

Designer's
NOTEBOOK
BLAST CONSIDERATIONS

For a surface blast, the most directly affected building elements are the façade and structural members on the lower four stories. Although the walls can be designed to protect the occupants, a very large vehicle bomb at small standoffs will likely breach any reasonably sized wall at the lower levels. There is a decrease in reflected pressure with height due to the increase in distance and angle of incidence of the air blast. Chunks of concrete dislodged by blast forces move at high speeds and are capable of causing injuries. Additional protection from fragment impact can be provided by steel backing plates, carbon fiber materials or KEVLAR lining the interior of the wall; however, these are extreme measures that should be reserved for localized protection of high value assets.

The building structure, architectural precast cladding, and the window, window wall, and any curtain wall framing systems may be designed to adhere to the blast criteria within the Interagency Security Committee (ISC) 'Security Design Criteria for New Federal Office Buildings and Major Renovation Projects,' dated May 28, 2001 for the appropriate Hazard Level as determined by a threat consultant. By combining the criteria of the ISC with the applicable blast analysis standards mentioned earlier, the architectural precast cladding systems should be sufficiently sized, reinforced, detailed, and installed to resist the required blast loading criteria on the panels if they were tested in accordance with the General Services Administration's (GSA's) 'Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings' (GSA – TSO1-2003). In addition to transferring the blast pressures safely into the supporting structure, the panels must also be checked for their capacity to transfer the additional loading caused by the specified window framing and blast resistant glass units.

Architectural Precast Concrete Cladding

Architectural precast concrete can be designed to mitigate the effects of a bomb blast and thereby satisfy GSA and DOD requirements. Rigid façades, such as precast concrete, provide needed strength to the building through in-plane shear strength and arching action. However, these potential sources of strength are not usually taken into consideration in conventional design as design requirements do not need those strength measures. Panels are designed for dynamic blast loading rather than the static loading that is more typical. Precast walls, being relatively thin flexural elements, should be designed for a ductile response (eliminating brittle modes of failure). There are tradeoffs in panel stiffness and the forces that must be reacted to by the panel connections that must be evaluated by the engineer. Typically, the panels should have increased section thickness or ribs on the back and have as much as 75 percent additional reinforcement. However, the amount of flexural reinforcing should be limited to assure that the tensile reinforcing yields before concrete crushing can occur. Shear steel may be used to increase shear resistance, confine the flexural reinforcing, and prevent buckling of bars in compression.

For precast panels, consider a minimum thickness of five inches exclusive of reveals, with two-way, reinforcing bars spaced not greater than the thickness of the panel to increase ductility and reduce the chance of flying concrete fragments, or use the thinnest panel thickness that is acceptable for conventional loads. The objective is to reduce the loads transmitted into the connections, which need to be designed to resist the ultimate flexural resistance of the panels.

Precast concrete panels are subject to horizontal loadings due to wind, earthquake and blast and in plane loads due to earthquakes. As a means of addressing these loads, they may be analyzed separately. This is a satisfactory design approach based on the 2000 International Building Code (IBC) load combinations.

Deep surface profiling should be minimized; such features can enhance blast effects by causing complex reflections and lead to a greater level of damage than would be produced with a plane façade.

To accommodate blast loading, the following features are commonly incorporated into precast panel systems:

1. Increase panel size to at least two stories tall or one bay wide to increase their ductility.

Panels can then absorb a larger portion of the blast energy and transfer less through connections to the main structure. Typically, the largest panel is analyzed for wind, seismic and dead-loading and connections are based on those results. But with bomb blast criteria, the goal is to provide panels with the flexibility to bend, break, or crush while remaining essentially intact. As a result, in many instances, the smaller, less flexible panels in each group may be the critical components, and these are analyzed for loading instead.

2. Panels should be connected to floor diaphragms, rather than to columns, in order to prevent stressing of the columns. The panels would then fail individually. When panels are connected to the floors rather than the columns, movement of any panel causes the previously set and tied-back panel to lose alignment. The amount of deflection of the floor or beam varies with the panel's position on the floor or beam, requiring field estimates to determine how high to set each panel to allow for deflection caused by the adjacent panel.

3. Panels may be designed with integrally cast and reinforced vertical pilasters or ribs on the back to provide additional support and act as beams that span floor-to-floor to take loads, see Fig. 8. This rib system would make the panels more ductile and better able to withstand an external blast, but force the window fenestration into a "punched" opening symmetry.

Load-bearing precast panels need to be designed to span over failed areas by means of arching action, strengthened gravity connections, secondary support systems or other means of providing an alternate load path. The precast concrete structure must satisfy the requirements of ACI 318, Sections 7.13.3 and 16.5.



Fig. 8 – The 6 in. thick x 22 ft. tall panels were reinforced with ribs spaced 6 ft. apart.

Connection Concepts and Details

For load-bearing wall structures, the following detailing recommendations on connections/ties will help resist progressive collapse:

- Horizontal and vertical ties in vertical joints between adjacent or intersecting bearing walls.
- Panels must be connected across horizontal joints by a minimum of two connections per panel.
- All members must be connected to the lateral force resisting system and their supporting members. Tension ties must be provided in the transverse, longitudinal, and vertical directions and around the perimeter of the structure.
- Ties between transverse bearing walls and connecting floor panels.
- Connection details that rely solely on friction caused by gravity loads are not to be used.

Architectural precast construction relies on mechanical connectors at discrete locations that may be damaged in a blast event, posing specific design problems to the engineer. These problems can be overcome with proper detailing. The governing connection forces are based on the maximum percentage of reinforcement for wind, seismic or blast loading, since the amount of steel is proportional to panel stiffness. The reaction forces for the design of the anchorages and connections should be based on panel width and be considered factored loads. The wind load reactions are based on elastic deformations of the panels.

Precast concrete cladding wall panel connection details may be strengthened versions of conventional connections with a likely significant increase in connection hardware, see Figs. 9-11 or connection details emulating cast-in-place concrete to provide a building which provides building continuity. For a panel to absorb blast energy (and provide ductility) while being structurally efficient, it must develop its full plastic flexural capacity which assumes the development of a collapse mechanism. The failure mode should be yielding of the steel and not splitting, spalling or pulling out of the concrete. This requires that connections are designed for at least 20% in excess of the member's bending capacity. Also, the shear capacity of the connections should be at least 20% greater than the member's shear capacity, steel-to-steel connections should be designed such that the weld is never the weak link in the connection. Coordination with interior finishes needs to be considered due to the larger connection hardware required to resist the increased forces generated from the blast energy.

Where possible, connection details should provide for redundant load paths, since connections designed for blast may be stressed to near their ultimate capacity, the possibility of single connection failures must be considered. Consideration should be given to the number of components in the load path and the consequences of a failure of any one of them. The key concept in the development of these details is to trace the load or reaction through the connection. This is much more critical in blast design than in conventionally loaded structures. Connections to the structure should have as direct a load transmission path as practical, using as few connecting pieces as possible.

Rebound forces (load reversal) can be quite high. These forces are a function of the mass and stiffness of the member as well as the ratio of blast load to peak resistance. A connection that provides adequate support during a positive phase load could allow a member to become dislodged during rebound. Therefore, connections should be checked for rebound loads (even if the panel is not designed for rebound). It is conservative to use the same load in rebound as for the inward pressure. More accurate values may be obtained through dynamic analysis and military handbooks.

It is also important that connections for blast loaded members have sufficient rotational capacity. A connection may have sufficient strength to resist the applied load; however, when significant deformation of the member occurs this capacity may be reduced due to buckling of stiffeners, flanges, or changes in nominal connection geometry, etc.

The capacity of a panel to deform significantly and absorb energy is dependent on the ability of its connections to maintain integrity throughout the blast response. If connections become unstable at large displacements, failure can occur. The overall resistance of the panel assembly will reduce, thereby increasing deflections or otherwise impairing panel performance.

Both bolted and welded connections can perform well in a blast environment, if they can develop strength at least equal to that of the connected elements (or at least the weakest of the connected elements).

**Figs. 9-11 –
Connection details**

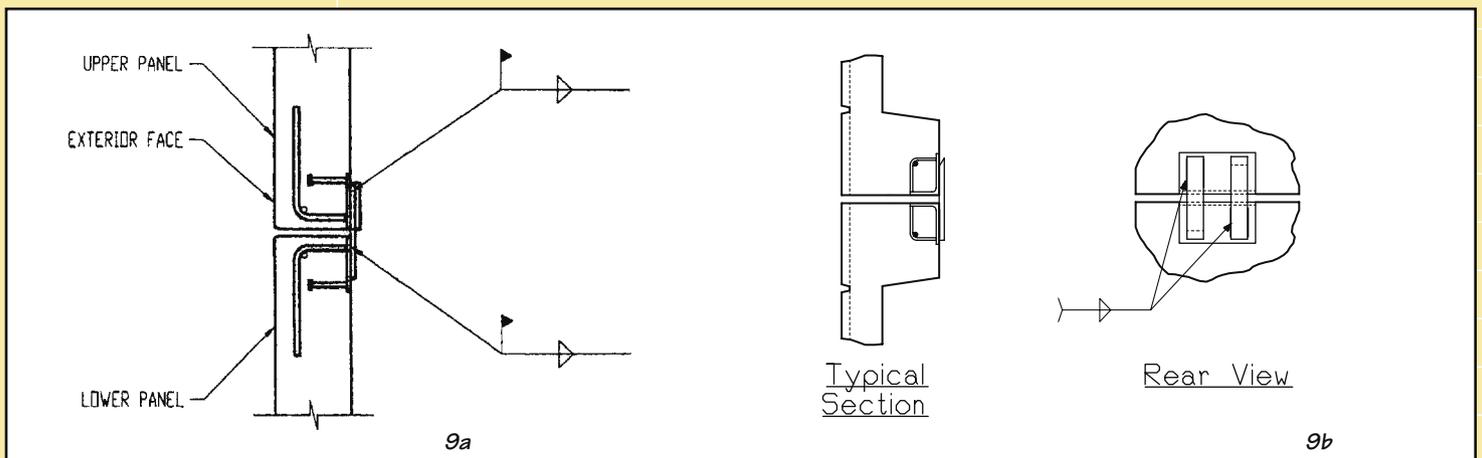


Fig. 9a through 9b – Panel to panel or alignment connections

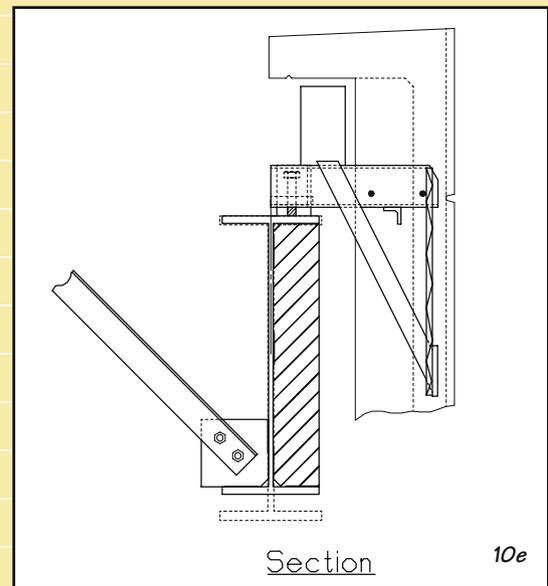
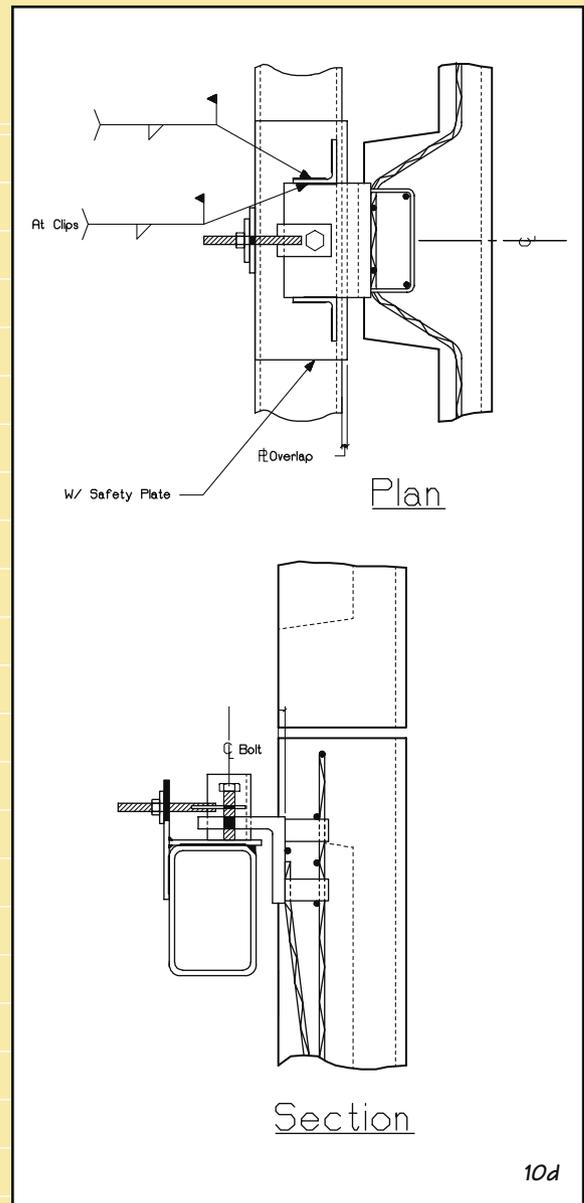
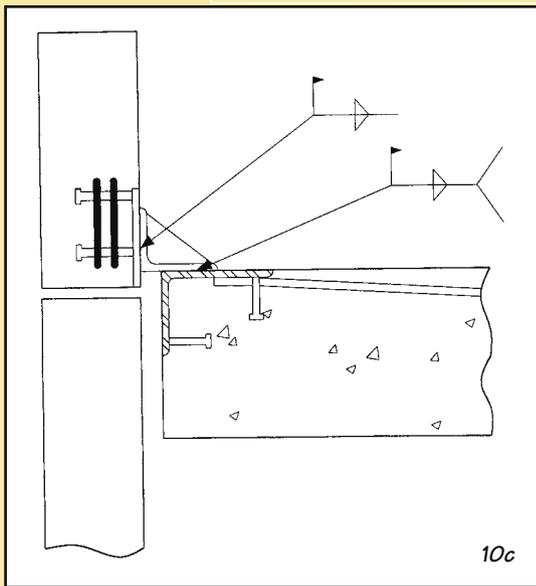
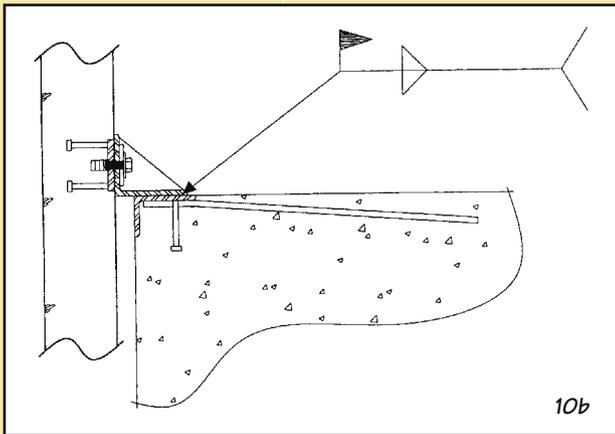
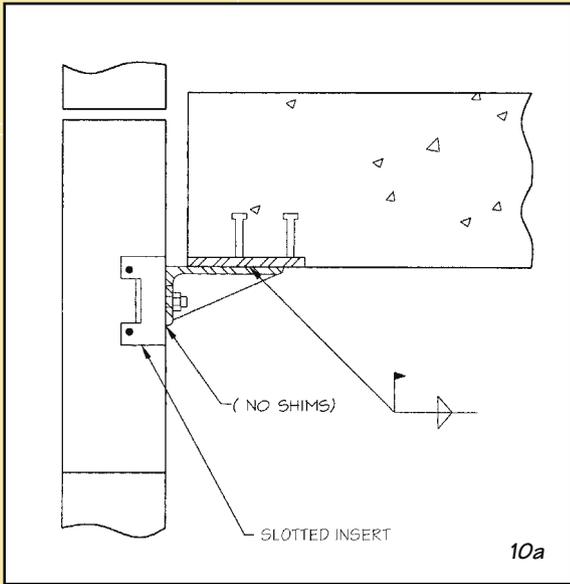


Fig. 10a through 10f - Bearing connections

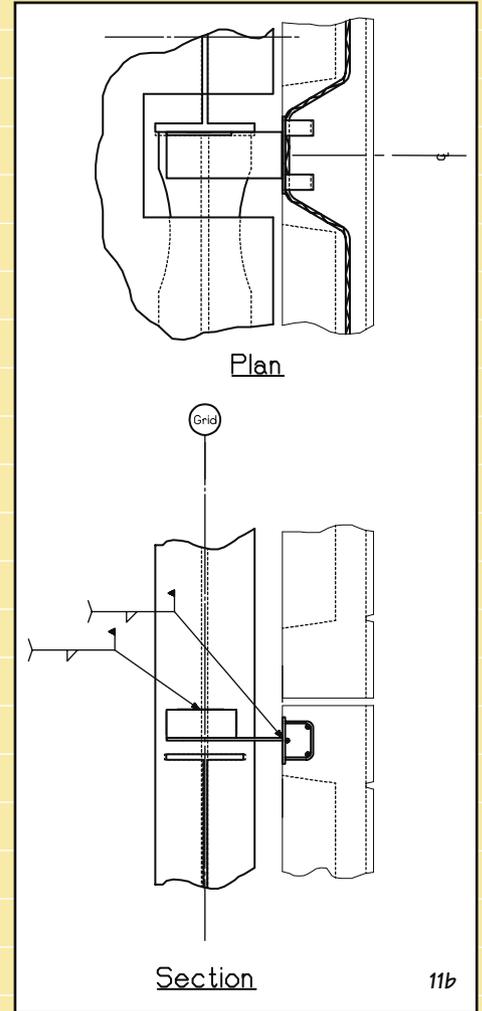
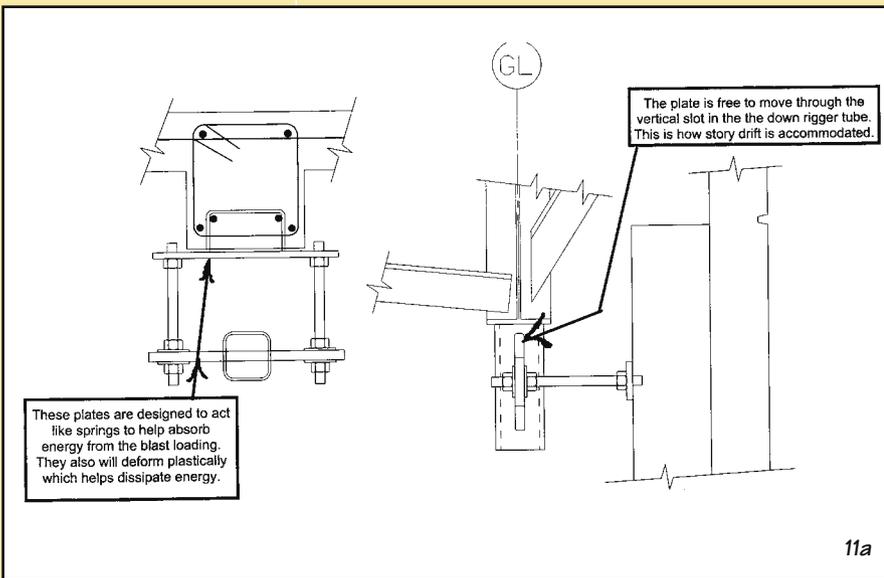
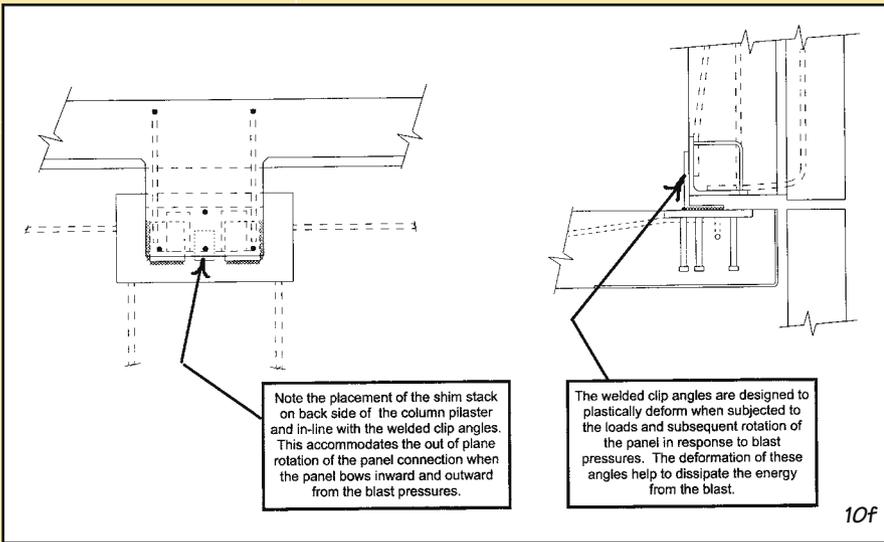


Fig. 11a through 11b – Push/pull or tie-back connections

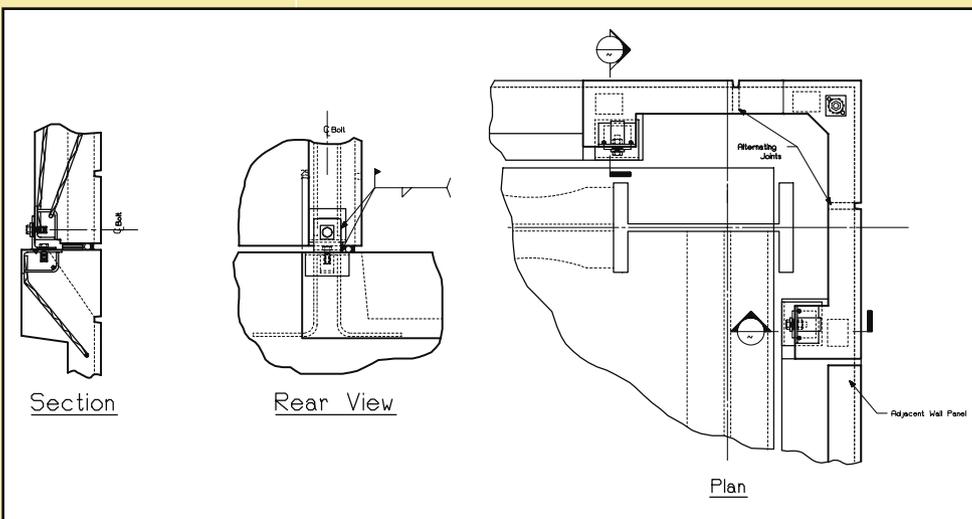


Fig. 12 – Column cover connection