From the fall of 2009 through the spring of 2012, Gage Bros. Concrete Products secured contracts to provide architectural blast-resistant precast concrete cladding on three large government buildings. This paper presents the experience of this precaster in the design, detailing, and production of blast-resistant cladding. We hope other precasters and specialty engineers will benefit from the lessons learned by Gage as they embark on projects with similar requirements.

Many large government buildings are assigned a security team to determine the required facility security level for the building design, including blast-resistant design requirements. The design blast load is specified in terms of a peak pressure and impulse or in terms of design charge weights at specified locations near the building corresponding to a protected perimeter. Design details associated with the required facility security level, including the design blast load, are only available in government documents with restricted distribution (in other words, not publicly available). Only engineers and designers with a need to know have access to these documents. This makes it important for the design team to include a qualified blast engineer in the bidding process so that an accurate estimate can be made of the blast design requirements. Typically, the blast design requirements do not significantly increase the panel thickness or reinforcement over that required for conventional loads. However, the connection design loads are typically much greater than those for conventional design. Also, connection forces associated with precast concrete members that function as shear walls and diaphragms can increase significantly.
The curved north facade of the U.S. courthouse in Cedar Rapids, Iowa, is clad in architectural precast concrete, blast-resistant glass, and metal panels. The general contractor on this facility was Ryan Cos. The architects were William Rawn & Associates Architects Inc. and OPN Architects. The structural engineer of record was LeMessurier Consultants.
be significantly increased for some buildings (for example, a one-story building with a light roof). It is important to have accurate estimates of all connection loads, diaphragm loads, and shear wall loads affected by blast design at the time the project is bid. Typically, the precast concrete panels are initially designed to resist conventional loads. Then an experienced blast-design engineer will verify or modify the panel reinforcement as necessary to resist the design blast loads and provide equivalent static connection loads for the precast concrete design engineer. Much of the challenge for the precast concrete design engineer is to design connections to resist these large blast reactions while still accounting for acceptable stresses and deformations due to restraint of temperature deformations and shrinkage. Large, complex connections should be considered for their effect on constructability of the cladding. Oswald and Morgan discuss connections for blast-resistant precast concrete cladding in more detail.

Blast-resistant precast concrete panels are most commonly used for non-load-bearing applications. However, they can also be designed as load-bearing members subjected to more restrictive blast-design criteria. Also, both solid and insulated precast concrete panels can be designed to resist blast loads. Current blast-design criteria penalize precast concrete with prestressed steel reinforcement compared with conventional reinforcement because prestressing strands are less ductile than conventional reinforcing bars. Therefore, it is more efficient to use only conventional reinforcement for blast-resistant precast concrete panels. Ongoing blast testing may provide test data to allow less restrictive blast-design criteria for panels with prestressed reinforcement and load-bearing panels.

It is important for this paper to respect the sensitive nature of the information presented. The authors are not allowed to publish calculations or construction details specific to any of these buildings. The intent of this paper is to convey the experience of architectural blast-resistant precast concrete design in text and photographs.

**U.S. courthouse, northern district of Iowa, Cedar Rapids**

In September of 2009, Gage was awarded a contract from Ryan Construction to provide blast-resistant architectural precast concrete cladding on the new federal courthouse in Cedar Rapids, Iowa. The scope of the project included 54,000 ft² (5000 m²) of off-white, light acid-etched, 7 in. (180 mm) thick cladding plus 15,000 ft² (1400 m²) of 7 in. thick natural gray back-up to metal panels. Gage had not designed blast-resistant cladding before...
and was unfamiliar with the process.
Gage proceeded with phase one of the precast concrete cladding submittal with all of the panel reinforcement and connections designed in accordance with the wind and seismic load requirements. Gage had the process backward, essentially thinking that a conventional design would be reviewed by a blast consultant with comments incorporated into the final design.

After the first submittal was rejected, Gage hired Protection Engineering Consultants, an experienced blast consultant, and proceeded to follow their direction with regard to the process. Oswald and Morgan provided a helpful introduction to blast-resistant design for Gage. Gage then contacted the window supplier and received the reactions associated with the maximum dynamic capacity of the windows in the form of peak pressures. Each panel was given a control number, and Gage located connections in accordance with the contract structural drawings. Gage provided Protection Engineering Consultants with a minimum reinforcement section.

The blast design requirements necessitated between 0% and 60% increased reinforcement in the panels, but the real surprise was that the connection loads were roughly 10 times that required for conventional load cases.

In addition to the high connection loads, there were special requirements for the design of the connections. It is important to determine from the blast specifications whether the load can be reduced by half in the rebound. In this case, a 50% rebound reduction was allowed, greatly simplifying connection design.

It is also important to acknowledge a requirement in blast connection design: that the governing link in the load path must result in a ductile failure. This can be counterintuitive to structural engineers who are accustomed to simply making sure that the capacity of each link exceeds the required demand. It may be necessary to weaken a ductile link to get it closer to the required demand and weaker than any brittle link in the connection.

Secure federal building

In August 2010 Gage entered into a contract with Kraus-Anderson to provide architectural precast concrete cladding for a secure federal building in Brooklyn Center, Minn. The project consisted of 33,000 ft² (3100 m²) of primarily stone-clad and light acid-etched cladding, 10,000 ft² (930 m²) of natural gray metal back-up, and 18,000 ft² (1700 m²) of light acid-etched insulated wall panels forming an annex adjacent to the main office building.

A great majority of the panels on the main office building were two-story verticals with a punched window at each level. Gage hired Protection Engineering Consultants and requested blast data from the window supplier. On this project, a balanced design approach was required, in which panels supporting glazing needed to be designed to resist the full blast capacity of the glazing if this capacity exceeded the design blast load. This requirement, which does not apply to most current blast-design projects, ensures that the panels are stronger against blast loading than the glazing that they are supporting. The precast concrete panels can be designed to resist the applied blast load over the tributary supported window area. Unlike in the Cedar Rapids courthouse, these panels had replication. Gage was able to categorize all of the office building design in 12 analysis series. The next step would be to analyze the reinforcement required to resist conventional loads with this section. This information, along with the blast specification and the blast information from the glass supplier, was then sent to Protection Engineering Consultants for the blast design calculations.

In most cases it is not advisable to design connections to resist both vertical load and blast load because of the iterative nature of blast load design. Any change in reinforcement will change the load to be resisted by a combined vertical and lateral load connection. However, for a majority of the verticals on this project, Gage was required to combine gravity and blast tieback loads because of space limitations.

It is important not to forget about the basics of precast concrete connections in light of the other considerations brought on by blast-resistant design. One should always give proper consideration to both construction tolerance and thermal effects when designing precast concrete tieback connections. Even on the tiebacks designed to resist the largest blast load, Gage was careful to accommodate construction tolerances and thermal effects.

The parking structure was the first use of insulated precast concrete wall panels in a blast-resistant application for Gage. Gage designed a 10 in. (250 mm) thick fully composite section and cast them with mild reinforcement because the ductility factor is more favorable than for prestressed reinforcement. The blast analysis indicated that an insulated precast concrete panel is effective for dissipating blast energy.

James F. Battin U.S. Courthouse, Billings, Mont.

After extensive preconstruction efforts with both the design team and the general contractor, Gage was signed on in September 2010 to supply blast-resistant precast concrete cladding for the U.S. courthouse to be built in Billings, Mont. The scope of work consisted of 26,000 ft² (2400 m²) of 6 in. (150 mm) thick cladding cast on a formliner, 15,000 ft² (1400 m²)
of 7 in. (180 mm) light acid-etched cladding, and 13,000 ft² (1200 m²) of 4 in. (200 mm) C-shaped, light acid-etched column covers.

Because this was a design-assist project delivery system, Gage was on a tight schedule to provide design loads to the design team for incorporation into the final contract documents. Gage again hired Protection Engineering Consultants and requested peak blast pressures from the window supplier. Gage spent the first two weeks of design developing sketches that located every vertical load and tieback for the fourth, fifth, and sixth stories of the parent structure. This served a dual purpose: providing Protection Engineering Consultants with the information they needed for the blast analysis while also connecting each lateral load magnitude to a location on the building. Gage supplied the vertical and blast loads to the design team a few weeks later. Along with tables provided by Protection Engineering Consultants and coordinated with these sketches, the design team used this information to design bracing for the steel frame parent structure.

The self-weight of the first three levels of cladding was transferred via panel-to-panel shims to the foundation. The battered formliner left a net thickness of 5 in. (125 mm). Gage needed to balance the requirements of reinforcement distribution against the blast load attracted by this reinforcement. To save time, Kraus-Anderson, the general contractor, directed Gage to design tiebacks to the steel framing only, not to the cast-in-place concrete floor slab. The resultant connections resisted large inbound and outbound blast forces in the confined space between the slab edge and the back of the precast concrete cladding, about 5 in.

The sixth-level vertical precast concrete cladding panels were intended to mimic shutters on a very large scale. The architectural detail required the precast concrete cladding jamb to be slotted so that the blast-resistant glass system could be slid into place from above. For this reason, it was critical to main-
tain erection tolerances and virtually no outward bow in the precast concrete cladding.

Conclusion

Based on these experiences with the blast-resistant design of architectural precast concrete cladding, we recommend the following:

- Involve a qualified blast-design consultant from the beginning. Even in the preconstruction phase, conversations with your blast consultant will help identify and quantify items that will result in significant cost increases compared with a conventional precast concrete cladding project.

- Precast concrete panels are designed to resist blast primarily by relying on their ductility to absorb the applied blast load energy. A ductile system will minimize the panel reinforcement and, consequently, the corresponding design connection loads.

- Connection loads are generally governed by the load capacity of panels rather than the applied load because they almost always yield to the high magnitude of the peak blast load. A limited amount of yielding and deflection is acceptable per the design criteria and is generally desirable.

- The connection design typically accounts for most of the additional cost of blast-resistant design compared to conventional design. Therefore, panels should ideally have only the minimum load capacity required to resist all conventional and blast loads.

- The precast concrete designer may take more time to optimize the minimum amount of reinforcement required for wind and seismic loads knowing that the load capacity and the corresponding connection design loads are governed by the reinforcement.

- Avoid short spans for panelization. Spans of less than about 10 ft (3 m) will have a high load capacity even with minimum reinforcement. This will result in high connection loads. Also, generally avoid using prestressed reinforcement because prestressing strands are less ductile than conventional reinforcing bars, making it more efficient to use only conventional reinforcement for blast-resistant precast concrete panels.

- It is important to determine in the design stage the required connection capacity in rebound. This requirement can vary from 50% to 100% of the inbound load and can have an important effect on the design and cost of the connections.

- It is a good idea from a practical standpoint not to combine vertical loads and blast tieback loads in one connection because of the iterative nature of blast design calculations.

- Blast-resistant windows and blast-resistant doors should be centered in panels. The ideal consideration is for these openings to be punched with some section to either side. However, this is not a requirement. Additional panel-to-panel connections can be used as necessary where openings are near panel edges.

- Contact the window supplier early in the process and coordinate window blast loads to be resisted by the precast concrete cladding. This step is necessary only if a balanced design approach is required by the project specifications, in which panels supporting glazing must be designed to resist the full blast capacity of the glazing if this capacity exceeds the design blast load. This is usually only required for buildings that must meet security requirements from the Interagency Security Committee.

- Architectural precast concrete cladding should be the first choice for a blast-resistant building because it meets all the requirements for ductility and energy dissipation while still providing an aesthetically appealing facade.

References


About the authors

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Abstract

This paper summarizes the experience of one precast concrete fabricator in design, detail, and production of blast-resistant architectural precast concrete cladding for three government buildings. Compared with conventional design, blast design requirements do not significantly increase the required panel thickness or reinforcement; however, the connection design loads are typically much greater. Because certain items will result in significant cost increases compared with conventional precast concrete cladding, it is wise to engage a qualified blast-design consultant in the preconstruction phase. Precast concrete panels are designed to resist blast primarily by relying on their ductility to absorb the applied blast load energy. Connection loads are generally governed by the load capacity of panels rather than the applied load. The designer may wish to optimize the reinforcement for wind and seismic loads because load capacity and the corresponding connection design loads are governed by the reinforcement.

Keywords

Architectural precast concrete, blast, cladding, connection, panel.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute’s peer-review process.

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