpreservation.com

JESSICA H. SENKER, ASSOC. AIA
jessica@jmpreservation.com
GOALS

- Understand common terms of art
- Learn how to hire the right engineer
- Learn engineering assessment procedures
- Understanding the approach to analyze existing structures
- Learning common repairs to avoid demolition and/or removal of historic fabric

- Review of a case study that showcases procedures, design, and implementation

- Earn AIA 1.5 LU
PROCEDURES

- Identify the issues
- Find the right Engineer
- Develop the scope of work
- Understand the deliverables
- Observations & site evaluation
- Analysis

IDENTIFY THE ISSUES

- What are your concerns for the building/site?
- How long has this issue been present?
- Has there been an event that caused the issue?
- Has any attempt at repair been made?
- Do you understand the cause and effects of the issue?
**Finding the Right Engineer**

- Inquire with fellow historic site operators
- Are your building/site issues something the Engineer has experience with?
- Are they familiar with the Secretary of the Interior’s Standards as it applies to historic buildings?
- Review credentials and references
- Review the Engineer’s approach to the issue and the scope of work proposed.
- Are there access issues for gathering information? Is the issue readily visible or will it require equipment or selective demolition. If so, who is the responsible party?
- Are there hazardous materials on-site?
- What are the deliverables from the Engineer?
- Fee and Contract Terms
- Availability / Schedule / Deadlines

**Scope of Work Development**

- Pre-proposal site visit (pro bono)
- Provide as much info. as possible! If you don’t have this in time for the initial meeting, try to get it in hand prior to having the engineer begin their assessment
  - past reports
  - any drawings of the building/site
  - general history & significance of the building/site
  - photos of the issues (past and present)
  - your understanding of potential issue
  - goals & expectations for the building/site
  - existing and proposed use changes
  - funding sources/requirements
  - schedule/deadlines
DELIVERABLES

- Assessment Report with recommendations
- Opinion of Probable Cost (Cost estimate) aka Order of Magnitude Cost Estimate
- Schematic Documents
- Construction & Permit Documents
- Bidding
- Contract Administration
- Meetings with the client, board, interested parties?
- Do the deliverables proposed match what may be required of grantors or funding sources?

DESIGN PHASE DEFINITIONS

- Schematic Design
  To illustrate the concepts of the existing conditions, design or repairs, noting the scale, form and relationship to existing conditions.

- Design Development
  To illustrate the design or repairs, noting all materials, systems, coordination between items, and product lifespans (warranties if applicable). Outline specifications of all materials and contracting requirements is developed.
**Procedures**

- **Design Phase Definitions**
  - Construction/Permitting Documents
    To provide a set of drawings and specifications for the contractor price and build the project. This set of documents will also be used to obtain building permits within the designated jurisdiction.
  
  - Bidding
    To assist the owner in obtaining and comparing contractor bids for the project. Design professional shall provide invitations to bid, bidding requirements, outline experience requirements and facilitate fair and equal bidding amongst the contractors. Final selection of the contractor is always made by the owner. The design professional shall prepare the construction contract.

- **Contract Administration (CA)**
  Provided at the owner’s discretion, but is highly recommended. The professional will observe the work to help the contractor with conformance with the construction contract. The design professional will provide answers to contractor questions or issues that may arise during construction. The professional will also review the contractor’s applications for payment to determine the appropriate billing schedules.
**PROCEDURES**

- **Observations & Evaluation**
  - Provide the engineer any information you may have for the building/site if you haven’t already done so.
  - Review the goals and expectations for the project together.
  - Current and proposed use and occupancy must be understood.
  - Engineer will observe, measure, photograph, create field sketches, and any other sampling/testing that may be necessary in order to analyze the issue.
  - Testing may include, borings, moisture meter, plaster sounding, resistograph drilling, load testing, etc.

**Analysis**

- **Structural Analysis**
  - Identify structural component
  - Determine which standards apply
  - Determine which building codes apply
  - Classification of work
  - Determine material properties
  - Determine minimum design loads and combinations
  - Determine load capacity
  - Determine if components are code compliant
Structural Components & Systems

- Flexural Members: Beams, joists, girders, rafters
- Axial Members: Columns, pilasters, ties, struts
- Diaphragms: Slabs, walls, floors
- Frames: Truss (formed by a group of members arranged in the shape of triangles)
- Connections: Bolts, rivets, welds, anchors, dowels, pins, etc.

Standards

- Research on how structures respond to specific weather and geological hazards determines the building standards that specify the loads that structures must be able to withstand.
- Standards have no legal standing on their own.
- These minimum design loads are periodically updated by:
  - American society of Civil Engineering (ASCE),
  - American Society of Testing Materials (ASTM),
  - American National Standards Institute (ANSI), and similar professional organizations.
Standards

- Design Specifications to aid engineers:
  - ASCE Minimum Design Loads for Buildings & Other Structures (ASCE 7)
  - American Institute of Steel Construction (AISC)
  - National Design Specification for Wood Construction (NDS)
  - Building Code Requirements for Structural Concrete (ACI 318)
  - Building Code Requirements for Masonry Structures (ACI 530)
  - American Association of State Highway and Transportation Officials (AASHTO)
  - And many more…

Building Code

- Building codes are written by regional and/or local authorities – which use the standards determined by the professional organizations as guidelines.
- The US has never had one national building code. There have been as many as 5,000 separate codes have been in use in the country at a time.
- 1915: Building Officials and Code Administration (BOCA) was formed
- 1927: Uniform Building Code (UBC), the first set of model codes to be published – attributed to Herbert Hoover’s efforts.
- 1950: National Building Code (NBC) was published as a single compilation.
**Building Code**

- Over the past roughly 75 years, 3 sets of model building codes came to be widely accepted as the basis for most of the local codes now in use:
  - Uniform Building Code (UBC)
  - Standard Building Code (SBC)
  - National Building Code (NBC)

- In 1994, the International Code Council (ICC) was formed to develop a single, national, and comprehensive set of building codes.

**INTERNATIONAL CODE COUNCIL**

- International Building Code (IBC)
- International Residential Code (IRC)
- International Existing Building Code (IEBC)

  - International Energy Conservation Code
  - International Fire Code
  - International Fuel Gas Code
  - International Green Construction Code
  - International Mechanical Code
  - ICC Performance Code
  - International Plumbing Code
  - International Private Sewage Disposal Code
  - International Property Maintenance Code
  - International Swimming Pool and Spa Code
  - International Wildland Urban Interface Code
  - International Zoning Code

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IBC EXISTING STRUCTURES

Ch 34: Additions, alterations or repairs to any building or structure shall conform with the requirements of the code for new construction. An addition or alteration shall not increase the force in any structural element by more than 5%, unless the member will still be in compliance with the code for new construction, and shall not decrease its strength below the new construction code level. Strengthening of deficient members must conform to the code for new construction.

IBC CHAPTER 34 OR IEBC?

- At the discretion of the designer
- IEBC provides flexibility to permit the use of alternative approaches to achieve compliance with minimum requirements
- Bottom line: DO NOT REDUCE SAFETY
CLASSIFICATION OF WORK PER IEBC

Repairs  
Alterations  
Change of Occupancy  
Additions  
Historic Structures  
Relocated Structures

 Definitions

• Repairs: Restoration to good or sound condition of any part of an existing building for the purpose of its maintenance.
• Alterations: Any construction or renovation to an existing structure other than a repair or addition. Classified as Level 1, 2, or 3.
ALTERATIONS

A Level 1 alteration is similar to a repair except that newer materials, elements, equipment or fixtures are installed that provide the same purpose of the previous items.

A Level 2 alteration includes the reconfiguration of space, the addition or elimination of doors or windows, extension of any system, or the installation of any equipment. Level 2 alterations must comply with the requirements for Level 1 alterations.

A Level 3 alteration is where the work area exceeds 50% of the total building area. The work area, by IEBC definition, includes all reconfigured spaces. Level 3 alterations must comply with the requirements for Levels 1 & 2.

MORE DEFINITIONS

Change of Occupancy: IEBC 305.1 Building must comply with IBC for division or group of NEW occupancy.

Additions: An extension or increase in floor area, number of stories, or height of a building or structure.

Historic Structures: Buildings located on local, state, or national registries.

Relocated Structures: Structures moved shall comply with the provisions of IBC for NEW structures.
NO SUCH THING AS “GRANDFATHERED IN”

- IBC Ch 34: Where repairs are made to structural elements of an existing building and uncovered structural elements are found to be unsound or otherwise structurally deficient, such elements shall be made to conform to the requirements for new structures.

- As soon as you touch it, bring it up to code!

Determine Material Properties

- Obtain original documentation
- Age, environment, and history of structure
- Proprietary structural systems
- Configuration and surface texture may differentiate between cast iron, wrought iron, steel
- Grade and species of lumber
- Material sampling & testing, load testing
**Determine Minimum Design Loads**

- Forces or other actions that result from the weight of all building materials, occupants and their possessions, environmental effects, differential movement, and restrained dimensional changes.

- Magnitudes of loads consist of dead, live, soil, wind, snow, rain, flood, and earthquake.

**Dead Loads**

- Dead, soil, and hydrostatic loads based on weight of material of construction. These loads are permanently attached to structure.
- Includes walls, floors, roofs, ceilings, stairways, partitions, finishes, cladding, fixed service equipment, weight of cranes.

**Live Loads**

- Determine live loads based on maximum loads expected by the intended use or occupancy. LL vary in magnitude and position with time.
- Typical LL as per ASCE-7 Table 4-1:
  - Lobbies of assembly areas, 1st floor of office & retail, restaurants, public rooms, stairways, fire escapes, roof gardens: 100 psf
  - Residential, classrooms: 40 psf
  - Attics with storage: 20 psf, Attics without storage: 10 psf
  - Roofs: 20 psf
FLOOD LOADS

- Applies to buildings in areas prone to flooding as defined on a flood hazard map
- Provisions for erosion and scour

SNOW LOADS

- Ground snow loads used to determine design snow loads for roofs established by statistical analysis of snowfall across the country.
- Philadelphia: 25 psf

WIND LOADS

- Buildings, including the Main Wind-Force Resisting System and all components & cladding shall be designed and constructed to resist wind loads based on basic wind speeds.
- Philadelphia: 90 mph

EARTHQUAKE LOADS

- Seismic ground motion values
- Mapped acceleration parameters
- Site soil properties
- Philadelphia is in Moderate-Low region
Rain Loads

- Each portion of roof shall be designed to sustain the load of all rainwater that will accumulate on it if the primary drainage system is blocked plus the uniform load caused by water that rises above the inlet of the secondary drainage system at its design flow.

Ice Loads

- Ice load shall be determined using the weight of glaze ice formed on all exposed surfaces of structural members.

Design Philosophies

- Allowable Stress Design (ASD): The designer ensures that the stresses developed in a structure due to service loads do not exceed the elastic limit. This limit is usually determined by ensuring that stresses remain within the limits through the use of factors of safety.

- Load & Resistance Factor Design (LRFD): load factors are applied and a member is selected that will have enough strength to resist the factored loads. Theoretical strength of a member is reduced by the application of a resistance factor. The load and resistance factors are determined using statistics and a pre-selected probability of failure.
Design Philosophies

- Wood, steel, and other materials are still frequently designed using ASD, although LRFD is more commonly taught in the USA university system.
- ASD is more conservative in designs with a live to dead load ratio of 3 or lower. With a higher ratio, LRFD is more conservative.

Load Combinations

Strength Design: Structures shall be designed so that their design strength equals or exceeds the effects of the factored loads of the following combinations:

1. 1.4D
2. 1.2D + 1.6L + 0.5(Lr or S or R)
3. 1.2D + 1.6(Lr or S or R) + (L or S or R)
4. 1.2D + 1.0W + L + 0.5(Lr or S or R)
5. 1.2D + 1.0E + L + 0.2S
6. 0.9D + 1.0W
7. 0.9D + 1.0E

Allowable Stress Design: Consider the combination that produced the most unfavorable effect in the building:

1. D
2. D + L
3. D + (Lr or S or R)
4. D + 0.75L + 0.75(Lr or S or R)
5. D + (0.6W or 0.7E)
6a. D + 0.75L + 0.75(0.6W) + 0.75(Lr or S or R)
6b. D + 0.75L + 0.75(0.7e) + 0.75 S
7. 0.6D + 0.6W
8. 0.6D + 0.7E
FUNDAMENTAL PRINCIPLES

1. A body will exist in a state of rest or in a state of uniform motion in a straight line unless it is forced to change that state by forces imposed on it.
2. The rate of change of momentum of a body is equal to the next applied force.
3. For every action there is an equal and opposite reaction.

\[ \Sigma F = ma \]

\( \Sigma F \) = summation of all the forces
\( m \) = mass
\( a \) = acceleration
EQUATION OF EQUILIBRIUM

\[ \Sigma F = 0 \]

Our buildings are NOT moving!

DETERMINE LOAD PATH

- Trace the external loads through the structure
- Calculate tributary areas for load computation
- Draw free body diagram for individual structural members
- Determine support conditions: fixed, free, cantilever
- Compute reactions
Determine Load Capacity

- Typically, analysis of existing framing is computed by hand because it is rare to have a model of the entire building electronically and expensive to prepare.
- Computational spreadsheets are often utilized to assist with the analysis.
- Computer software may be used to analyze framing, but many assumptions must be made if the existing structure is not known.

Computer Software Analysis Programs

- Microsoft Excel
- Enercalc
- RAM Structural System
- Web Structural
- RISA
- Retain Pro
- Woodworks
- NCMA Masonry
Computer Software Programs

- Drafting:
  - Autodesk AutoCAD
  - VectorWorks

- Building Information Modeling (BIM):
  - Autodesk Revit
  - ArchiCAD

*BIM is often not utilized for existing buildings due to the complexity of gathering all the relevant information.*

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Code Compliant

- Determine deficiency:
  - Are members sized properly?
  - Are the connections sufficient?
  - Is there material deterioration?

- Engineer will recommend a course of action to stabilize the deficiency
COMMON REPAIRS

WOOD
STEEL
MASONRY
CONCRETE

Understand the cause before making the repair!

Determine Cause of Deterioration

- Weathering, freeze/thaw cycles
- Moisture infiltration (from roof leak, flooding, building systems, etc.)
- Settlement from poor preparation of site (compaction methods)
- Bacteria, insect infestation
- Storm runoff, soil erosion
- Fire
- Material incompatibility (metal corrosion)
- Imposed alterations, demolition
WOOD

- Causes of Failures:
  - Rot from water infiltration
  - Rot from infestation (termites, borers, squirrels)
  - Overloading and/or undersized
  - Improper bearing (lintels, headers, beams, posts, etc.)
  - Failed or inadequate connections
  - Utility installation compromise capacity

WOOD

- Scab
- Sister
- Replace
COMMON REPAIRS
WOOD
- Dutchman
- New connectors

COMMON REPAIRS
WOOD
- Improve bearing
- Increase loading capacity

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**COMMON REPAIRS**

**WOOD**
- Reconstitute member by repairing checks, cracks, rot

*Note:
Rot must be treated before it can be repaired!

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**COMMON REPAIRS**

**WOOD**
- It can be repaired!

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WOOD

Failure Mechanisms:
- Corrosion
- Overloading and/or undersized
- Instability
- Creep (prolonged exposure to stress @ high temps)
- Fatigue (repeated cycling of load)
- Brittle fracture (usually associated with flaws or defects in the material where bulk stresses concentrate)

STEEL

Failure Mechanisms:
- Corrosion
- Overloading and/or undersized
- Instability
- Creep (prolonged exposure to stress @ high temps)
- Fatigue (repeated cycling of load)
- Brittle fracture (usually associated with flaws or defects in the material where bulk stresses concentrate)
COMMON REPAIRS

STEEL
- Reinforce

STEEL
- Add new members
COMMON REPAIRS

STEEL

- Add new members
**Common Repairs**

**Steel**
- Coatings

**Concrete**
- Cause of Failures:
  - Corrosion of steel reinforcement
  - Freeze/thaw cycles
  - Sulfate attack
  - Surface delamination
CONCRETE

- Shorten the span

- Install reinforcement
COMMON REPAIRS
CONCRETE
❖ Substitution

COMMON REPAIRS
CONCRETE
❖ Reconstruction
**COMMON REPAIRS**

**MASONRY**

- **Cause of Failures:**
  - Freeze/thaw cycles
  - Loss of connection between wythes
  - Incompatible mortar
  - Overloading

- **Effects of Failures:**
  - Cracking
  - Spalling
  - Overturning

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**COMMON REPAIRS**

**MASONRY**

- **Repoint**
Common Repairs

Masonry

- Reconstruct

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Common Repairs

Masonry

- Reinforce

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COMMON REPAIRS
MASONRY
- Hardware reinforcement

COMMON REPAIRS
MASONRY
- Reinforce

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**Common Repairs**

**Masonry**
- Reinforce

**Common Repairs**

**Masonry**
- Rebuild
COMMON REPAIRS
MASONRY
❖ Substitution

CASE STUDY

ST. PETER’S CHURCH
PHILADELPHIA, PA

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BUILDING HISTORY

- Peter’s Episcopal Church is a National Historic Landmark
- The church first opened its doors in 1761, and served as a place of worship for many of the United States’ Founding Fathers.
- Designed and built by Scottish architect/builder Robert Smith, who also designed Carpenter’s Hall and the tower of Christ Church.
- Organ is a E.M. Skinner, Opus 862, is housed in the historic 1764 Philip Feyring case.

TIMELINE

- Fall/Winter 2010: Reported concern with roof swale and plaster ceiling.
- Early Winter 2011: Report provided noting recommendation of structural analysis needed for roof trusses, replacement of metal roofing, and repairs to wood cornice.
- Summer 2011: Cornice failures reported, temp. netting installed.
- Spring 2012: Structural assessment report submitted and Engineer reported necessary closure of church due to dangerous conditions. Vestry closed the church the next day.
- Summer 2012-Fall 2012: Design-build project initiated to repair dangerous conditions of roof trusses.
- Christmas 2012: Church reopened for services.
- Spring 2013: Project completed.
St. Peter’s

Cornice & Structure
Observations & Evaluations

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### St. Peter's Church Roof Structure Assessment - Structural Analysis

#### Timber Table

| No. | Member Name    | Species | Grade | F_k | F_r | Timber Member | H | V | Torsional Resistant Force, T | Compressive Resistant Force, C | F_k * Allowable Torsional Force | F_r * Allowable Axial Force Capacity | Status |
|-----|----------------|---------|-------|-----|-----|---------------|---|---|*****************************|*********************************|***********************************|***********************************|--------|
| 1   | Major Diagonal (Lower) | Sweet Gum | No. 2 | No. 2 | 515 | 575 | 9 x 11 1/2 | 34,640 | 18,656 | 40,036 | 42,305 | GOOD |
| 2   | Major Diagonal (Middle) | Sweet Gum | No. 2 | No. 2 | 515 | 575 | 9 x 11 1/2 | 26,260 | 13,380 | 29,678 | 42,983 | GOOD |
| 3   | Major Diagonal (Upper) | Sweet Gum | No. 2 | No. 2 | 515 | 575 | 9 x 11 1/2 | 22,340 | 11,505 | 25,245 | 43,075 | GOOD |
| 4   | Subfloor Chord 1 | Sweet Gum | No. 2 | No. 2 | 515 | 575 | 8 1/4 x 12 | 36,360 | 7,917 | 37,247 | 37,069 | NOT GOOD |
| 5   | Horizontal | Sweet Gum | No. 2 | No. 2 | 515 | 575 | 9 1/4 x 14 | 10,298 | - | 10,298 | 94,379 | GOOD |
| 6   | Interior Diagonal | Red Oak | No. 2 | No. 2 | 515 | 625 | 8 3/8 x 8 5/16 | 7,632 | 2,687 | 9,443 | 62,973 | GOOD |
| 7   | King Post | Red Oak | No. 2 | No. 2 | 515 | 625 | 8 1/8 x 13 1/4 | - | 18,306 | 30,396 | 28,833 | GOOD |

*Adjusted Factors as per Table 40 - Design Values for Visually Graded Timbers (1" x 1" and Larger)*

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St. Peter's

Installation
~ Steel reinforcements
~ Sisters
~ Scabs
~ Epoxy treatments
St. Peter's

Tower Roof

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Lessons Learned
~ Identify the appropriate engineer for the project
~ Provide as much information as possible to your Engineer
~ Have a joint understanding of the goals and expectations
~ Understand the issues and the root causes
~ Understand your project deliverables
~ Understand the options available to avoid demolition
~ Know that within the Engineer’s Code of Ethics is the responsibility of ensuring the health, safety, and welfare of the public for their projects. This is a big responsibility so it is important that all involved understand the process.

Thank you!