LECTURE 3
VERTICAL-LOAD RESISTING SYSTEMS

ARCH 4433

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Framing Layout & Design

- *Layout* of *horizontal* structural framing is important because *beams* function by bending, and depths can get large relative to *columns*, which function by carrying axial loads
- Attention to *span lengths* and framing *direction* can save weight and keep beam depths *uniform*
- Selection of *materials* should be made with consideration of the intended beam spans

Recall that the floor framing is usually allocated to a limited zone below the slab and above the ceiling.

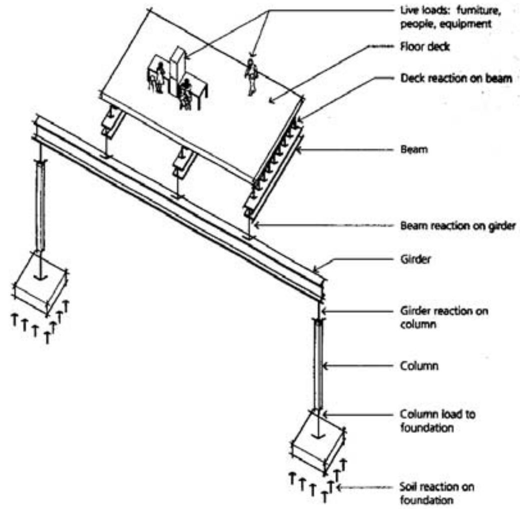
Effective utilization of structural depths means that members are more or less uniform in depth. Longer spans usually means deeper beams are needed to span. But loads and beam spacing also plays a part. Why?

$M = w * L^2 / 8$ is the *maximum moment* for a simply supported beam (the *demand*)
$S = b * d^2 / 6$ is the *section modulus* for a rectangular beam (the *capacity*)
M/S = maximum bending stress, or the controlling design stress so that span, L and depth, d are the most *sensitive* design parameters for floor framing

Increasing the beam span increases the demand by a factor of the increase squared.
Increasing the beam depth increases the capacity by a factor of the increase squared.

Load Path & Tributary Area

- Structural members transfer loads to each other until the forces reach the foundations (the *Load Path*)
- The area supported by each member is it’s *Tributary Area*
- Without a proper (or *viable*) load path, the structure is not stable



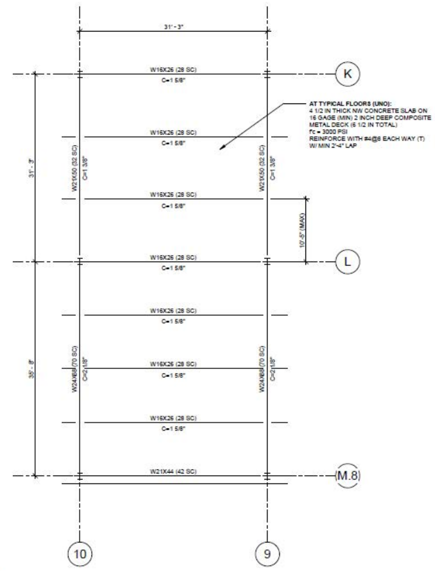
The *load path* is the route that loads take from their source to their final destination (the ground). In conventional framing systems, the load travels from its source to the *deck*, then to *joists* or *beams*, then *girders*, then *columns*, then the *foundation*, which bears on soil.

Every structural element in a framing system has a *tributary area*. This is an area in horizontal plan from which a member receives all its load. The load that a member takes can be estimated by multiplying unit loads by tributary area.

Both of these concepts are important to keep in mind when laying out framing (beams and columns).

Structural Bays

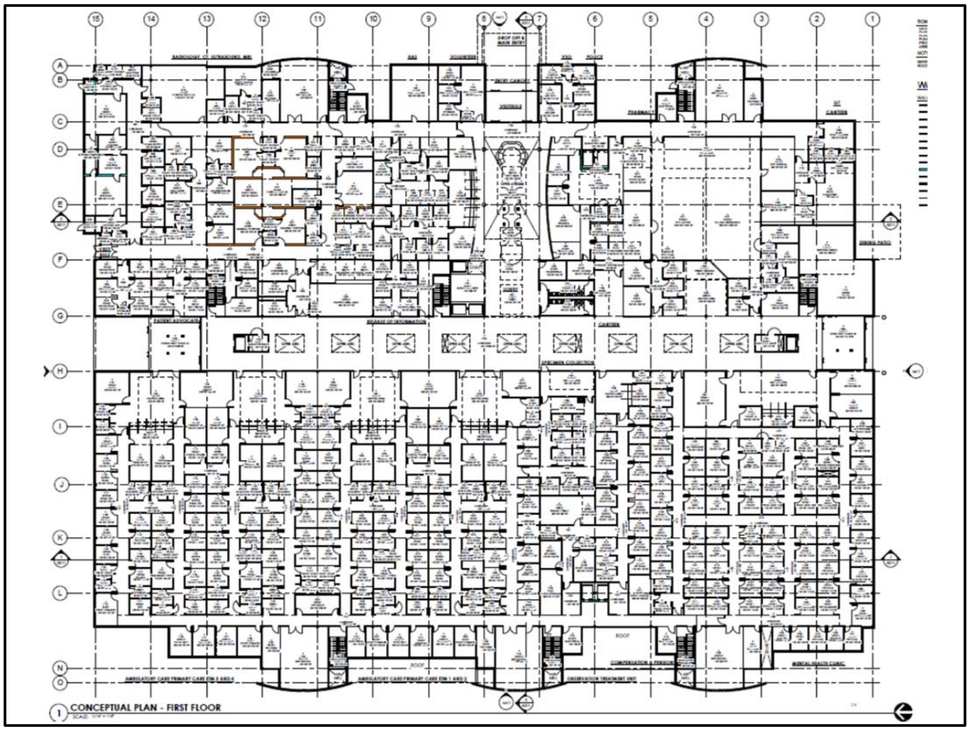
- The concept of a *bay* is used in laying out horizontal floor framing
- Bays are *delineated* by columns (here each bay has 4 columns)
- The framing needs to *infill* the bay so that the deck is fully supported



2 LEVEL 1 (PART), 2 & 3 TYPICAL BAYS

Again the load path in a conventional framing bay is:

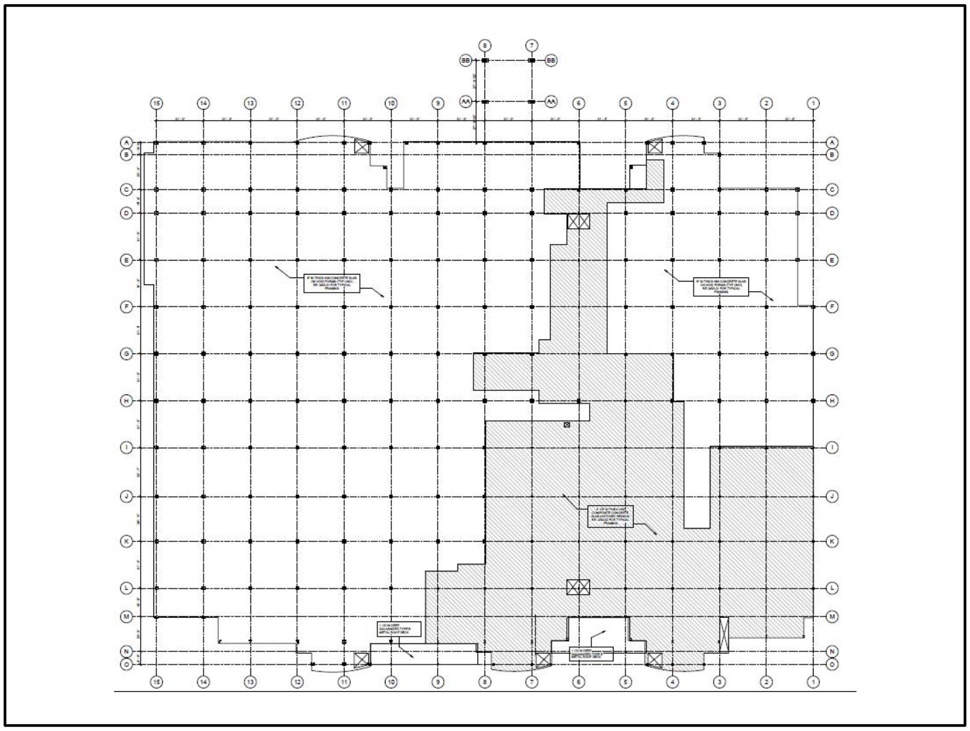
- Load source to deck
- Deck to infill framing
- Infill framing to girders
- Girders to columns
- Columns to foundations



VA Winston-Salem. First floor plan

Here we see an architectural floor plan showing the program layout and building exterior. These architecturally driven items need to be coordinated with the structure. One of the most important steps in coordination of architecture and structure is establishing a *grid* system that will become the common link between the program/building exterior and the structural column locations.

Columns are located as needed, but for practicality and streamlining of the structure they are usually placed on a regular grid. The basic grid is usually chosen to correspond to a *module* within the interior so that grid lines often coincide with interior partitions. In other words the column grid spacing is chosen based on the program module. For example the spacing between two typical offices divided by a hallway repeats at every 31’-3”, which is the grid spacing for most of the interior column grids. **This is how the program drives the grid spacing.**



Note how the building exterior (re-entrant corners) drives the location of some grids.
This is how the building exterior drives the grid spacing.

The grid intersections define the preferred column locations, which delineate the structural bays. If the columns are all “on-grid” then the bays become more regular and the framing is simpler and more cost effective. This is a goal but not a strict requirement.

Importance of Columns

- Unlike beams, columns pass through the space and impact the architecture
- Unlike beams, columns have to maintain their location from the ground up to the roof (unless they transfer)
- The success of the vertical-load resisting system depends on a reasonable column layout because **the column locations determine the bay dimensions and the beam and girder spans**
- Columns are laid out based on a *grid* in order to promote a *regular* and *simple* structural system
- But…deviation from the grid is usually necessary because of the demands of the space and program

As in most things there are rules and there are exceptions to rules:

Rules:

(1) Columns need to extend from the roof down to the foundation without any interruption
(2) Column bays need to be regular (i.e. based on a grid)
(3) Column spacing needs to be no more than the practical span limit for the material

Exceptions:

(1) Columns can "transfer" at any level so that the column does not bear on the foundation, but rather on a girder that carries the load to two other columns.
(2) Columns can be off-grid as needed and the framing can adapt but be less regular
(3) Column spacing can get as large as it needs to be as long as the appropriate structural framing is used to span between (this usually means deeper members, or more complicated systems such as steel trusses, engineered wood, or post-tensioned concrete beams).

Practical Span limits

- Normal span limits for typical materials:
  - **Wood** (dimensional lumber, nominally 2-4 inches thick) can span up to about 20 feet. Glulam and other engineered wood beams can span much further.
  - **Reinforced concrete** beams can span up to about 35 feet. Longer spans can be accommodated using post-tensioned systems.
  - **Rolled steel sections** (wide-flange shapes) can span up to about 45 feet. Longer spans employ trusses or plate girders (deep, built-up steel shapes).
- Spans beyond the normal range for all materials involve structural systems that are deeper or more expensive
- Cantilever span limits are much shorter – about 1/4 to 1/3 of the usual span limits

These span limits assume a reasonable structural depth that varies depending on the material used.

The notion of *practical* span limits presumes that an economical structural system will be used. Spans that exceed these limits are possible but require a *premium* structural system (such as post-tensioned concrete).

It should be noted that wood framing is usually supported by bearing walls so that the spacing between load-bearing walls should be 20 feet or less.

As a general rule of thumb when columns are used to support the framing, a target grid of 30 ft by 30 ft is a good starting point.

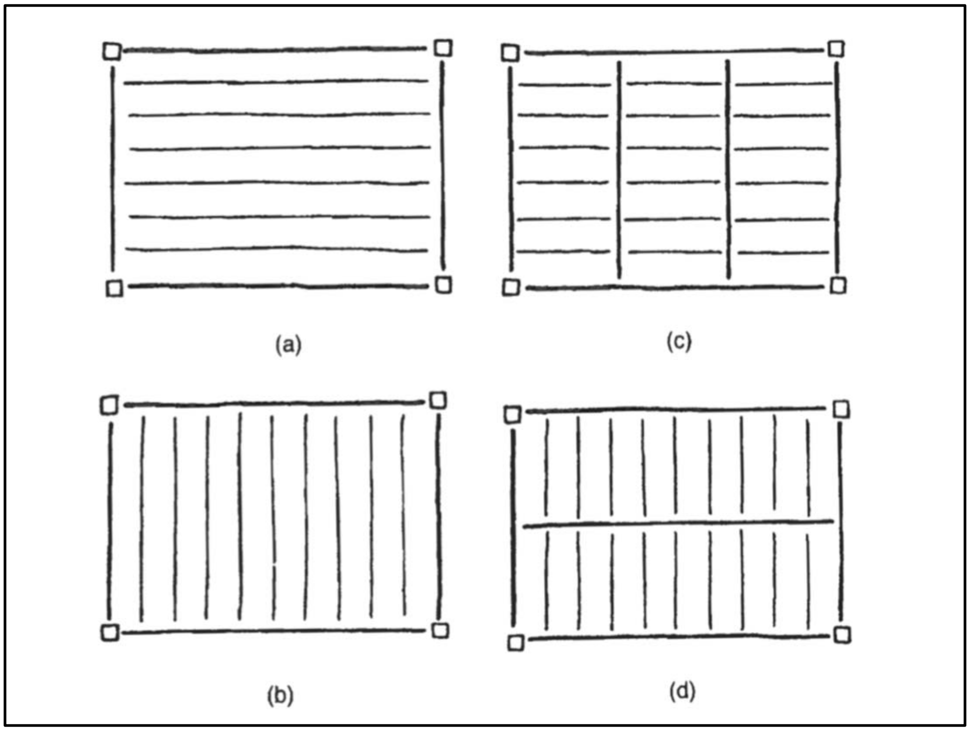
Typical Span Limits by Material

Material and Type of Framing	Span Limit (ft)
Steel Beams & Girders (rolled shapes)	45
Steel Bar Joists	50
Steel Trusses	150+
Steel Joist Girders	100
Mild Steel Reinforced Concrete Beams & Girders	35
Mild Steel Reinforced Concrete Two-way Slabs	30
Prestressed/Precast Concrete Beams	60
Post-Tensioned Concrete Beams & Girders	60
Post-Tensioned Concrete One-way Slabs	20
Post-Tensioned Concrete Two-way Slabs	40
Wood Framing (dimensional lumber)	20
Wood Trusses	30
Engineered Wood Girders (e.g. glulam)	50

This table gives span limits that include conventional as well as premium structural systems such as glulam, post-tensioned concrete, and steel trusses.

When planning column layouts the span limits should be considered and if practical span limits (given in the previous slide) are exceeded, then a specific structural system needs to be planned. For example, when laying out columns in a steel framed building it is best to use a grid with girder spans of about 30 feet and beam spans no more than 45 feet. If this can't be done, then a particular system such as steel joist girders should be planned. The column layout would then be based on a 30 ft by 100 ft (maximum) grid. **Depth of structure would be determined accordingly based on the depth of the premium system.**

In most cases where a premium system is needed it is common to use a conventional system in parts of the building that have less demanding program requirements.



The bay size is controlled by the column layout. Here a rectangular bay allows for multiple framing scenarios. Because of span limits one might choose these framing systems and materials:

(a) Say the bay is 45x30 ft with steel beams spanning the long direction (45 ft), and girders spanning the short direction (30 ft). Girders carry more load and should have short spans when possible.
(b) Say the bay is 45x30 ft with concrete joists spanning the short direction (30 ft) and post-tensioned concrete girders spanning the long direction (45 ft). Since the post-tensioned system can carry load more efficiently, the joist and girder depth may be uniform despite the girder having longer spans and more load. If the bay was 30x20 ft then wood joists with engineered wood beams (e.g. glulam) would be an option for the same reasons.
(c) Say the bay is 100x40 ft with steel beams spanning the short direction (33.33 ft left-to-right), steel girders spanning 40 ft up-and-down, and steel trusses spanning the long direction (100 ft left-to-right). Trusses are more efficient than beams and can span between columns while the beams span the shorter distance between girders.
(d) Say the bay is 45x40 ft with steel joists spanning the short direction (20 ft up-and-down), steel beams spanning 45 ft left-to-right, and steel girders spanning the long direction (40 ft up-and-down). Alternatively, a system of concrete joists with post-tensioned beams and girders could also be used.

Note that in all these examples the spans are in line with span limits given previously.

Wood Framing

Conventional wood framing for residential construction uses:

- Plywood deck at floor levels and roof
- Joists for infill framing at the floor and attic levels
- Rafters for infill framing at the roof
- Beams to frame around interior floor openings
- Header beams to frame over wall openings
- Stud bearing walls
- Wood posts as needed to support large concentrated loads that exceed the capacity of the stud wall

It is not uncommon to use prefabricated wood trusses or I-joists as infill framing instead of dimensional lumber.

Practical Span limits

- Normal span limits for typical materials:
  - Wood (dimensional lumber, nominally 2-4 inches thick) can span up to about 20 feet. Glulam and other engineered wood beams can span much further.
  - Reinforced concrete beams can span up to about 35 feet. Longer spans can be accommodated using post-tensioned systems.
  - Rolled steel sections (wide-flange shapes) can span up to about 45 feet. Longer spans employ trusses or plate girders (deep, built-up steel shapes).
- Spans beyond the normal range for all materials involve structural systems that are deeper or more expensive
- Cantilever span limits are much shorter – about 1/4 to 1/3 of the usual span limits

Recall that for wood framing the maximum span for joists and rafters is about 20 feet. This means that bearing walls need to spaced at no more than 20 feet.

Framing Examples

1. Typical layouts between walls
2. Framing around openings
3. Framing at door and window headers
4. Cantilever framing
   – Parallel to direction of joists
   – Perpendicular to direction of joists

Wood framing examples are available for download.

Steel Framing

Conventional steel framing for commercial construction uses:

- Metal deck with concrete slab at floor levels
- Metal roof deck at the roof
- Wide flange beams or bar joists for infill framing at the floor and roof levels
- Wide flange girders
- Wide flange or tubular columns

Practical Span limits

- Normal span limits for typical materials:
  - Wood (dimensional lumber, nominally 2-4 inches thick) can span up to about 20 feet. Glulam and other engineered wood beams can span much further.
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- Spans beyond the normal range for all materials involve structural systems that are deeper or more expensive
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Recall that for steel framing the maximum beams is about 45 feet. This means that columns need to spaced at no more than 45 feet. Also recall that since the girders are more heavily loaded a good structural column bay is about 30x45 ft.

Framing Examples

1. Typical Layout with known column spacing
2. Framing around openings
3. Framing to brace columns
4. Framing on a skew
5. Cantilever framing
   – At floor level
   – At roof level

Steel framing examples are available for download.