OPEN FORUM
PROBLEMS AND SOLUTIONS

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Bowing of Insulated Precast Concrete Wall Panels

Q1: What are the principal causes of bowing in insulated precast concrete wall panels?

A1: The causes of panel bowing in insulated precast wall panels, or sandwich panels, can be broken down into a number of environmental and structural causes. These include the following:

Environmental Causes:

Temperature – Differences in temperature between the outside face and inside face of an insulated wall panel can cause the panel to bow noticeably, usually on a daily cycle. This bowing occurs because the warm side expands and the cool side contracts. The panel then bows to relieve the stresses caused by this condition. The PCI Design Handbook, Fifth Edition, in Section 3.3.2 provides a sample calculation for the bowing of a wall panel subject to differential temperature strain.

Humidity – Low humidity causes concrete to shrink faster. A consistent difference in humidity between the inner and outer face of a panel can therefore induce bow in a panel. This effect can be readily seen in a temperature-controlled building in a northern climate. In the winter, the inside of the building is heated, with low humidity inside. Likewise, if the inside is air-conditioned in the summer, there will be lower humidity inside. This condition causes the inner wythe to dry out faster and shrink faster than the outer wythe, causing an outward bow. This bow can be permanent, or it can vary in magnitude over an annual cycle.

Structural or Internal Causes:

Composite action between wythes – Panels with stiff shear connections between the wythes are said to act compositely – that is, the panel acts as a unit in resisting bending forces (see Fig. 1). This composite behavior has a drawback in that differential strain between the wythes produces bowing. Composite connections usually consist of steel trusses, solid concrete zones, or both.

By comparison, non-composite panels have connectors that are strong in tension but weak in shear. The wythes act independently as linked walls. Differential strain can be resolved without bowing the panel. Non-composite wythes need to be much thicker to achieve the strength of a comparable composite panel. (As a general estimate, assume a non-composite panel thickness 1.5 times the equivalent composite panel thickness.) Steel or carbon fiber pins are commonly used as non-composite wythe connectors. A PVC slip sheet or vapor barrier may also be used to ensure that the insulation does not bond to the concrete and provide unintentional composite action.

True non-composite panels do not bow significantly from environmental causes and, therefore, are preferred where panel bowing would be unacceptable – for example, cooler and freezer panels.

Creep – If a concrete panel is stored in a horizontal position and not supported (or "bunked") properly, it will deflect. Over time, this deflection will increase, and some of it will become permanent. This effect is called creep. When the panel is later erected onto the building, it will have a permanent bow. Bowing due to creep is most noticeable in tall, thin panels. It can be best observed by sighting along the panel edge while the panel is bunked in the yard (see Fig. 2).

Differences in concrete modulus of elasticity between wythes – Using different concrete mixes in the two wythes can cause differential shrinkage and resultant bowing (or curling) after prestress transfer if the two mixes have differ-

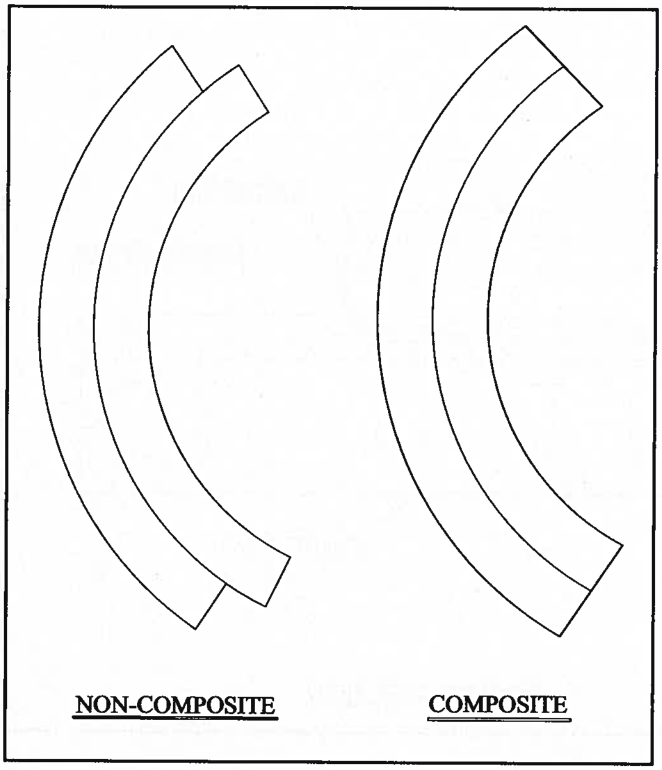

Fig. 1. Behavior of non-composite and composite panels.

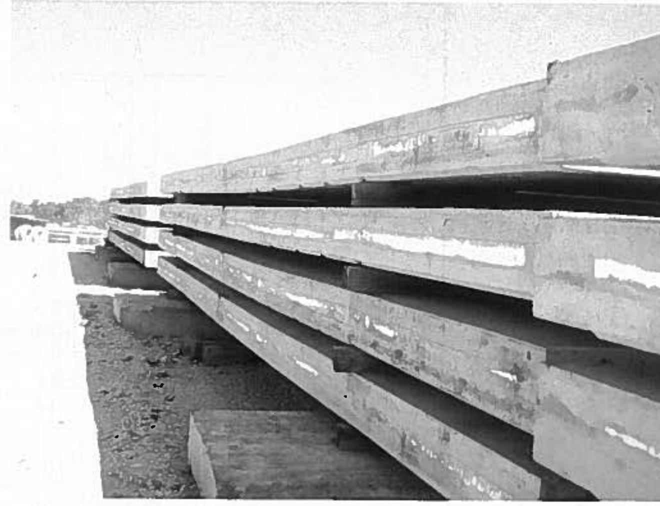

Fig. 2. Wall panels in storage.

ent values for their modulus of elasticity, *E*. This bowing can be reduced or eliminated by lowering the effective strand prestressing force in the wythe with the lower *E* to compensate.

Q2: Can the magnitude of bowing be predicted accurately?

A2: In a word, no. Because multiple factors with unknown magnitudes contribute to bowing, as noted above, it is virtually impossible to calculate accurately the magnitude of bowing. Further, the actual thermal gradients occurring within a particular panel are not precisely known. The best estimate that can be made is determined through a simplified procedure that provides a magnitude of bowing in line with field observations.

Those in the precast industry who have experience with composite precast concrete panels have made the following observations:

- Panels usually bow outward, even in the winter.
- Panels on the south and west elevations bow more than north- and east-elevation panels.
- Sandwich panels bow more than solid panels
- Panels stored in a bowed condition remain bowed after erection.

Some of these observations do not match what would be expected if temperature gradients alone caused panel bowing. For example, one would expect a panel on a heated building in a northern climate to bow inward in the winter, but this is not usually the case. One theory on why this phenomenon occurs has to do with the relative humidity inside the building versus outside the building. In this case, the indoor humidity would be very low, causing the inside wythe to shrink, counteracting any expansion caused by the higher indoor temperature. Consequently, most designers consider the summer condition as the worst-case scenario for panel bowing, with the outer wythe temperature as high as 100 to 110°F and the inner wythe temperature at about 75°F.

It is this designer's opinion that the temperature differential used for design need not be greater than 40°F for most parts of the country. Solid test data are lacking, however, to prove this point. As such, the PCI Precast Sandwich Wall Committee is interested in any observations or tests made by PCI members of temperature differentials in sandwich wall panels.

Q3: What can designers do to minimize problems associated with this phenomenon?

A3: The following actions can be taken to minimize bowing problems:

Allow for bowing in the building design. In other words, just let the panels move. Do not connect anything to the panels between floors. For example, a ceiling tile track was attached to the south-facing precast wall of a building. The result was that some ceiling tiles fell down daily as the panels bowed outward due to sun exposure, bewildering the occupants. Disconnecting the track from the wall solved the problem.

Vary the prestress between wythes. Panel bow is relatively predictable for standard building types. For panels that tend to bow outward, the designer can reduce the level of prestress force in the inner wythe to induce an initial inward bow. This inward bow will counteract the tendency to bow outward.

Connect all floor levels (including mezzanines) to the structure with ductile connections. If the floors need to be connected to the panels to prevent a separation between the floor and panel, the connections should be designed to act in a ductile manner in the event of overstress. Embedded tension rods should be fully developed and a bond breaker used at the panel end, as illustrated in Fig. 3. The size of the rod

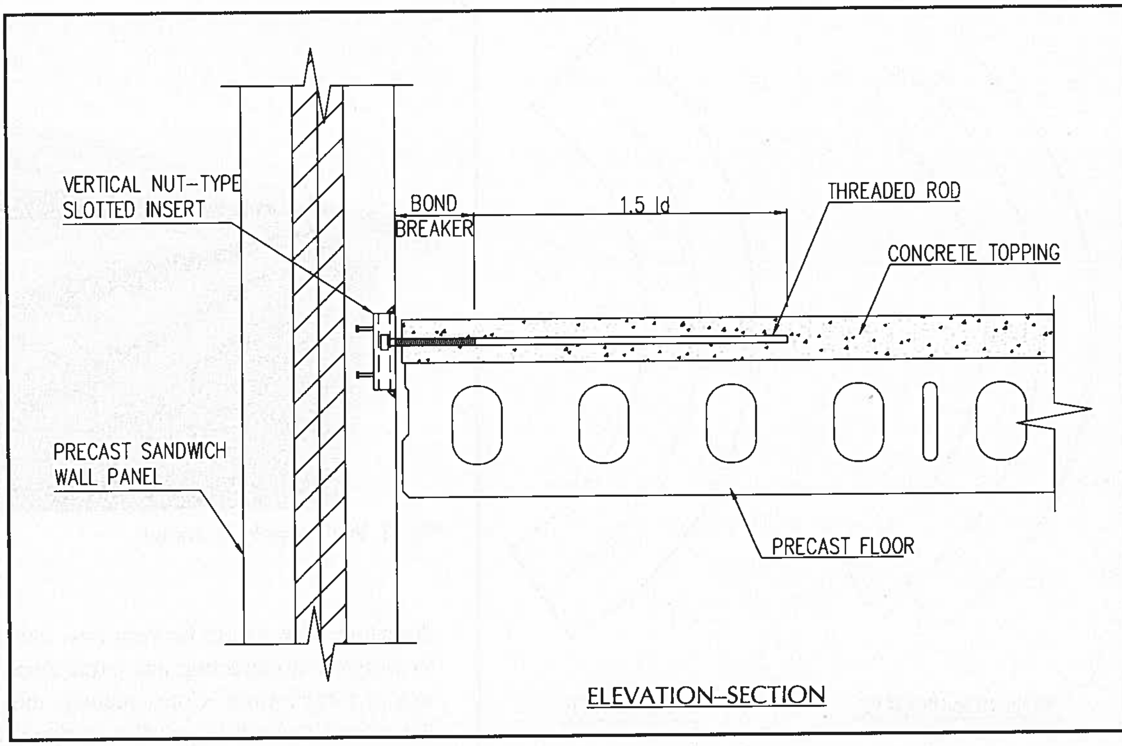

Fig. 3. Midheight connection to restrain panel bow.

should be determined by calculating the force required to restrain the predicted bow. For welded connections, the welds should not be the weakest link. Use fully developed deformed bar anchors for embedded plates rather than headed studs to avoid a sudden concrete fracture.

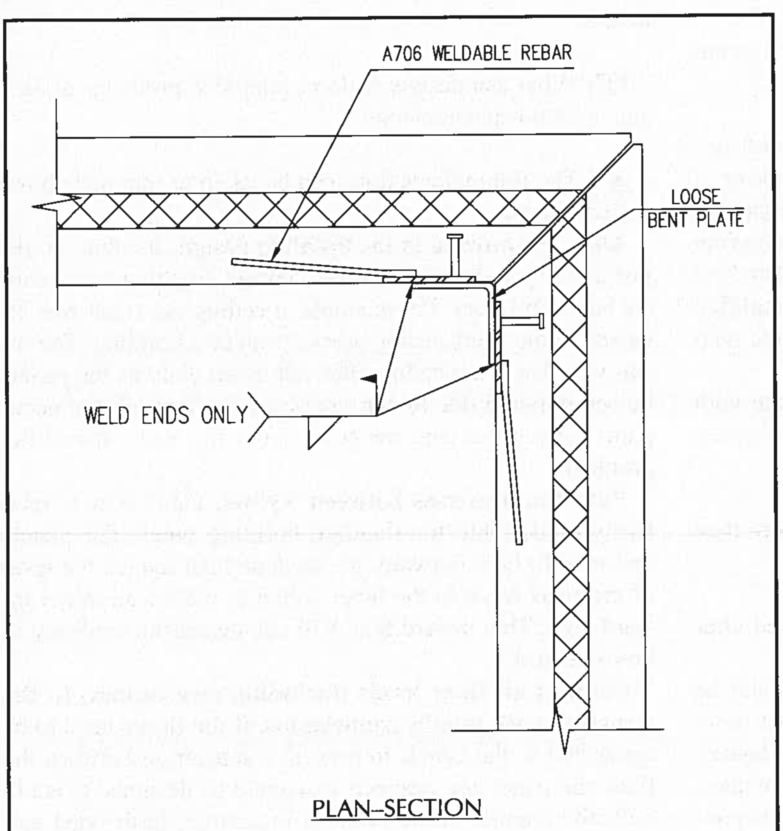

Fig. 4. Ductile corner connection.

Use corner connections to avoid "fish-mouthing." Outward panel bow is most apparent at corners of the structure, where a joint separation may occur at mid-height due to panels bowing in two separate planes. This separation may result in a sealant failure. Corner connections are used to keep this joint together (see Fig. 4), with the connections spaced closely together near mid-height. A bent plate is preferred for the loose weldment to provide ductility. If over-stressed, the plate can bend, relieving the stress and preventing the embed from spalling the concrete.

Use a non-composite design with a combination vapor barrier and slip-sheet. This is commonly used for cooler and freezer walls. Panels will be much thicker and heavier, however, than an equivalent composite design.

For loadbearing panels, account for the secondary moments caused by the predicted bow in the design. Secondary moments can increase the magnitude of bowing in a loadbearing panel to the point that it is often the critical design case for the panel. The PCI Design Handbook, Fifth Edition, includes a design example for the second-order analysis of a wall panel in Section 3.5.1. More design examples can be found in the PCI wall panel report (Reference 1). Commercial software is also available that can account for secondary moment effects in loadbearing sandwich wall panels.

Correct differential bowing between panels. Add a mid-height connection that is used only as needed to align panels with differing magnitudes of bowing. The panels can be jacked together, as shown in Fig. 5, and then the mid-height connec-

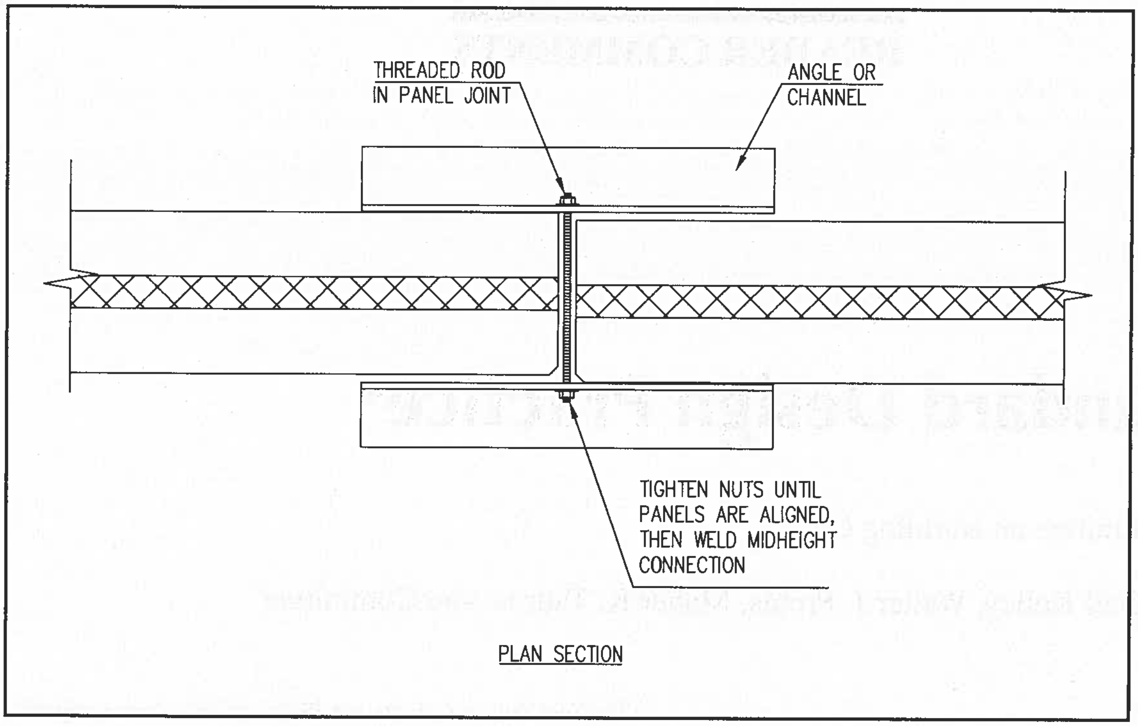

Fig. 5. Panel alignment jacking method.

tion welded to hold them in place. It is best not to weld more than a few panels together in a row to avoid excessive shrinkage restraint in the plane of the panels.

Insulated precast wall panel bowing is a complex issue that deserves further study by the precast concrete industry.

REFERENCE

1. PCI Committee on Precast Sandwich Wall Panels, "State-of-the-Art of Precast/Prestressed Sandwich Wall Panels, Part 1," PCI JOURNAL, V. 42, No. 2, March-April 1997, pp. 92-134, and "State-of-the-Art of Precast/Prestressed Sandwich Wall Panels, Part 2," PCI JOURNAL, V. 42, No. 3, May-June 1997, pp. 32-49. Also available as PCI JOURNAL Reprint No. JR-403.

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