PRACTICAL SOLUTIONS

solutions for the practicing structural engineer

Post-Tensioned Concrete Balcony Deflections

Maintaining Positive Drainage

By Seth Rogge, P.E.

Seth Rogge, P.E. is an Associate at Smislova, Kehnemui, and Associates located in Potomac, Maryland. He has over 10 years of design experience of residential high-rise, post-tension buildings. He is currently pursuing his Ph.D. at The University of Maryland. Seth may be reached at ***sethr@skaengineers.com****.*

Balconies are considered a desirable feature in apartment units. They represent an important extension of the living space into the outdoors and provide homeowners their own quiet spot to enjoy the surroundings and city views. However, within the last decade, an explosion in the use of post tensioning in high rise buildings has given way to a common complaint – negative drainage of rainwater in balconies. While there are a variety of factors that can affect water draining into residential units, careful engineering should be key in maintaining a positive slope. With tight construction tolerances placed on the general contractor to maintain positive drainage away from units, the blame for poor drainage has shifted in some cases to the design engineer. While the design of a balcony may seem eerily simple, thinner slabs, longer spans, and higher post tensioning forces have given way to this recurring issue in residential construction. Careful design and review of the entire lifecycle of a balcony should be analyzed – from the time of stressing to long term deflection reviews.

Balcony Types

The geometry of a balcony can vary from each building, but usually fall within two categories. The first category is the true cantilevered balcony (*Figure 1*). These types of balconies project approximately 5 feet from buildings and can vary in width from 8 to 12 feet. The second category includes interior balconies. An interior balcony is usually supported by the same floor system and has columns in relative close proximity (*Figure 2*). There is no cantilevered action occurring at these types of balconies. Regardless of the type of balcony, fall protection is either in the form of a standard railing or heavy built-up parapet walls. Architects typically determine the drainage requirements and the required step in the slabs for balconies.

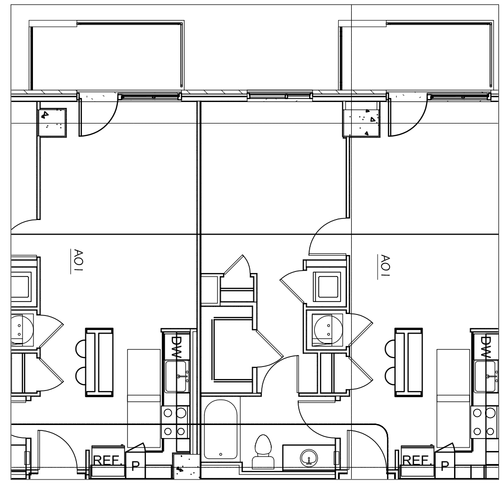

Figure 1: Typical floor plan with a true cantilevered balcony.

Obviously, positive drainage is needed away from the residential units and off the edge of the exterior balcony. A step in the slab followed by a sloped top slab leaves 1 to 2 inches less of concrete at the ends of the balconies. A minimum required slab thickness is often stipulated by the structural engineer. With the requirement of a step down in the slab, the end result leaves a minimal slope between ⅛ inch to 1⁄16 inch per foot of slope. While the two types of balconies serve the same purpose for the unit owner, the designs are somewhat different.

Design and Rotation

True cantilevered balconies are often designed to account for positive bending stresses over the top of the slab. To counterbalance these top stresses, additional top steel and post tensioning cables often continue over the column and into the balcony slab. While maintaining serviceability requirements can be achieved with enough post tensioning and reinforcing bars, deflections in the cantilevered balcony are often difficult to determine. The final slope of the balcony for drainage will depend on the

continued on page 20

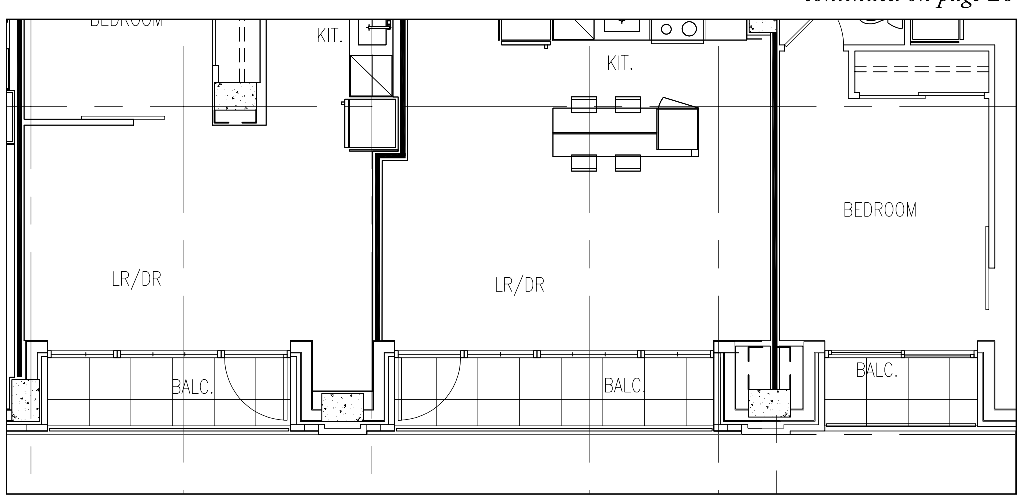

Figure 2: Typical floor plan with interior balconies.

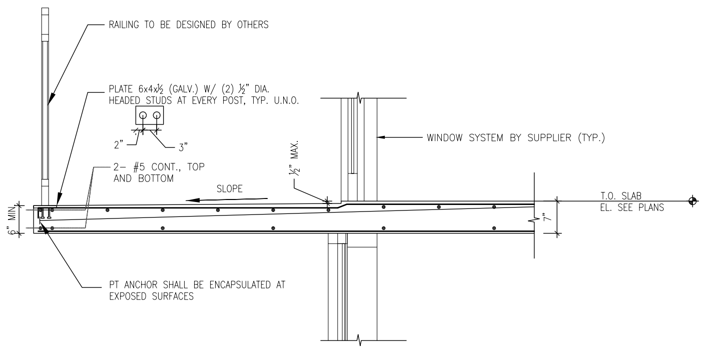

Figure 3: Cross-section of a true cantilevered balcony.

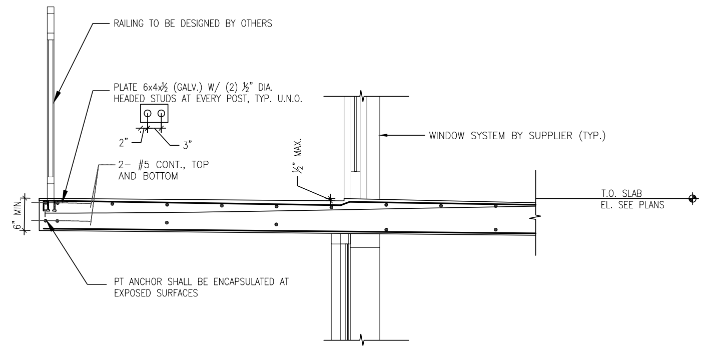

Figure 4: Cross-section of a true cantilevered balcony with anticipated rotation.

back span of the slab and the relative rotation (*Figure 3*). With a thinner slab at the ends, this has the reverse effect of less dead load over the balcony, thereby creating a horizontal plane or even a reverse slope on the balcony. If deflections in the exterior bay due to dead load are approaching the maximum tolerable limit, this in turn would provide more rotation at the ends of the balcony (*Figure 4*). Interior balconies, on the other hand, have the same stresses as a typical floor. The main difference is a reduced slab thickness within the balcony. The slope of the interior balcony significantly impacts the deflection of the exterior bay. Rotation along the exterior edge of the balcony due to the deflection in the exterior bay will certainly cause some loss in slope of drainage. If the immediate dead load deflection was equal to the step in the slab, the rotation induced by this deflection would cause a balcony slab that was practically level. Any additional induced deflection due to the long term effect of live load will certainly reverse the drainage in the balcony slab.

Post Tensioning Concerns

Post tensioning can also have a large impact on the design and deflections of balconies. As slabs become thinner and spans become longer in residential units, the need to counterbalance the forces and stresses in the slab is provided with post tensioning (PT). While the PT cables can play a significant role in deflection issues within the flat plate construction, the high internal force can sometimes have the opposite effect in balconies. A careful evaluation in the pre-compressive forces needs to be performed during design. For a true cantilevered balcony, post tensioning cables are often continued over the column and into the balcony to help with downward deflections and top stresses. However, pre-compressive forces can be much higher at the balcony edge. With the step in the slab and top of slab sloping to a minimum stipulated thickness at the ends, the effective area can be reduced by as much as 15%. This potentially can cause two problems. The first problem may arise during stressing. With a reduction in area, the compressive forces acting at the edge of the balcony during stressing could cause the concrete to crush and debond (*Figure 5*). This can be a headache for the general contractor and the concrete subcontractor. Remedial fixing and spliced stressing may be required. The second issue with a high amount of stressing at the ends could result in an over amount of reversed deflection. While post tensioning is used to control deflections, a high amount of stressing could negate any possible downward slope required for drainage. For an interior balcony, not only is the amount of stressing force an important characteristic in controlling reversed defections, but low points within the balcony slab need to be analyzed. If too much force and too much drape are placed within the interior balcony, the force pushing up in the slab due to drape can also reverse the slope and drainage requirements. A potential of tendon pop outs is also probable with less concrete in the interior balconies (*Figure 6*).

Figure 5: Crushed PT ends at a balcony slab edge.

Figure 6: Tendon popout at a balcony slab.

Loading

Anticipated loading can also play a huge role in how a balcony slab will deflect. While long term deflection is an important benchmark and guideline for following and maintaining standards, the life cycle a balcony slab experiences should also be evaluated. From the start of concrete pouring and stressing, deflections need to be evaluated for the construction loads and attachment of doors and railings. If the initial deflection of a balcony slab is out of tolerance, the attachments of railings become difficult and sometimes improbable. Live loading within the balcony should also be evaluated and reviewed. *Figure 7* shows a typical post tensioned floor slab with the anticipated long term deflection, including

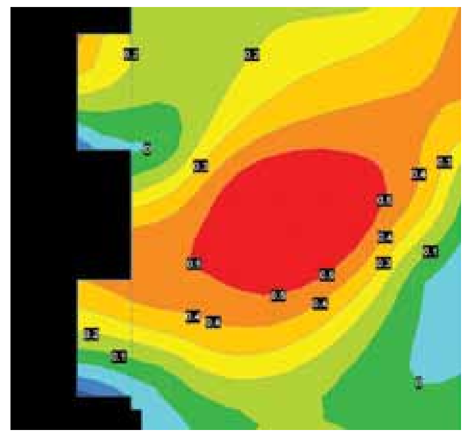

Figure 7: Anticipated long term deflection at a true cantilever balcony with full dead and live loading applied.

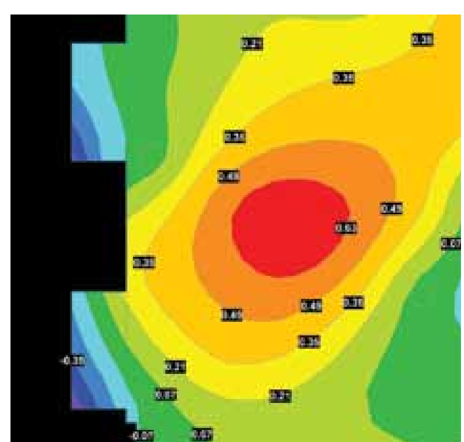

Figure 8: Anticipated long term deflection at a true cantilever balcony with only dead load applied.

full live load on the balconies. With full live load added to the deflection load combinations, minimal positive deflections at the balconies are prevalent. In *Figure 8*, the long term deflection is also calculated but the live load is removed from the balconies. With the removal of live load, the balcony deflects upward due to the amount of post tensioning in the slab. While building codes stipulate a minimum live load the balcony must support, an interesting study by Johnson and Merkel reviewed 100 balconies to determine the actual live load placed on balconies. It was found that, on average, a residential balcony can experience 50% less live load during a one year study period. While long term deflections are often difficult and hard to predict, balconies should be reviewed not only for the full long term dead and live load deflection, but also take into consideration that most balconies experience far less live load demand. If there is an anticipated live load that is missing from the balcony slab, this has the direct effect of less load weighing the slab down and therefore only has the full long term dead load and self-weight associated with a downward deflection.

Corrective Measures

Depending on the nature and severity of the drainage, certain corrective measurements can be taken. In a recently built apartment building in Alexandria, Virginia, several of the tenants complained about water ponding on the top of the balcony (*Figure 9*). Although water was not seeping back into the units, the standing water was causing concern for the unit owners. A survey of the existing balconies was done to determine the severity of sloping. A ground penetrating radar scan was done to determine the clear cover of the top bars. After reviewing

Figure 9: Water ponding at an existing balcony.

Figure 10: Typical completed through wall flashing repair for remedial fix to balcony drainage issue.

the existing structural drawings, it was determined that minor grounding of the top concrete surface could allow for proper drainage and not compromise the required clear cover for the top bars as specified in the structural drawings. In other cases, a small amount of patching compound was applied to the top surface and skimmed down to the edge of the balcony creating the necessary sloping needed to drain the water off the balcony. The patching compound applied could only be ¼-inch thick at its maximum point due to the proximity of the door and not create a tripping hazard when tenants walk in and out of their balconies. On more severe cases, when the amount of patching compound or grinding would not be sufficient to create the necessary drainage, a thick continuous waterproofing membrane on the top surface of the concrete balcony and an adhesive waterproofing sheet was applied at the joint between the exterior of the balcony and the edge of the unit (*Figure 10*). While this only created a temporary fix to help protect the residential unit from ponding water seeping into the livable area, more invasive measures would be needed later. These measurements included demolishing the balcony and rebuilding with appropriate drainage requirements.

Conclusion

While the ACI Building code specifies total long term deflections due to live load and incremental loading of structures after the attachment of non-structural components, there has yet to be a total deflection criteria adopted. Therefore engineers that look to the code for deflection requirements often overlook the entire load history a balcony may experience and not take into consideration the possibility of a reversed deflection. While designing a balcony may seem like just another extension of the flat plate slab system, prudent engineering should be maintained to ensure and verify that deflections do not interfere with the required drainage requirements.▪

ADVERTISEMENT - For Advertiser Information, visit www.STRUCTUREmag.org