Deflection and Drift Considerations for the Enclosure Design of Prefabricated Facade Panels

By Brad Carmichael, PE, CPHC

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The structures that hold up our buildings are not infinitely rigid. Instead, building structures are intentionally designed to undergo a limited amount of movement under wind loads, live loads, seismic loads, and other forces. The magnitude of this movement can often be fairly small (in the order of several inches). However, even small movements can affect continuity in the building structure unless the design accounts for them. Therefore, when one is maintaining the performance of a continuous air- and water-control layer, it is important to consider the impact of structural movements on the building enclosure.

In particular, the movement of building structures has unique implications for panelized enclosure systems that are designed to move along with the structure. This article focuses on the deflection and interstory drift considerations of panelized framed wall systems. Other types of movement from sources such as thermal movement, creep, and column shortening are outside the scope of this article but should be considered in design as well.

LIVE-LOAD DEFLECTION

Building structures experience some level of vertical deflection whenever load is applied. One common location that is affected is where floor lines intersect with the enclosure—particularly when panelized facades are attached along floor lines. The deflection of the floor under loading is then transmitted through the enclosure, where it needs to be accommodated.

In the *International Building Code* (IBC),[1] limits on the magnitude of live-load deflections are provided in Chapter 16, "Structural Design." In IBC, structural members supporting floors are often limited to deflecting 1⁄360 of their span, although the limitation can vary. Ultimately, the project's structural engineer is responsible for establishing the designed deflection of the superstructure, but the implications of that design carry through to the design of components and cladding. On a project-specific basis, we commonly see a need for the components and cladding in the enclosure to account for a design deflection of ±½ in. to ±¾ in.

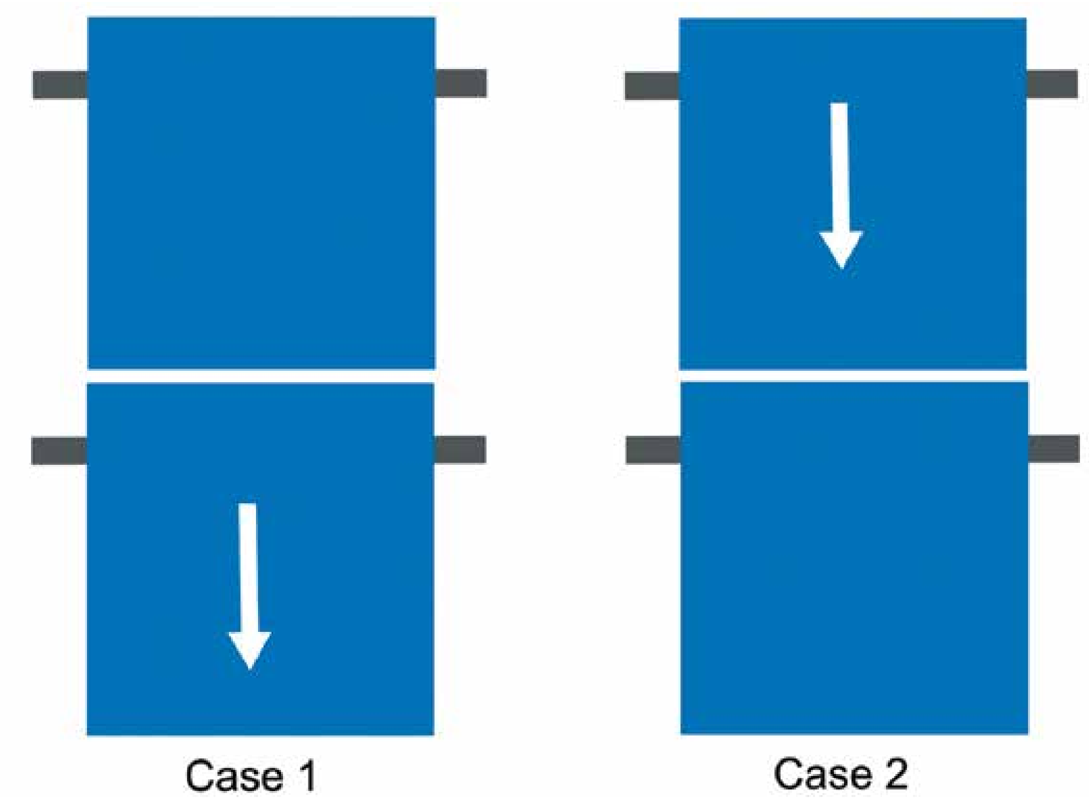

Figure 1. Load cases for facade panels under live-load deflection.

Table 1. Allowable inelastic drift limits per ASCE 7[2]

	RISK CATEGORY		
	I or II	**III**	**IV**
Structures, other than masonry shear wall structures, <4 stories above the base, with interior walls, partitions, ceilings, and exterior wall systems designed for drifts	2.5% of story height	2.0% of story height	1.5% of story height
Masonry cantilever shear wall structures	1.0% of story height	1.0% of story height	1.0% of story height
Other masonry shear wall structures	0.7% of story height	0.7% of story height	0.7% of story height
All other structures	2.0% of story height	1.5% of story height	1.0% of story height

Floor-line deflection is typically expressed as plus or minus a distance because the movement is relative to the floors above and below. When a given floor is loaded and deflects, the distance between it and the floor above increases and floor-line joints open (see Case 1 for panels in **Fig. 1**). Conversely, the difference between a loaded floor and the floor below decreases and floor-line joints close (Case 2 in Fig. 1). Therefore, when this deflection translates through to enclosure elements, accommodation for deflection at floor lines must occur in both the upward and downward directions.

INTERSTORY DRIFT

Buildings structures are designed to move laterally, particularly during seismic events, such that one floor will displace relative to the floors above and below in what is referred to as interstory drift. In seismic regions, this differential displacement can affect the design of components and cladding systems.

When designing components and cladding systems for drift, there are two types of interstory drift to account for: inelastic and elastic drift limits. The inelastic drift limits are larger values that generally represent the extent to which permanent displacement or deformation of the structure can occur without jeopardizing the serviceability of the building structure. Under these circumstances, it is important that the building not present a risk to the safety of the public or the serviceability of the structure. For example, breaking glass, falling cladding, or other hazardous phenomena should not occur during these levels of drift.

The elastic drift limits are smaller values that generally represent the displacements that are permitted to occur within the regular operation of the building. Below the elastic drift limit, the building and its components should continue to perform as designed. For the enclosure in particular, this means that design levels for airtightness, watertightness, and thermal efficiency should be maintained throughout movements within these limits.

The amount of inelastic design story drift is prescribed in the American Society of Civil Engineers' *Minimum Design Loads for Buildings and Other Structures* (ASCE 7)[2] and is generally a function of the occupancy risk of a building, the type of structural system, and the floor-to-floor height (see **Table 1**). For example, using a common commercial floor-to-floor height of 15 ft, the maximum inelastic design story drift can range from ±1.26 in. to ±4.5 in.

The maximum allowed amount of elastic interstory drift δ_{xe} is prescribed as a fraction of the inelastic design story drift δ_x. The magnitude varies by building because it depends on the ratio of the deflection amplification factor to the importance factor. The deflection amplification factor C_d is specific to the seismic force—resisting system and generally ranges from 1 (for example, for ordinary reinforced concrete) to 6 (for example, for dual systems

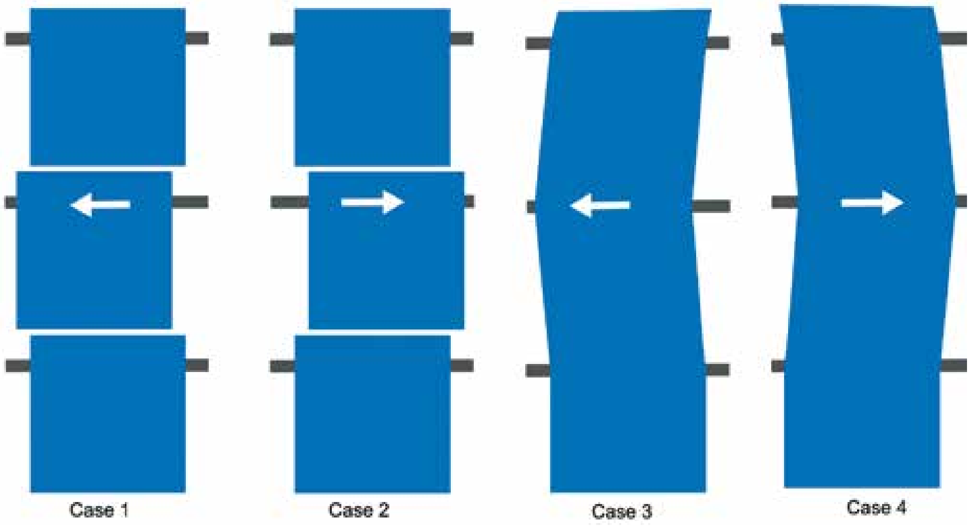

Figure 2. Schematic of in-plane panel movement under interstory drift.

with steel and concrete composite shear walls). The seismic importance factor I_e relates to the use of the building and ranges from 1 (typical buildings) to 1.5 (essential facilities).

The relation between the elastic drift limits and the inelastic drift limits is prescribed by ASCE 7[2] as follows:

$$\delta_x = \frac{C_d \delta_{xe}}{I_e}$$

For example, a commercial office building with a 15-ft floor-to-floor height and a steel buckling—restrained brace frame structure, occupied as Risk Category II, would have a maximum allowed inelastic story drift of ±3.6 in. at each floor. The elastic story drift for this structure would be ±0.9 in., which in absolute terms is a total design movement of 1.8 in. These magnitudes are not unusual for commercial buildings in seismic regions.

Building enclosures should be designed to maintain the performance of the air- and water-control layers under movements within the elastic range. Because the enclosure is required to maintain performance within the elastic range, it can be challenging to create a design capable of accommodating both the live-load deflection and the elastic story drift while also maintaining airtightness and watertightness. The following sections will review some of the design considerations.

FACADE CONSIDERATIONS

The two most common ways of designing facade systems to accommodate drift is to translate (**Fig. 2** Cases 1 and 2) or to rack (Fig. 2 Cases 3 and 4).

Unitized Curtainwalls

The building movement discussed in the previous section should ultimately be accommodated by the facade and other enclosure components. Some systems such as unitized curtainwall systems are designed and tested to accommodate these movements in a manner that is well established and has been tested over time. In some cases, early curtainwall systems did not accommodate building movement, and the effects can be seen in out-of-plane and dislodged glass at floor lines (**Fig. 3** and **4**).

Contemporary unitized curtainwall panels have features that accommodate movement better than their early predecessors. Contemporary panels are typically hung from a slab edge, and they interface with the panels on the lower floor at the stack joint. The geometries of the various stack joints in these systems are designed to accommodate both drift and deflection of the structure, as the "chicken head" gasket connection is allowed to move up and down, translate side to side, and rock back and forth under building movement. This gasket and similar gaskets at the sides of the panels also allow the units to maintain airtightness and watertightness across the facade even while the facade moves.

This type of movement accommodation is commonly tested in a performance mock-up using the full American Architectural Manufacturers Association's AAMA 501 testing protocol, which includes options for testing for vertical deflection (AAMA 501.7[3]), interstory drift (AAMA 501.4[4]), and dynamic seismic movement (AAMA 501.6[5]), among other tests.

While the testing sequences for different AAMA 501 performance mock-ups may vary slightly among projects, one common characteristic is that when structural and movement tests are performed in the elastic range, the curtainwall is then tested for air and water resistance afterward to confirm that performance is maintained. The final structural tests of a performance mock-up are typically in the inelastic range, and testing of air and water resistance is typically not performed afterward. This underscores the expectation that airtightness and watertightness are to be maintained within the elastic movement range, but they are not expected to be maintained in the inelastic movement range.

Panelized Framed Wall Systems

As energy codes increasingly reduce glazing percentages, prefabricated panelized framed wall systems are emerging as an alternative to curtainwall systems for projects that require greater insulated opaque wall area and yet are of the height or scale that makes the use of field-assembled stud wall sections less practical. The advent of factory-applied air and water barriers onto sheathing boards has also improved the efficiency of off-site panelized framed walls, greatly reducing the amount of fieldwork needed once panels arrive on site. These systems are well suited for high-rise construction (**Fig. 5**) because the framed wall panels can be hung from slab edges in a manner that is similar to curtainwall.[6,7] Panels can be fairly large in size and encompass more than one story if desired. Because there are many different configurations for the components, layouts, attachment methods, and other variables, designers have a high degree of flexibility when designing with panelized framed wall systems.[8] This article focuses primarily on panelized framed walls that have framing, sheathing, and weather barriers applied off site; however, many of the implications discussed here may also apply to other similar panelized wall types and field assembles walls as well.

Panelized framed wall systems fixed to floor lines are subject to the same types of building movement from the supporting structure as unitized curtainwalls, and they also have the same need for continuous air- and water-control layers. In comparison with unitized curtainwalls, panelized framed walls are less product-driven and do not have as extensive a history of performance mock-up testing using the AAMA 501 testing sequence. As a result, care must be taken on a project-by-project basis to review how the panels will interact with the moving structure, and how the movement joints are designed to remain airtight and watertight.

One method of constructing a panelized framed wall to accommodate building movement is to attach an extrusion for a unitized curtainwall system onto the perimeter of the framed panel. This will allow the panel to behave similar to a curtainwall under deflection and drift conditions.[6] One downside of this approach is the higher cost of aluminum extrusions relative to cold-formed steel; another is the thermal bridging that comes with adding an aluminum extrusion around the perimeter edge of the framing panel. An upside to this approach is that the joints do not require treatment after installation, so the panels could be prefabricated with exterior insulation and cladding already installed.

The alternative to using unitized curtainwall extrusions is to leave clearance gaps at joints between panels that can accommodate the anticipated amount of movement. This approach will require project-specific design of the movement joints. The following sections review design considerations for these types of joints.

Drift and Deflection Joint Design Considerations

The layout of drift and deflection joints in panelized framed walls is important to understand during the design phase because the joints will likely need to be continuous through the wall assembly—from interior finishes through the cladding—and the layout will therefore affect the aesthetics, finishes, and structure. Layout considerations include the following:

- Locating horizontal joints near floor lines can reduce the potential need for a moving joint through the interior finishes. Installing drift joints slightly below floor lines can place the joint in a location less visible at the interior (such as a ceiling cavity).
- Intersecting drift and deflection joints away from punched window rough openings will negatively affect the water-control layers of

Figure 3. Out-of-plane glass across a floor line in an early curtainwall.

Figure 4. Dislodged glass below a floor line in an early curtainwall.

the rough opening as well as the attachment of the frame.

- Drift at outside and inside corners occurs in two orthogonal directions. To maintain sheathing and cladding on the same plane, consider a one-piece L-shaped corner, if possible.

Parapet Considerations

Panelized wall parapets are often balloon framed past the roofline because the added stiffness provides structural efficiency and because installation is easy. However, there are implications for how the roofing ties into the parapet because the joint between the roof deck and parapet could then be subject to live-load deflection as well as interstory drift.

Many roofing and waterproofing systems have details for simple roof-to-wall joints that can accommodate some movement due to deflection of the roof deck, but not all roofing and waterproofing systems can accommodate the total differential translational movement of 1.5 to 2 in. that would occur with interstory drift. In particular, fluid-applied roofing systems do not perform well when subject to this kind of movement, and if sheet membranes are used, the seams can be stressed during repeated movement.

One way to address this differential movement is to eliminate it at the roof by platform-framing the parapets, pouring the parapets in concrete, or dead-loading the panels to the roof deck. These techniques will fix the parapet to the roof deck and eliminate differential movement. A downside to this approach is that it results in having to move the drift/deflection joint to another location that may be less convenient for the overall design.

A variety of roofing-grade expansion joints can accommodate both drift and deflection, although they are often intended to be used as building expansion joints for larger joint sizes and larger ranges of movement. These types of joint systems are a good option, but they tend to be costlier and require longer lead times than field-fabricated alternatives.

It is important to note that in many conventionally insulated roof assemblies, particularly in colder climates, the roof membrane layer is not the only control layer in a roof assembly—there is a separate air- and vapor-barrier layer at the roof-deck level. A roofing membrane expansion joint at this transition will address the water-control layer, but the air-control layer might be a separate layer. In this case, the air barrier should also maintain continuity during building movements. It is important to review whether drift/deflection provisions are needed at just the roof membrane layer or if they are also necessary at the air-barrier layer, in which case you may need two movement joints at the roof intersection with the parapet.

Use of expansion joint membranes at the deck level can also place an expansion joint integration detail that can be more prone to leaks at a roof elevation where it may be in contact with more water (**Fig. 6** Case 1). Another approach, which is commonly used with unitized curtainwall parapets, is to construct a small knee wall on the interior side of the parapet (Fig. 6 Case 2). While this does not eliminate the need for a movement joint altogether, it moves the joint to a place above the deck level where water collects and where the movement can be accommodated with a field-fabricated silicone sheet and self-adhered membrane. An additional benefit with conventionally insulated roof systems is that that the air-control layer at the roof deck can reintegrate with the water-control layer at the roof membrane flashing such that there is a need for only one movement joint instead of two.

Figure 5. Large-format panels on a commercial high-rise building. Panel size is indicated by the blue dashed lines.

Corners

As noted in the earlier design considerations, panelized corners behave uniquely under deflection and drift for several reasons. One reason that panelized corners behave uniquely is that the drift movement occurs in two orthogonal directions. A panel designed to translate along with floor drift movement can clash with a panel at the corner because each panel is designed to translate in plane with the elevation when drift occurs. Therefore, at least one movement joint, and preferably two, should be considered at corners.

For corners with a single movement joint between panels, drift can translate panels out of plane if the direction of the drift is out of plane with the joint.

Mitered joints are one option at corners, but this strategy can result in a larger joint and increase the complexity of panel fabrication and cladding detailing at the corner. A one-piece corner can result in an improved condition because having a joint in each plane will allow for adjacent panels to translate while staying in plane with the respective elevations. Refer to the green panel in **Fig. 7**.

Care should be taken to consider how these joints terminate at the bottoms of walls (soffits) and tops of walls (parapets) as the movement may need to be accommodated at the parapet coping as well as the backside of the parapet wall. This complicates matters as the vertical wall drift joints at the panel connections will need to intersect with the live load and drift joints already at the parapet as shown in **Fig. 8**. This intersection of multiple joints becomes more apparent in saddle conditions.

Parapet Saddle Conditions

Parapet saddles can be geometrically complex under normal circumstances, but the complexity compounds when panelized walls that drift and deflect are involved. **Figure 9** demonstrates some of the geometry of these types of conditions and the layout of the movement joints that results.

Jambs at Curtainwalls and Window Walls

As discussed earlier in this article, prefabricated wall panels typically have similarities to unitized curtainwalls; these similarities are also shared with window walls. However, prefabricated wall panels, curtainwalls, and window walls may not bear on the structure in the same way. For example, if a panelized frame wall is fixed to a floor slab at its base and is adjacent to a unitized curtainwall that is hung from the floor slab above, the two systems will deflect and translate differentially with each other, and the movement should be accounted for.

Similar conditions can occur with adjacent precast concrete panels, window wall systems, and other types of facade assemblies depending on how each one is connected to the structure.

Stick-built curtainwalls can also drift and deflect differentially from panel systems because the curtainwalls are often dead-loaded at a given floor and designed so that they rack with building movement rather than translate. Sufficient clearance should be provided between translating wall panels and racking curtainwall mullions.

Wall Panel Joint Waterproofing Material Selection and Sizing

The movement joints between panels are commonly waterproofed at the sheathing layer with materials designed to be compatible with the surrounding water-control layer. The materials used at this layer need to accommodate movement while still maintaining airtightness and watertightness.

Compression gaskets can be a very effective approach to consider when designing movement joints—and they have a proven track record of success with unitized glazing systems. In our experience, these gaskets work best when integrated with aluminum extrusions that mount to the perimeter of panels, as discussed earlier in this article as well as in papers by Gannon[6] and Loush.[7]

Self-adhered membranes that have foil or polyethylene facers have been used to bridge these

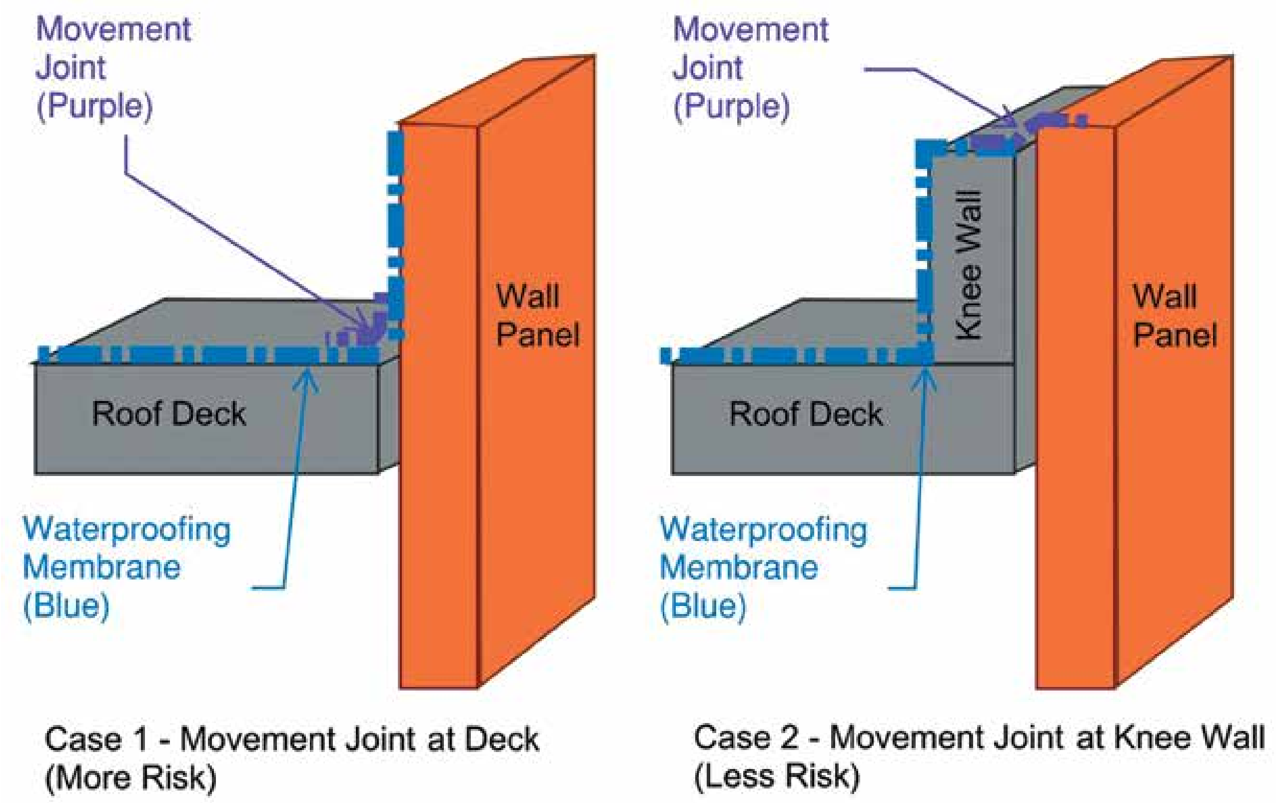

Figure 6. Roof-to-parapet joint considerations.

joints, but they often have limited movement capacity due to the facers. Although forming a bellows with these membranes over a backer rod can add a degree of movement flexibility, the range of allowable movement is often limited when joints are subject to both deflection and drift in more than one direction.

Sealant joints are another method of treating the panel movement joints. However, this approach can result in larger joints because sealant joints do not fully compress (they typically compress 25% to 50 %). Recalling the earlier example of drift joints that have elastic movement of ±0.9 in., if backer rod and sealant are used for waterproofing, those joints would need to be approximately 1.8 in. wide for sealant with 50% compression and designed to expand up to 2.7 in.

If sealants are used for drift joints at the cladding layer, the same movement should be accounted for. Note that the result could be wide and rather visible sealant joints at corners, jambs, and other transitions.

There are alternatives to consider to reduce the width of movement joints. Extruded silicone sheets are a suitable material that can be used for these types of joints because these sheets allow for multidirectional movement

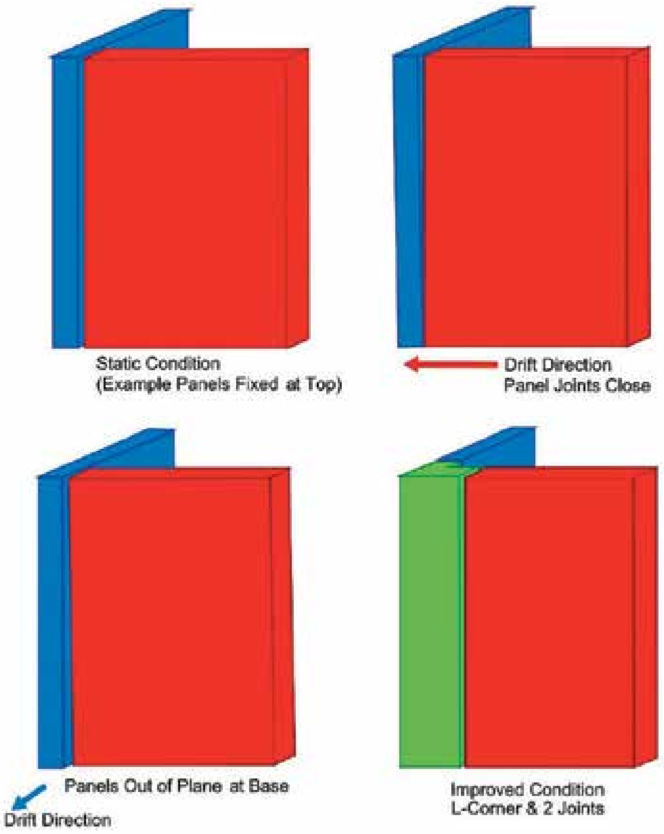

Figure 7. Drift cases at outside corners.

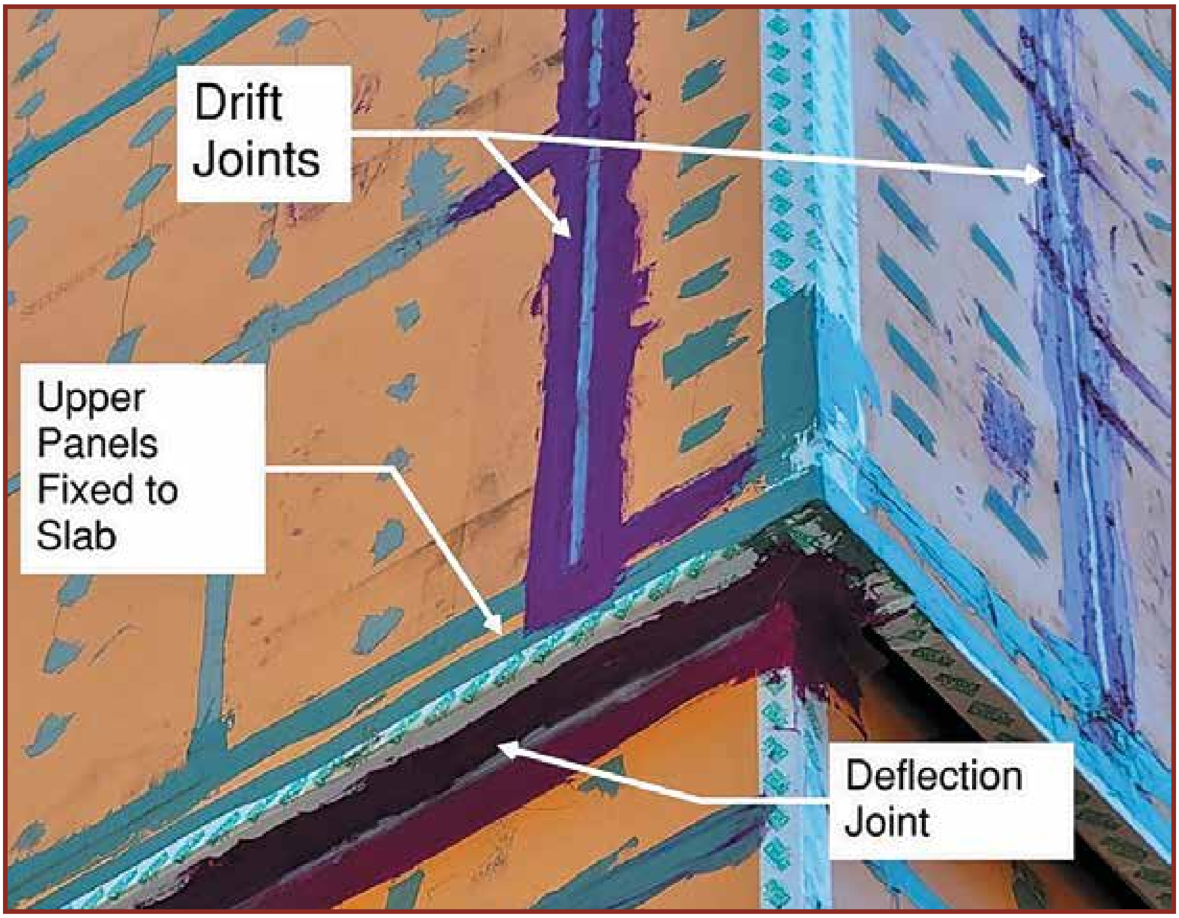

Figure 8. Drift and deflection joints at outside corners and floor lines.

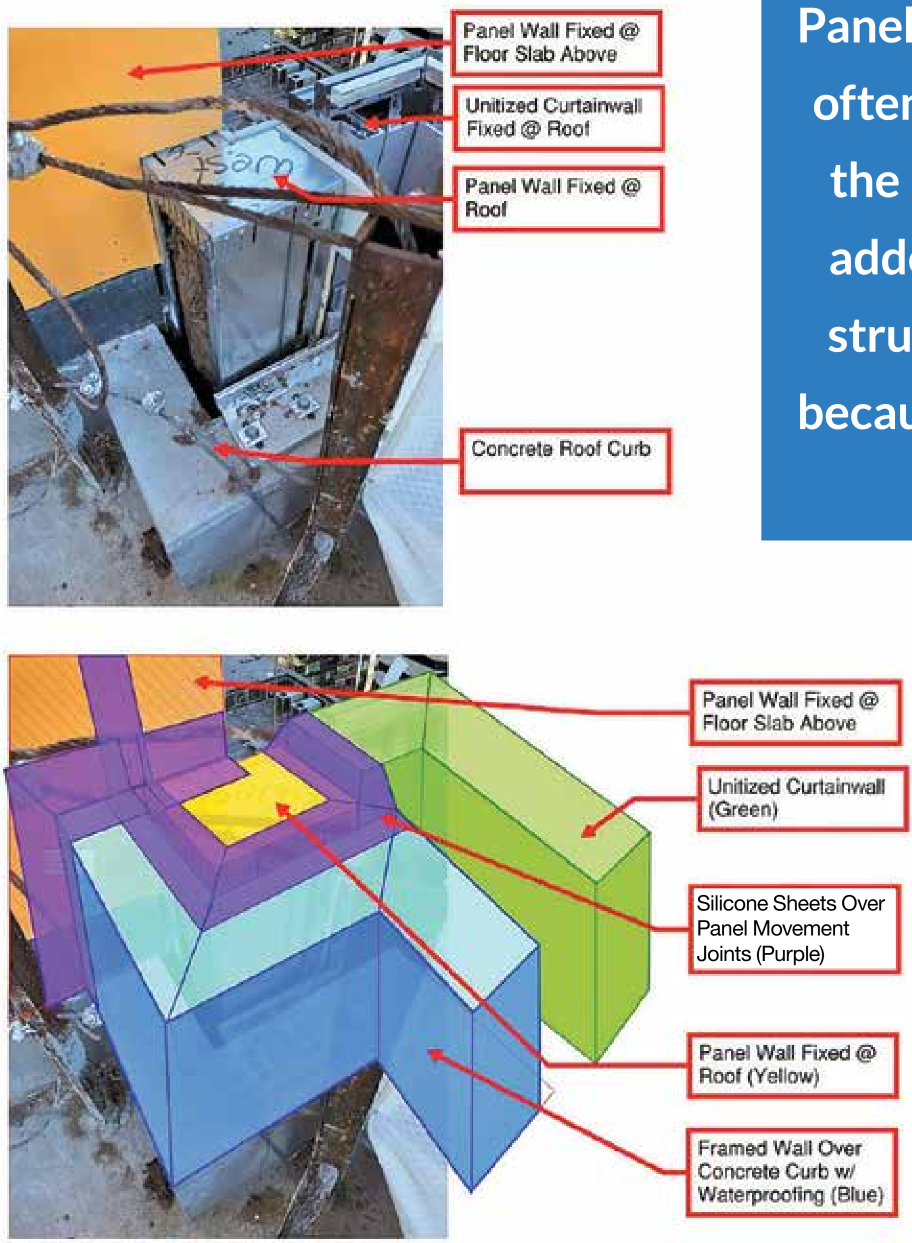

Figure 9. Schematic drift/deflection joint layout at parapet saddle.

Panelized wall parapets are often balloon framed past the roofline because the added stiffness provides structural efficiency and because installation is easy.

and can compress more than 50%. Care should be taken with the use of extruded silicone sheets as they can be subject to tears and punctures.

At the cladding layer, there are other options available beyond large sealant joints, but they need to be carefully considered. Open-joint cladding systems can allow for drift and deflection with adequate clearance gaps, and closed-joint systems can use joints that rely on shiplap-type slip connections, splice plates, and other means of accommodating movement without the use of sealant. This can allow for smaller joints that are less conspicuous on the facade (see **Fig. 10**).

All of these steps—from determining the magnitude and directions of movement to laying out the panels and their joints to accommodate the movements, to designing waterproofing and cladding systems that work—are often necessary for the successful execution of a high-performance enclosure (see **Fig. 11**).

CONCLUSION

Building structures are designed to move, and this movement of the structure can affect the design of enclosure systems. This is especially the case in seismic regions and when panelized wall systems are used. Projects with these characteristics require careful attention during design.

Once the layouts and sizes of the movement joints are established in panelized walls and their cladding systems, thoughtful and intentional design can accommodate the movements of a facade system while still achieving an elegant aesthetic. The use of prefabricated panelized frame walls allows for faster installation on site, factory-controlled quality, and more efficient project delivery. As such, we expect this emerging form of enclosure construction to become more broadly used in the future.

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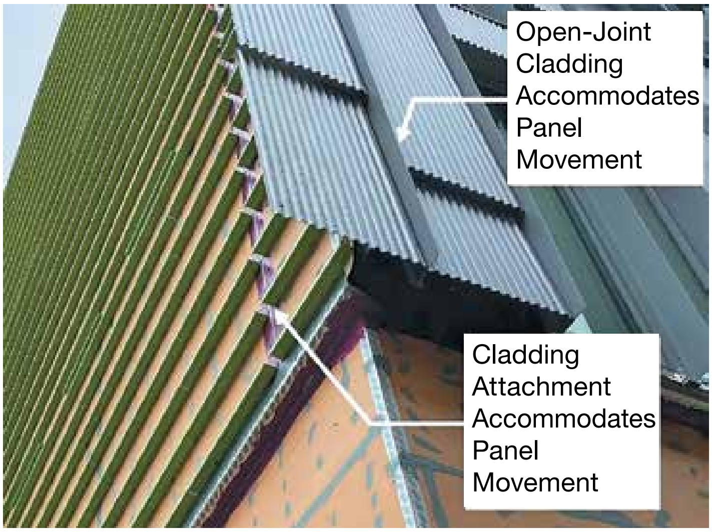

Figure 10. Open-joint cladding and furring spaced to accommodate drift.

Figure 11. Panelized wall facade nearing completion.

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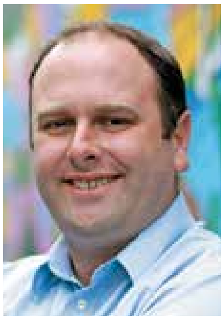

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special interest

ASCE, NOAA Collaborate on Climate Data for Codes and Standards

The American Society of Civil Engineers (ASCE) is continuing its work with the National Oceanic and Atmospheric Administration (NOAA) to update ASCE's future standards with climate data.

ASCE said that the efforts of the ASCE-NOAA Task Force for Climate Resilience in Engineering Practice are ongoing. Also, ASCE hosted the final Structural Engineering Institute Climate Impacts Workshop on October 12, 2022, at the society's Virginia headquarters; that event and others in the workshop series brought together representatives from ASCE, NOAA, the National Institute of Standards and Technology, and the Federal Emergency Management Agency, as well as other organizations, to partner on the climate data efforts.

ASCE said last October that the cycle of work to prepare the next edition of ASCE/SEI 7, *Minimum Design Loads for Building and Other Structures*, would begin soon, and that ASCE and NOAA would cohost a Leadership Summit on Climate-Ready Infrastructure on February 1–2, 2023, at ASCE headquarters.

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