Concrete Members—Assembling Loads

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"Assume a dead load of 25 psf and a live load of 40 psf." Sound familiar? When you were in college, this phrase, or some variation, may have been a common utterance. It's this simple phrase, however, that forms the basis of this article (and could be the subject of a complete series of articles).

The concept of loads acting on a member, and the closely related concept of load paths, are two of the most critical, and sometimes abstract, ideas junior engineers must grasp. Not to appear overdramatic (we acknowledge that arguably everything a structural engineer does is critical to the safety of the public), and without attempting to prioritize the relative importance of structural concepts, we begin our series with this often-trivialized step in design. In this article, we summarize the major load constituents.

THE ORIGINS OF LOADS

The reality is that many academic programs may not have adequate time to devote to this abstract topic. While most "working stress" era engineers went straight from analysis to design, their fledgling colleagues spent additional time on the concepts of strength and probability. This disconnect widens the gap for passing information from mentor to mentee, because they may not even be communicating in the same engineering dialect. The following is our best attempt to outline the thought process as an engineer considers load.

The first step is to determine everything your concrete member will support. Even though this seems like common sense, it is not as simple as it may sound. There are a number of questions such as: Is your beam helping to support a floor or roof? If it is an exterior beam, will it support a façade? If so, are there special conditions and/or serviceability requirements that must be considered? For instance, there are different deflection limitations depending if the member supports curtain or glass wall or brick veneer. Of course, there could also be concerns such as controlling crack widths, minimizing vibrations, detailing for seismic loads, or even designing for blast resistance. The requirements for the structure should be viewed holistically.

In fact, the questions become even more detailed and complex. If the concrete member is supporting a roof, one must consider the roofing material. It may be built-up, and it could include ballast, concrete pavers, clay tiles, or some other material. If it is a floor member, one must determine the flooring material. It may be carpet, wood planking, tile, or perhaps raised computer flooring.

Members of the roof or a particular floor will normally also support suspended materials. These items may include such elements as suspended ceilings and mechanical ductwork and piping. Many of these materials are compiled

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into the elusive and mysterious "10 psf miscellaneous" superimposed dead loads. This value is not a constant and each of the load constituents must be examined carefully.

All loads supported by the structure must be carried to the vertical members to transfer them safely to the supporting ground at the foundation. Visualizing appropriate load paths to eliminate any discontinuities is very important. If different loads are spread in a complicated fashion over your structure, one of the authors has had success in color coding the floor plan to visualize and track the different loads—the key is to make sure you account for all loads acting on a member.

HITTING THE BOOKS

The American Society of Civil Engineers document ASCE 7-02, "Minimum Design Loads for Buildings and Other Structures,"[1] is a comprehensive resource that discusses many minimum design loads. Many building codes have adopted ASCE 7 for their design load criteria. It defines loads as "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. Permanent loads are those loads in which variations over time are rare or of small magnitude."[1]

The commentary of the American Concrete Institute's ACI 318-02, "Building Code Requirements for Structural Concrete and Commentary,"[2] discusses loads in this manner: "A number of definitions for loads are given as the code contains requirements that are to be met at various load levels. The terms dead load and live load refer to the unfactored loads (service loads) specified or defined by the general building code."

Section R8.2 of ACI 318-02's commentary states "The provisions in the code are for live, wind, and earthquake loads such as those recommended in 'Minimum Design Loads for Buildings and Other Structures,' (ASCE 7), of the American Society of Civil Engineers…If the service loads specified by the general building code (of which ACI 318 forms a part) differ from those in ASCE 7, the general building code governs. However, if the nature of the loads contained in a general building code differs considerably from ASCE 7 loads, some provisions of this code may need modification to reflect the difference."[2]

Further on in Section 8.2.4 of ACI 318-02, it states specifically: "Consideration shall be given to effects of forces due to prestressing, crane loads, vibration, impact, shrinkage, temperature changes, creep, expansion of shrinkage-compensating concrete, and unequal settlement of supports."[2] Some of these topics will be discussed in future articles.

Table 4.1 — Minimum unit weight, , for evaluat

Material	unit weight γ (lb/ft^3)	
Aluminum	170	Iro
Bituminous products		
Asphalt and tar	γ81	
Gasoline	42	Le
Graphite	135	Lin
Paraffin	56	
Petroleum	53	
Brass	526	Ma
Bronze	552	Ma
Cement, portland, loose	90	Ma
Ceramic tile	150	Ma
Charcoal	12	Mo
Cinder fill	57	Pa
Coal, piled	50	Ply
Concrete, plain	144	Sa
Concrete, reinforced	150	
Copper	556	
Cork, compressed	14	St

Fig. 1: IPS-1[3] is a comprehensive resource for weights of all types of materials (figure excerpted from IPS-1)

DEAD LOAD

Dead load is probably the easiest for junior engineers to understand. The definition provided by ASCE 7-02 says, "Dead loads consist of the weight of all materials of construction incorporated into the building including but not limited to walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding and other similarly incorporated architectural and structural items, and fixed service equipment including the weight of cranes."[1] Interestingly, as codes have increased in complexity, many no longer include fundamental information on weights. Fortunately, IPS-1[3] has a current and comprehensive listing of material weights (Fig. 1).

Self-weight of the structure is the most definitive load to calculate. Based on the density of the concrete, the member dimensions are easy to transform into dead loads…or are they? Did you know that pan forms have a 1:12 side slope for easier removal (Fig. 2)? This slope is negligible for the weight of a girder, but it has a greater effect on the total weight of a single joist.

Say you have a 6-in.-wide (150 mm) joist for a 20-in.-deep (500 mm) pan and a 4-1/2 in. (114 mm) slab thickness. This will add 3-1/3 in. (85 mm) to the rib width at the top of the pan. Instead of its nominal self-weight totaling 153 plf (2.2 kN/m) {[(24.5 × 6 in.)/144] × (150 pcf)}, the actual self weight is 188 plf (2.7 kN/m) {[(4.5 in. × 6 in.)/144 + (20 in. × 7-2/3 in. (avg. width))/144] × (150 pcf)}. This is a 20% increase in the joist weight, translating to an 8 to 12% increase in the floor dead load.

Self-weight is only a portion of the dead load. The tricky part of determining overall dead load, as mentioned earlier, is figuring out what the member is actually supporting. If the member is an exterior beam, it may have exterior cladding to support. Consider the cladding to be comprised of precast spandrel panels. How the panel is attached to the structure greatly affects the design of the perimeter framing.

One option may be to connect the spandrel panel directly to the columns without requiring the exterior beam to support the additional gravity load. The other option is to rest the panel directly on the beam, adding to its total dead load and perhaps inducing additional deflection limitations.

These questions are all related to load path. Even though a structural engineer may be focused on the design of structural members, other disciplines must be considered as well. As an example, consider the weights of mechanical and installed systems and their associated structural requirements. ASCE 7-02 states, dead load should also include "…the weight of fixed service equipment such as plumbing stacks and risers, electrical feeders, and heating, ventilating, and air conditioning systems..."[1] Project coordination with the mechanical engineering design team—and other relevant disciplines—is necessary.

LIVE LOAD

Of course, not all live loads are literally alive. *All* human beings do constitute live load (think of occupancy requirements). Movable partitions and storage are live loads as well. If it's not a permanent fixture or caused by nature, you must consider it as live loading.

Live load due to occupancy is defined in ACI 116R-00[4] as "…any load that is not permanently applied to a structure; transitory load." Also, according to ASCE 7-02, "Live loads are those loads produced by the use and occupancy of the building or other structure and do not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load, or dead load. Live loads on a roof are those produced (1) during maintenance by workers, equipment, and materials, and (2) during the life of the structure by movable objects such as planters and by people."[1] IPS-1, IBC,[5] and ASCE[7] all list the minimum uniformly distributed live loads to be used in the design of buildings and other structures. Chapter 2 of ASCE 7-02 contains provisions for partitions, concentrated loads, live-load reduction, minimum roof live loads, crane loads, and impact forces.

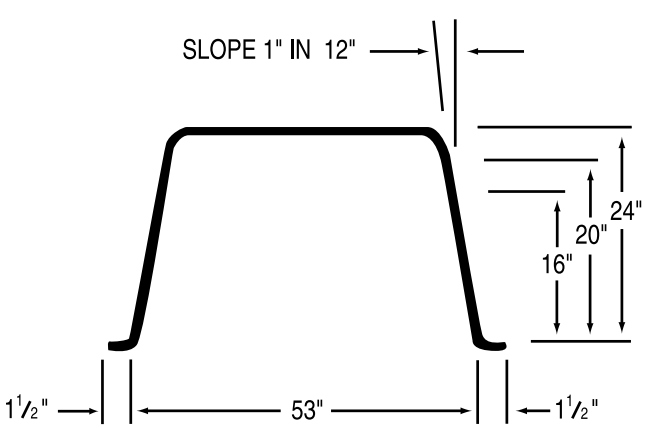

Fig. 2: Typical pan forms are tapered at 1:12, and this extra concrete weight can add up (figure adapted from Ceco Concrete Construction)

SOIL AND FLOOD LOADS

There may be instances when soil is a gravity loading on the roof of a concrete structure or a permanent lateral loading on a building with a subgrade portion. Lateral soil loads typically equal some percentage of the weight of the soil acting against a basement or retaining wall. When water is present, the loadings become more complex. Soils retaining moisture may induce increased pressure on basement walls, as well as uplift on floors and foundations.

WIND LOAD

Wind loads on a building must be examined at two stages: at construction and during service. Because the weight of the building and its components typically counteract forces caused by wind loading, the building connections and members may have to resist more of the wind force during construction, before the full load of the building is applied. For example, a tilt-up wall panel that is not yet braced by the roof will act differently during construction than when the roof is in place, at which time the wind loading can dissipate through the structure. It also must be noted that loads anticipated during construction can be based on a shorter recurrance interval (and thus lower in magnitude).[6] ASCE 7-02, Chapter 6 states, "buildings and other structures, including the main wind force resisting system and all components and cladding thereof, shall be designed and constructed to resist wind loads as specified herein."[1]

SNOW LOAD

Designers of most structures located in the U.S. have to consider snow loadings on roofs. There are different snow loadings given in Chapter 7 of ASCE 7-02, depending on ground snow loads that relate directly to a structure's location in the U.S. In some locations, such as the warmer

southern and southwestern portions of the U.S., the snow loading will not control design. For the remaining locations with governing snow loads, it may not be as simple as applying a uniform surface load.

Complexity in determining the resultant snow loads on a given roof member depends on whether or not the structure's roof is flat or sloped, warm or cold, partially loaded and/or subject to unbalanced loading, has projections, whether the snow drifts, or even if there is rainwater caught on the snow. If the sloped roofline is stepped, there may be conditions where the snow slides off a higher elevation and generates an impact sliding snow load on a lower roof elevation.

Even adjacent buildings can affect the snow loading. Depending on a building's proximity to an adjacent higher structure, your building may experience additional snow drifting. Again, the holistic approach to design of the structure from a local and global perspective must be considered.

RAIN LOAD

Chapter 8 of ASCE 7-02 includes design rain load, ponding instability, and controlled drainage. The document states: "'Ponding' refers to the retention of water due solely to the deflection of relatively flat roofs."[1] With proper slope to a concrete roof, this is rarely a problem. This type of loading is more critical for steel construction that does not have adequate stiffness nor sufficient slope for a relatively long span.

SEISMIC LOAD

Just because you may be designing a structure in the midwestern region of the U.S. does not mean you can completely ignore this type of loading. Seismicity is no longer based on the frequency of a seismic event, nor is it limited to California and Alaska. IBC 2003 has a more refined seismic risk definition incorporating the importance and usage of the structure, as well as the soil conditions at the site. Determination of the seismic

design category (SDC) per the IBC 2003 may require seismic detailing for structures once excluded from seismic consideration in previous editions of the model codes.

For concrete buildings, Chapter 21 of ACI 318-02 gives the code requirements when detailing for seismic "…design forces (that are) defined in documents such as IBC, the UBC, and the NEHRP…,"[2] as noted in the commentary 21.2.1.1. "Seismic and Wind Design of Concrete Buildings"[7] collates and explains these code requirements, based on the type of lateral force resisting systems. These documents all provide similar methods for determining the forces felt by the structure based on the structure's weight and geometry.

A HEADS UP

As mentioned previously, all loads must be considered during construction, not just when the structure is in service. Sometimes, depending on the construction job's sequencing, construction loads may be critical. When will the shoring be stripped? It will almost always be prior to 28 days when concrete attains its design compressive strength. A post-tensioned structure has member stresses that must be checked at time of tendon stressing, normally occurring at approximately 60% of its 28-day concrete strength.

The final point: most of the loads discussed thus far, except the weight of the member itself, are externally applied—wind, live loadings, and the like. There may be cases where the structure must resist internally applied forces. For instance, shrinkage and temperature change generate additional stresses that must be considered. Depending on the geometry of the building, these stresses may be large enough to consider pour strips or expansion joints. This enters into the world of constructibility, which will be discussed in future articles.

Yes, it's complicated. It's all part of the learning process as you hone your engineering abilities and grow your expertise as a designer. In conclusion, these are only brief discussions on some of the aspects in assembling loads.

Do you have another topic that might be worthy of an article? As a young engineer, is there something that you find confusing? Seasoned engineers—do you remember back when you were a new designer—the problems you had? Please send in your ideas—we welcome ideas for additional topics.

Selected for reader interest by the editors.

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