by Bruce A. Suprenant

Understanding Balcony Drainage

Why does water drain the wrong way when it rains?

The contractor was frustrated as he prepared to place the eighth story of a cast-in-place reinforced concrete frame. The multifamily residential structure included balconies on all four sides. After formwork for the first floor frame had been stripped, the architect and general contractor noticed that rainwater on the balconies drained toward the living area. The architect's drawings required a surface that sloped away from the living area, so the contractor was told that his formwork must have been set wrong, thus causing the water to run the wrong way. Workers ground and patched the first floor balconies to correct the situation, and the contractor was determined to make sure the formwork was set right for the second floor. However, the same thing happened again.

The contractor determinedly tried to get the forms set in the right place during subsequent placements and monitored elevations while concrete was being placed. But after the forms were removed, rainwater still ran in the wrong direction on the balconies. After trying to solve the problem on each of the first seven floors, but still having to grind and patch, the contractor asked a consultant to review the formwork procedures to make sure this problem wouldn't occur on any future projects. The consultant's response was brief: "Form setting methods can't compensate for the deflection of the structure, which is the cause of the problem; therefore the water will always drain toward the living area." To understand why this is true, we need to examine what happens during and after design and construction.

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SETTING THE DRAINAGE SLOPE

Architects typically determine drainage requirements for balconies. Obviously, they want water to drain away from the living area. The minimum recommended balcony width is 5 ft (1.5 m) and most residential balconies are 5 to 7 ft wide (1.5 to 2 m). A 1/2 to 1 in. (13 to 25 mm) stepdown in the balcony deck at the door is typically specified, with the deck sloping away from the door.

The architect's choice for the depth of the stepdown and the engineer's recommendation for minimum slab thickness at the slab perimeter typically determine the slope of the deck. For the 8-in.-thick (200 mm) slab shown in Fig. 1(b), the engineer set a 7 in. (175 mm) minimum slab thickness at the building edge. With a 1/2 in. (13 mm) stepdown at the door, the vertical fall over 7 ft (2 m) of balcony could not exceed 1/2 in. Based on a 7-ft-wide balcony, a 1/2 in. stepdown, and the engineer's requirement for 7 in. minimum slab thickness, the drainage slope can't exceed about 1/16 in./ft (5 mm/m).

Everyday Issues

ACI 302-96, "Guide for Concrete Floor and Slab Construction," states that "positive drainage requires a slope of 1/4 in. per ft (20 mm/m) for an exterior slab; for an interior floor slab, 1/16 in. per ft (5 mm/m) minimum is adequate for drainage, but 1/8 in. per ft (10 mm/m) is preferred." Because of the engineer's requirements for minimum slab thickness and the architect's choice of balcony width, balcony drainage slopes are almost always too mild to drain properly. With the added possible negative effects of construction tolerances for form setting and concrete finishing, it's highly likely that water will drain toward the living area even if the slab doesn't deflect. When the slab does deflect, drainage toward the living area is almost certain.

HOW DEFLECTION AFFECTS DRAINAGE

Figure 1 and 2 show typical details for a balcony set inside the perimeter columns and a cantilever balcony, respectively. The behaviors of both are similar. The architect draws the balcony as shown in plan view in Fig. 1(a) and 2(a). The section views through the balcony in Fig. 1(b) and 2(b) show the stepdown, the balcony slope, and the slab thickness at the door and at the balcony perimeter. These figures show the water draining away from the living area but don't take into account the deflected shape of the slab after form removal. Figure 1(c) and 2(c) show why, when the structure deflects, water drains into the living area. Unless this structural behavior of the slab is considered, as explained below, the water is unlikely to drain in the direction the architect planned.

Interior balcony

For the interior balcony, slab deflection inside the building rotates the slab about the exterior edge of the balcony, causing a slope change and drainage in the wrong direction. If the immediate dead load deflection at the middle of the slab was about 1/2 in. (13 mm), the edge rotation of the slab would make the initially sloping balcony surface about level. If the dead-load deflection exceeded 1/2 in., the balcony slab edge rotation would create a slope on which water drained the wrong way—back toward the living area. With long-term dead-load deflection added to any live-load deflection, the wrong-way drainage becomes worse. Most multistory residential structures are built using flat plate or flat slab construction. For this type of construction, the slab edge rotation will almost always cause the balcony surface to slope in the wrong direction.

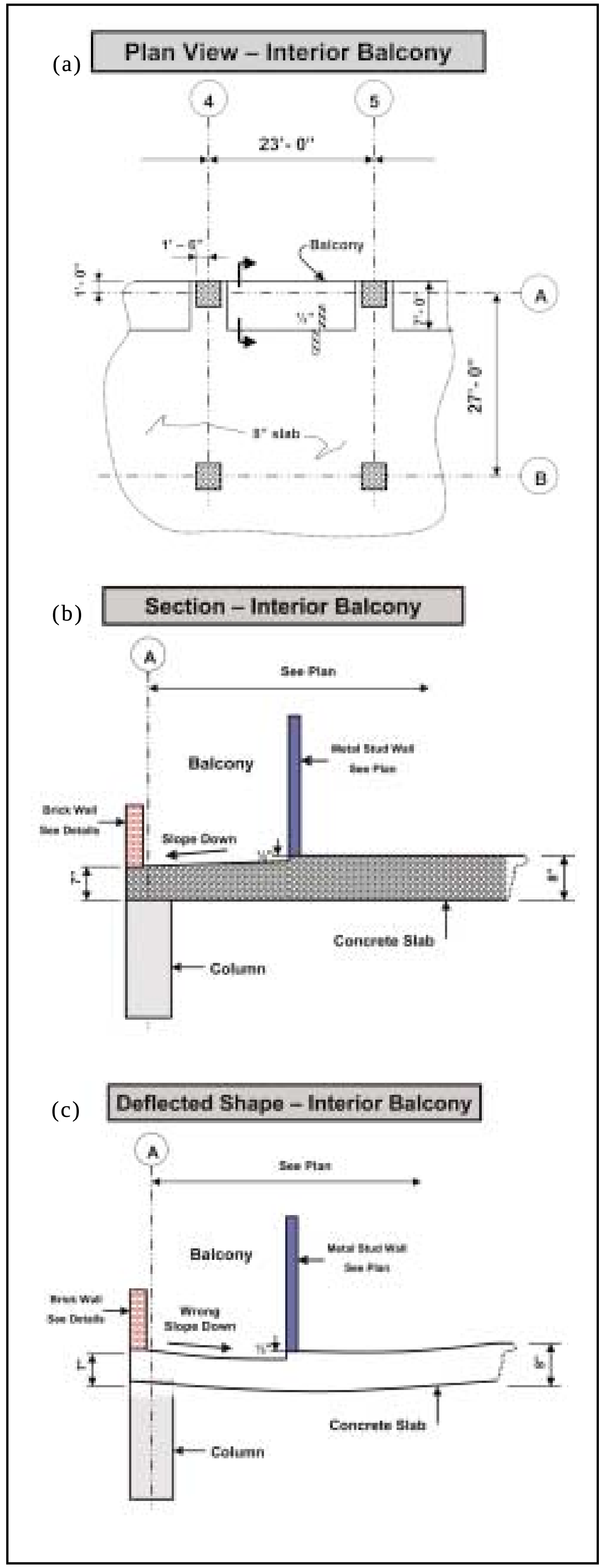

Fig. 1: The surfaces of reinforced concrete balconies set inside perimeter columns (a) are designed to slope such that rainwater drains away from the living area (b). But after the slab deflects, rainwater often drains toward the living area (c)

Cantilever balcony

The cantilever balcony is more difficult to assess because its final slope depends on the rotation of the interior slab relative to the deflection of the balcony slab. Dead and live loads on a typical balcony don't cause a downward deflection of the balcony slab large enough to offset the upward rotation of the slab at the perimeter of the balcony due to the interior slab deflecting. A wrong-way slope is even more likely if the designer reduces the cantilever slab thickness (thus reducing the slab's dead load and stiffness).

CONSIDER THE STRUCTURAL BEHAVIOR

Generally, the engineer doesn't review the architect's plan for drainage slopes. Drainage slopes are chosen by the architect who may not be aware of the possible deflection effects on drainage. Communication between the architect and structural engineer needs to improve if effective drainage is to be part of the finished structure. But quantifying drainage effects isn't easy because estimating deflections of reinforced concrete structures isn't an exact science.

Accuracy concerns

When estimating deflections, and the resulting rotations at a slab perimeter, the accuracy of the deflection calculation must be considered. ACI 435.4R-89, "Variability of Deflections of Simply Supported Reinforced Concrete Beams," indicates that for a simply supported beam under laboratory conditions, "there is approximately a 90 percent probability that actual deflections of a particular beam will range between 80 percent and 130 percent of the calculated value. The variability of deflections in the field can be even greater."

Variability in measured slab deflections

Jokinen and Scanlon[1] measured 40 nominally identical two-way slab panels in a 28-story office tower. The measured 1-year deflections varied from about the mean minus 50% to the mean plus 70%. Sbarounis[2] measured 1-year deflections on 175 bays of a multistory building. The range in measured deflections varied from the mean minus 60% to the mean plus 60%. Based on this range of deflections, even if the calculated deflection is considered when setting the architect's drainage slope, some balconies will probably require repairs to correct drainage.

Post-tensioned slabs

It's hard to generalize how post-tensioning will affect structural deflections and subsequent balcony performance.

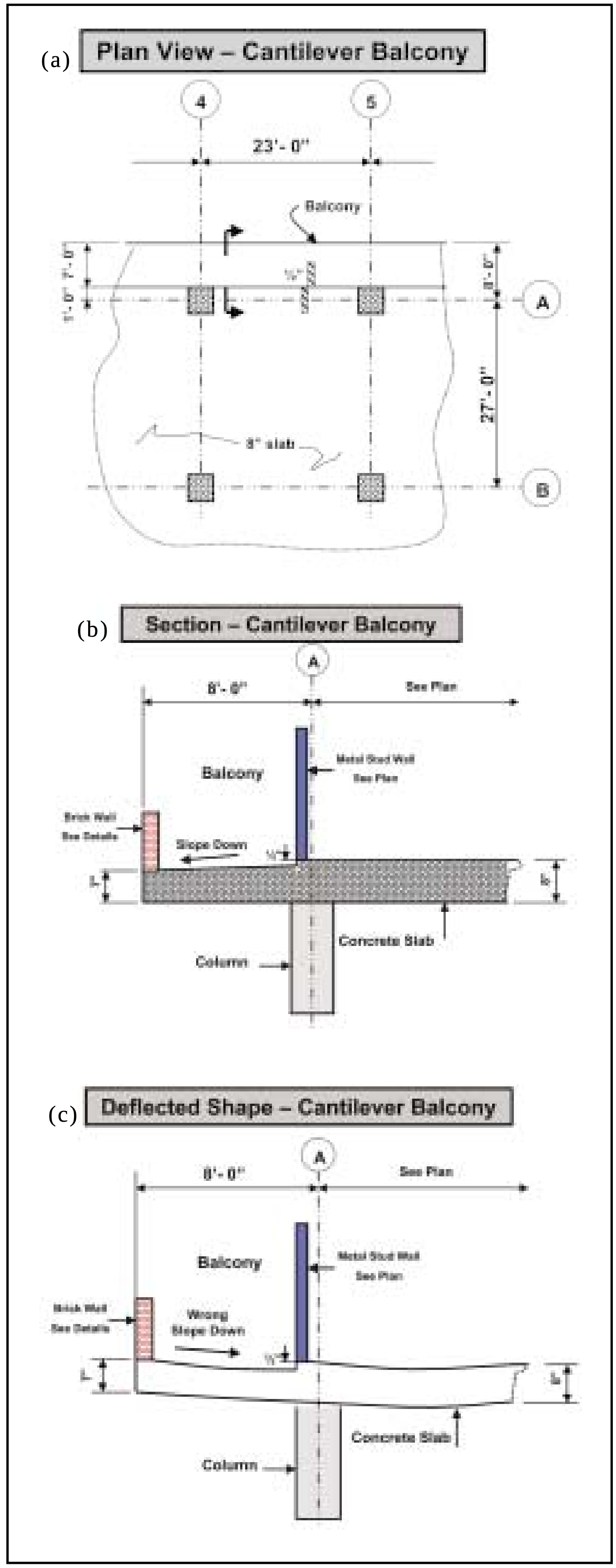

Fig. 2: The surfaces of cantilevered balconies (a) are designed to slope such that rainwater drains away from the living area (b). But even though the balcony slab deflects downward, rotation caused by deflection of the interior portion of the slab can sometimes cause rainwater to drain toward the living area (c)

The structure can be post-tensioned in one or two directions. The amount of live load included in the design load for post-tensioning affects the structure's initial and final deflection. When the live load hasn't been applied, the slab may have an initial upward camber that assists the drainage. After the live load is applied, however, the slab may still be cambered upward, be flat, or sag. Thus, the behavior of post-tensioned slabs and their effect on balcony drainage must be discussed with the structural engineer before deciding whether drainage conditions are acceptable or a repair is needed.

Effect of ACI 318 deflection requirements

ACI 318-02, "Building Code Requirements for Structural Concrete," specifies limits on calculated deflections due to live loads and incremental loads after installation of nonstructural elements. No total-deflection limit is specified. Public safety is the primary factor considered when ACI 318 provisions are adopted. As indicated in ACI 435R-95, "Control of Deflection in Concrete Structures," "…serviceability provisions are of a general nature intended to provide adequate serviceability for the majority of design situations. Individual cases may require more stringent requirements than the limited treatment given in ACI 318." Drainage has never been considered as a serviceability provision of ACI 318, so meeting ACI 318 deflection requirements doesn't guarantee that structural behavior won't adversely affect balcony drainage.

FIELD CHECK DEFLECTIONS AND ROTATIONS

In the example given, the contractor should have checked the structure before repairing all eight floors. He could have held a 4 ft (1.2 m) level at the edge against the bottom of the slab, measured the gap between the level and the concrete, and divided by 4 ft to get the actual slab rotation. For instance, if the gap is about 1/4 in. (6 mm), the slab edge rotation is about 1/16 in./ft (5 mm/m). This check will indicate if the slab rotation is great enough to cancel the effect of the architect's designed drainage slope.

A rod and level can be used to measure deflections in the middle of the slab. Given these measurements, the structural engineer can decide if actual deflections are in reasonable agreement with calculated deflections and also determine the resulting rotation at the perimeter of the balcony.

Once the field deflections and rotations are obtained, a meeting between the architect, engineer, and contractor can be called to consider appropriate corrective action.

PROBLEMS IN REPAIRING DRAINAGE SLOPES

Corrective action can typically take two forms:

- Grinding the top balcony slab to produce a desired slope; or
- Adding a curb at the door and using patching material to create a surface that slopes away from the living area.

The grinding option often requires enough concrete removal at the slab edge to create concrete cover problems. In some cases the top bars may be exposed. The possibility of reinforcing bar corrosion typically limits the amount of concrete removal that's considered appropriate.

Some architects will approve placement of a built-up curb at the door and application of patching material that slopes to the slab edge. This can be a successful solution if the architect can accommodate the curb height.

Repairs made too soon may not produce a permanent fix for drainage problems. As the long-term dead load deflection increases, or live loads are added, the repaired balconies might continue to rotate and again cause rainwater to drain toward the living area. Check with the engineer for advice on repair options and timing.

References

1. Jokinen, E. P., and Scanlon, A., "Field Measured Two-Way Slab Deflections," *Proceedings*, 1985 Annual Conference, CSCE, Saskatoon, Canada, May 1985.

2. Sbarounis, J. A., "Multistory Flat Plate Buildings: Measured and Computed One-Year Deflections," *Concrete International*, V. 6, No. 8, Aug. 1984, pp. 31-35.

Selected for reader interest by the editors.

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