

Floor Levelness in Building Construction

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An overview of how structural engineers can control deflection and pitch with regard to floors.

A FLOOR WITH ACCEPTABLE FLATNESS and levelness is important to the owner of the building and the client who leases the space. Items that can be affected by the floor include doors (see Figure 1), elevator sills, interior walls, workstation partitions, file cabinets, long storage areas, long conference tables, and floor tile. Some of these items—like workstation partitions—have adjustable components that can accommodate a vertical tolerance of about 2 in. to allow for leveling. Nonetheless, the designer should have an active strategy to provide acceptably flat and level floors so that the majority of these adjustments are nice to have but not needed in their entirety.

It should be noted that the typical structure does not have floors that achieve perfection; fortunately, perfection isn't required. Having floors that are level within a 2 in. vertical envelope means that the differences will be inconsequential for most applications. Where levelness to a more exact envelope is required, the occasional use of leveling compound may be an attractive and economical solution. Leveling compound is commonly used to prepare a floor to receive its final material finish.

As illustrated in Figure 2, floor flatness and floor levelness are two different things. A floor can be level but not flat, and conversely flat but not level. Flatness pertains to the surface roughness of the floor. It is traditionally measured over a 2-ft-square area.

Floor levelness refers more globally to the overall deflected shape and pitch of the floor over a certain dis-

tance. Deflection of floor framing is a matter applicable to all buildings regardless of height. Floor pitch is a potential levelness concern most often only encountered in tall building construction. Both deflection and pitch considerations will be addressed here.

Deflection Considerations

Every floor will deflect to some extent under service loads. An engineer can address floor deflection effects on levelness in one of three ways:

- ▶ Let the deflection occur and design for the extra “ponding” of concrete that will have to be added to the center of the span to form a flat slab. This is not a recommended solution.
- ▶ Choose deeper or heavier floor framing to limit deflections. If the designer is not limited in structural depth, choosing a deeper member is the most economical solution to diminish deflections. Extra stiffness can be achieved with little additional weight if the designer can choose a deeper member. However, if the structural depth is limited, a heavier member can be chosen but it can require a significant increase in material to achieve the desired effect. In this scenario, cambering may be a more economical choice.
- ▶ Camber the floor framing to account for a portion of the dead load. A good rule of thumb is to camber for 80% of the dead load deflection. This normally will mean that slab placement will cause the cambered beam to deflect to a mostly flat condition. It is advisable to have a conversation with the steel fabricator and general contractor to discuss the use of camber. Not all contractors have experience placing concrete on a cambered floor system. Also, there are some framing situations in which camber is not a good choice (see the “Additional Resources” sidebar).

In any case, there should be an adequate clearance dimension between the bottom of the floor structure and the finished ceiling to accommodate the amount of deflection that will occur. A 1-in. dimension is a good minimum starting point to accommodate this, but larger members may require more of a clearance. Having the finished ceiling abut tightly to the structure can create construction difficulties.



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► Fig. 1: Floor levelness can affect finishes like this office door.



Photos and figures by Magnusson Klemencic Associates, Inc.

Floor Pitch and Differential Shortening

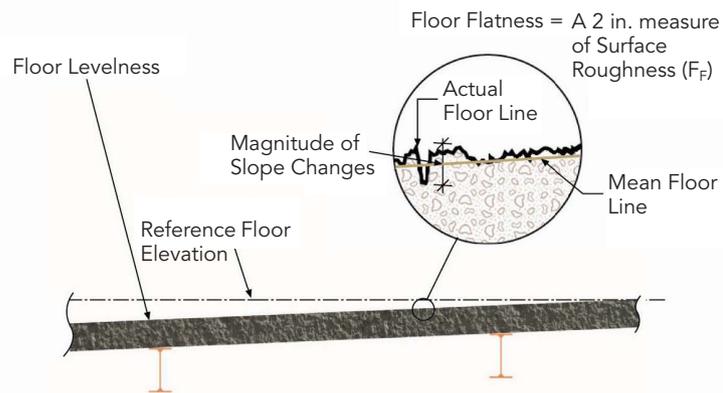
Floor pitch is the slope of a slab between two points, such as between the core and the perimeter of a building. It can be affected by many variables, including the type of structural system used. For example, a steel frame with a reinforced concrete core system has factors such as those illustrated in Figure 3. Concrete tolerances, core wall shortening, perimeter column shortening, foundation settlement, and steel fabrication and erection tolerances all can contribute to floor pitch.

Steel shortens elastically under load by an amount that can be calculated with the equation $\Delta = PL/AE$. Generally, this is not an issue in buildings with fewer than 20 stories. Although the engineer initially might be concerned about core wall shrinkage in a tall building with steel framing around a reinforced concrete core, perimeter column shortening will play a greater role in differential shortening of the perimeter relative to the core. The area of the column, A , in the equation gives a clue as to why. The combined cross-sectional area of all of the steel columns is usually much smaller than the cross-sectional area of the concrete core walls. In addition, the core walls usually are stressed to a lower percentage of their vertical strength than the steel columns because the core wall is normally designed to act as part of the lateral system in addition to carrying gravity load. Therefore, the majority of the shortening in tall buildings will be in the steel columns.

Floor Pitch Strategies

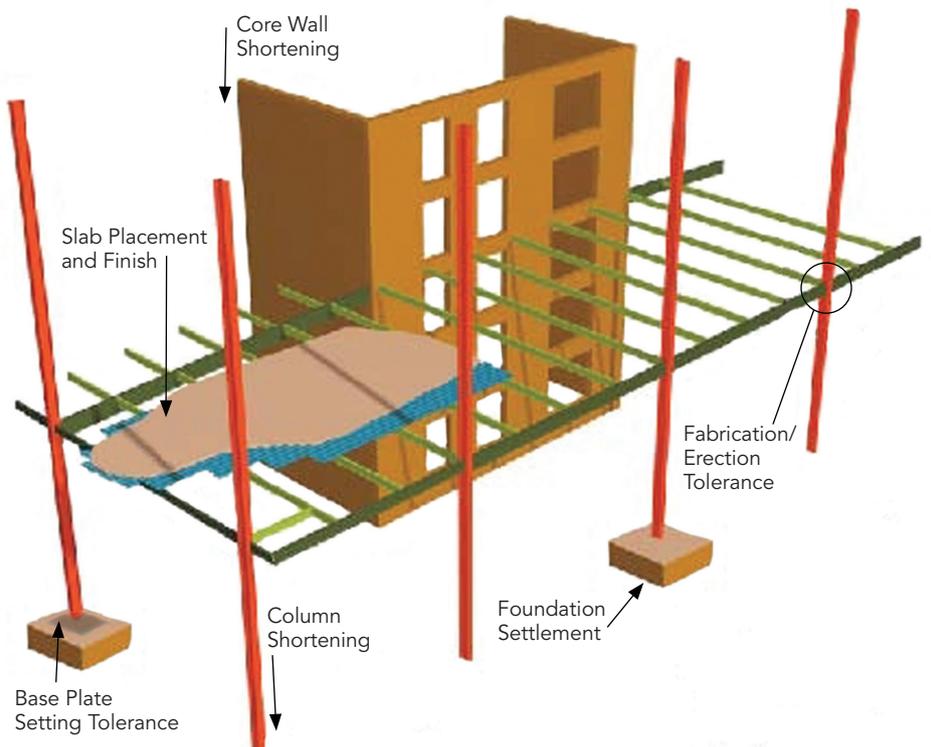
Because many variables contribute to floor pitch (as illustrated for one example building in Figure 3), it is helpful to decide which can be controlled and which can be accommodated through in-process adjustment. Understanding the means and methods the contractor will use to build the core and framing is important when selecting the right strategy to achieving a reasonably level floor. The recommended actions depend on the height of the building and the structural system. The recommendations below are for a building with a concrete core and steel perimeter framing.

On buildings of 20 stories or less, an active strategy to compensate for core and perimeter shortening generally is not needed. In this case, the contractor typically will use the “tape-up” method to build the core—the concrete core is built based upon the design floor-to-floor height,



▲ Fig. 2: Floor flatness vs. floor levelness. Note: Floor levelness (F_L) is not to be specified for elevated, unshored construction.

▼ Fig. 3: Variables affecting floor pitch.



measured from the previous floor. There does not need to be an active survey to level off columns or the core in most situations.

For taller buildings, a more typical strategy is to build the core walls to the design elevations and lengthen the perimeter columns based upon the loadings and construction sequence. As the core is built, it will experience shrinkage. On higher floors, the core might require an extra frac-

tion of distance to be placed to the design elevation level. By building the core to the design elevation, this is a variable that can be controlled. Then, the elevations of the steel column splices can be adjusted periodically. One possible strategy is to have the columns fabricated slightly long to offset some of the shortening they will experience. This strategy allows—and often requires—adjustment of the fabri-

cated length of columns in the next tier based upon the actual shortening in earlier sequences. This requires active coordination by the EOR, GC, fabricator and erector. Refer to Table 1 for recommendations for buildings of various heights.

Attempting to accommodate long-term shrinkage of the core by building it high is not recommended because it might take up to three years for the core to fully shrink. This will result in significant floor pitch for several years until the core experiences its final shrinkage.

Where floor levelness is a critical project consideration, it may be desirable to consider using a raised access floor. This can guide your decision on column over-lengths. If a building is to be built with a raised access floor, it may be best to err on the shorter side of adjusting column over-length. If there is a slight floor pitch to the outside, the ceiling below can normally accommodate it. This also ensures the maximum clearance below for any MEP runs at the core, which is where they need the most space. The raised floor can be adjusted slightly shorter at the elevators. If there is to be no raised access floor, it may be best to err on the side of having

Table 1 – Recommended strategies for controlling floor pitch.

Building Height	Recommended Action for Floor Pitch
1-20 stories	No action necessary for floor pitch.
20-30 stories	Evaluate system, possibly no action needed; possible use of shims to periodically level out columns. Build core to design elevation.
30-40 stories	Build core to design elevation. Consider lengthening each tier—usually a two-story column—by 1/16 in. Additional shims at column splices if necessary. Actively survey and level off columns to design elevation using shim plates twice, at third points of height.
40-60 stories	Build core to design elevation. Consider lengthening each tier (two-story column) by 1/8 in. on lower floors and 1/16 in. on upper floors. Actively survey and level off columns to design elevation using shim plates approximately every 15 floors.
60+ stories	Active strategy needed based upon detailed shrinkage analysis of core and perimeter using staged construction loading. Over-lengthening of columns recommended. Build core to design elevation. Actively survey and level off columns to design elevation using shim plates approximately every 15 floors.

the perimeter columns longer so that any pitch occurs down to the center. This can be accommodated with leveling compound at the elevator sills.

Team Coordination and Specification Language

A floor levelness approach needs to be adopted by the design team prior to construction. Typical language might state that the maximum allowable pitch between the slab at the central core and the perimeter is 2 in. However, this leaves open the possibility that one side of the building might be 2 in. high and one side 2 in. low. It is important to be specific and state the criteria, possibly that the envelope from high point to low point on the floor should be no more than 2 in. The strategy to be used may impact the chosen envelope, and should be discussed prior to specification.

Ideally, steel elevations during construction should be read early in the morning, before sunrise, to minimize the impact of temperature effects. Taking consistent surveys allows the erector to make mid-course adjustments as necessary. It is good to have column splice elevations sent to the GC and SEOR regularly to ensure that the necessary communication and coordination takes place.

The main goal is communication. Put floor levelness on the list of topics to be discussed at a pre-construction planning meeting. Getting everyone from the design team to the construction workers on board with the strategy will help keep the project running smoothly. **MSC**

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Additional Resources

Additional information related to floor construction can be found in the articles "Specifying Camber" by Erika Winters-Downey (MSC July 2006) and "Tolerating Tolerances" by Kurt Gustafson (MSC June 2005). Both are available as free downloads at **www.modernsteel.com/backissues**.

Another good reference on the subject is AISC *Steel Design Guide No. 3, Serviceability Design Considerations for Steel Buildings*. All of the AISC design guides are available at **www.aisc.org/dg** as free downloads for AISC members and for purchase by others.