Variations on a
Theme in Glass

The simultaneous renovation of three office buildings in Boston’s financial district created vibrant new public spaces and increased the value of the properties. The design and construction of the new glazed lobbies in each building also demonstrated the value of close cooperation on the part of the design team, the owners, and the various contractors.

By Eric M. Hines, Ph.D., P.E., M.ASCE

The original facade at 1 Post Office Square was replaced with a 30 ft tall glass entrance space that seems to invite the neighboring Post Office Square Park right into the lobby.
RAMATIC ALTERATIONS to buildings can be considered a necessary part of attracting and keeping tenants, and the recent renovations of three office towers in Boston’s Post Office Square, the city’s financial district, have demonstrated the potential for transforming underperforming assets into prized properties. Owned by Chicago-based Equity Office Properties, the trio of buildings—located at 1 Post Office Square, 225 Franklin Street, and 100 High Street—enjoy prime locations but until recently lacked contemporary presence and key amenities.

A design team led by Boston-based CBT Architects that included structural engineers LeMessurier Consultants, Inc., of Cambridge, Massachusetts, worked with Equity Office Properties on a strategy aimed at elevating the properties into positions of greater value in the market. All three renovations were designed and constructed simultaneously, making a significant effect on the street-level experience of Post Office Square as three distinct variations on a theme in glass.

The transformation work was concentrated at the street level because changes there can dramatically alter the perception of a property. At 1 Post Office Square, a 36 ft tall glass entrance space seems to invite the neighboring Post Office Square Park right into the lobby. A light-filled “great room” with a warm Italian marble backdrop graces the new entrance at 225 Franklin Street. The new entrance at 100 High Street features the conversion of single-story retail space into a double-height glass lobby with a facade that follows the outwardly curving form of the tower above.

Each lobby renovation was designed for a high level of transparency and a unique character in collaboration with Pilkington Planar/W&W Glass LLC, of Nanuet, New York, and their North American engineers, Glaswal Systems Ltd, of Newmarket, Ontario. The new lobbies showcase the potential of creative solutions to such standard challenges as the corners, the details of the entrance portals, the construction tolerances, the existing facade elements, and the building system movements. Critical to the success of each project was the coordination exhibited by the design disciplines and the detailed oversight of the construction phase. Examples from each design and construction process help to illustrate the measures required to achieve the desired synthesis of aesthetics, safety, constructability, and cost.

All three projects proceeded at roughly the same time, the design, contract documents, and construction milestones all completed within months or weeks of one another. The design process began essentially in the fall of 2007, and the contract documents were completed during the winter of 2007–08. Construction began during the spring and summer of 2008 and was completed in the spring of 2009. From a business point of view, the three projects had to be conducted together in order to minimize the turnaround time.

Each of the new lobby systems features a series of glass panes known as lites that were hung from structural glass fins. The design of the 1 Post Office Square system required these fins to be hung 36 ft from stainless steel brackets cantilevered from the fourth-floor framing. The 225 Franklin Street system was attached to building framing cantilevered 17 ft from the nearest column line. The fins for this structure stand several feet in front of the existing facade and curve inward toward the building. Since these fins are only 22 ft high, it proved more cost effective to make them base supported and to use the structure of the building only for lateral support. The 100 High Street system was hung 28 ft from curved framing, cantilevering up to 12 ft from the building column line but flush with the building’s existing facade.

Early in the design process, a cable net system had been considered for the 100 High Street project. The reinforcement required to support the heavy cable tensions, however, would have been several times greater than that required to support glass fins and thus would have been prohibitively expensive. By using structural glass fins as the basic form for each design, the design team was able to focus on details that would support the architectural character of each system.

While the appearance of the fins and lites themselves remained relatively consistent throughout all three projects, the site conditions required special detailing that complemented the architectural play between the elegance of glass...
and the richness of stone. These requirements for special detailing encouraged the design team to work together to invent new structural solutions that integrated the steel and glass systems. The success of these design inventions depended largely on a collaborative design process in which several key ideas were developed spontaneously during meetings or while design team members were on the construction site.

Considering the three projects as variations on a theme also helps to explain each major design challenge. For example, both the 1 Post Office Square and the 100 High Street fins were hung from framing cantilevered from the existing structural framing. In each case, the tops of the fins were located in areas that were several feet below the existing framing elevations. The two systems developed to hang the fins from these unique structures varied significantly, however.

For the 1 Post Office Square structure, the stainless steel cantilevered fins were supported at the building’s front column line by W 24 × 76 girders moment connected to the existing W 14 × 730 columns. These girders were stabilized torsionally by W 16 × 40 back-span supports that were kinked upward and pinned to hollow structural steel (HSS) members spanning between the webs of the fourth-floor beams above. To simplify the field connections, W 16 stubs were welded on either side of the girders in the shop and bolted in the field to adjoining members via end plate connections. The sizes of the girders and back spans were dictated by the stiffness requirements. Kinking the back-span elements upward avoided the need to carry this framing to the next bay and thus both stiffened the system and saved substantial material.

Pinning the back-span supports to the HSS members that were set below the bottom of the deck accommodated the fin locations with respect to the existing framing; it also obviated the need to tie these connections into the floor slab. The deflection limitations of the glass fin support points governed the stiffness considerations not only in the downward direction but also in the upward direction. A critical load case consisted of fourth-floor live loads pushing the back-span supports down and hence lifting the fin supports up on the opposite side of the girder on which they were propped. To mitigate this deflection, new posts were installed between the new prop girders and the existing fourth-floor girders above, ensuring compatibility between the two under live loads. At the locations where the floor beams would deflect the back-span supports downward, the floor girders would also deflect the prop girders downward and hence cancel out the fin’s tendency to seesaw upward.

At 1 Post Office Square, the stainless steel cantilevered fins were supported at the building’s front column line by W 24 × 76 girders moment connected to the existing W 14 × 730 columns.
The 1/2 in. thick, 18 in. deep stainless steel cantilevers supporting the glass fins were designed to support the 3/4 in. thick glass fins from either side. The connections at the tops of the stainless steel fins ensure that the only parts of the system visible from below are two horizontal lips of stainless steel and four bolt heads. The clip angles, the shims, and the support pin are hidden from sight above the lips.

The glass fins supporting the 100 High Street glass wall were hung approximately 4 ft below the existing framing. For this project, the existing framing consisted of curved spandrel beams cantilevered 4 to 12 ft beyond the building columns. The 100 High Street lobby featured the conversion of the existing single-story commercial frontage into a new two-story lobby space. The new lobby, the cantilevered framing, and the relatively light existing spandrel beams required the reinforcement of the entire structural system. Furthermore, each of the glass fin hanging points required bracing in both horizontal...
directions. These requirements led to the development of a double-angle truss structure that achieved the required hanger elevations while significantly stiffening the existing spandrels. The truss structure was braced back into the building with HSS tubes, which were also designed to stabilize the hanger eccentricities resulting from construction tolerances.

The removal of the second-floor slab required the columns to be stiffened not only to resist buckling but also to resist the tendency to bend since they would be acting as the back spans for the 12 ft cantilevers supporting the spandrel beams. After several conceptual studies for the reinforcement of this system were considered, the design team decided to stiffen the cantilevers by front and back bracing. Further complicating this design challenge was the fact that the removal of a second-floor slab also required the removal of lateral bracing from the midsection of two W 14 × 426 columns that supported this fully occupied 30-story building. The structural drawings prescribed an eight-step sequence for the stiffening of these columns and the demolition of the second-floor slab.

At 225 Franklin Street, the glass fins were base supported because the glass wall was designed to stand approximately 4 ft in front of a floor that was already cantilevered 17 ft beyond the building’s columns. For this project, the kinked glass fins required only lateral support, but this support had to penetrate the building’s 1963 concrete facade. The support system was developed in a form similar to the system at 1 Post Office Square, but since the members were not required to carry vertical loads they were developed as 8 in. square HSS tubes to offer equal stiffness in both directions. The tubes cantilevered from a prop girder similar to the 1 Post Office Square members, and the tube back-span elements were kinked upward and pinned just below the slab into the first beam line back from the spandrel beams. The prop girder was supported with double-angle connections from the 17 ft cantilever girders, which required flexural reinforcement in the form of WT sections that were welded to the bottom flanges of the existing cantilevers.

A lack of information regarding the existing concrete facade panels at 225 Franklin Street meant that nearly all of the structural details had to be redeveloped into their final form during construction. To maintain appropriate tolerances and quality control on the glass support system and to redesign the details in the midst of a tight construction schedule, the engineers designed all of the connection details in-house and expedited the shop drawing process, meeting regularly with the construction manager and the steel fabricator until all of the existing field conditions had been appropriately considered.

After the fin support systems had been established, the design discussions turned toward the portals for each project. The 1 Post Office Square project entailed an all-glass portal with a slender stainless steel frame to support the door hardware, which is set slightly inside the lobby. The 100 High Street project involved a slender stand-alone canopy cantilevering 8 ft beyond its column supports. The 225 Franklin Street project features a slender stainless steel bar that supports door hardware that was mounted flush with the glass wall and is in turn supported by the glass fins. These were not necessarily the original concepts, however. In the case of the 1 Post Office Square portals, those systems were originally proposed as significantly larger steel frames. The 1 Post Office Square wall itself had been conceived architecturally as an independent glass plane cantilevering beyond both the sidewalls and the slight roof return at the top of the wall. To preserve the purity of this plane, the entrances were set approximately 28 in. inside the lobby. The design team determined, however, that a large metal frame would have disturbed this purity; the team therefore worked closely with the glass fabricator to investigate the potential for a transfer beam made of structural glass. Although the construction of such a beam was definitely possible, the 18 ft length of the beam meant that at least one splice
would be required. Otherwise the design team would have to place a special lamination order with a larger autoclave. Even if the expense of this special order had been acceptable, it could not have been completed within the project schedule. The glass beam still required a steel frame to support the proposed balanced door hardware; however this frame could be much smaller than a frame designed to act as the entire portal structure. This steel frame allowed the use of standard balanced doors and standard connections—something required by the project’s budget—while satisfying the seismic requirements that the doorways remain structurally independent of the glass wall.

To assemble the standard fittings, the design team ultimately decided to use two splices at each of the two fins that required support, instead of a single splice at the beam’s mid-span. The stainless steel frame was shop-welded into a single piece from 1 1/2 by 6 in. bars and mounted in the field to special base plates for fixity, while the glass beam itself was suspended vertically from the fins above. A 1/4 in. diameter cable attached to the rear of the beam was included as a fail-safe against collapse in the case of glass breakage.

In contrast to the 1 Post Office Square glass wall, which extends about 5 ft in front of its building’s facade as an independent and pure glass plane, the glass wall at 100 High Street acts as a transparent curved surface in the same plane as the existing curved facade of its building, and the entrance portal pierces this surface. To keep the canopy edges as thin as possible, the structure was reduced to a 3/4 in. plate stiffened in a manner that is concealed from passersby. The 22 ft long by 13 ft wide canopy weighs 6 tons and has an 8 ft exterior cantilever. It is supported on two 18 in. deep by 6 in. wide steel tubes standing on infill framing over an existing garage. The challenges presented by the infill framing concerned the location of the column bases, the differences in elevation with respect to the existing framing, the requirements for stiffness, the significant bending capacity at the column bases, and the constructability of the design. As in the 225 Franklin Street project, the engineers designed all of the details for the 100 High Street column base supports on the basis of actual field dimensions in order to meet the tight tolerances and adhere to the construction schedule.

The 225 Franklin Street entrance is a glass box protruding from the intensely textured 1963 precast-concrete facade, which in turn is supported by floor slabs cantilevered 17 ft from the building columns. The box is transparent but is also ordered with respect to the proportions and arrangement of the insulated glass lites. Accentuating this order, the lites have a horizontal orientation, the joints between the lites are filled with black silicone, and the entrance portals assume the exact space of two lites. The repose of the glass box intensifies the rare marble wall, which is made from Italian Paonazzo stone and presides over the lobby’s interior with its golden and rust-colored limonite markings.

The 225 Franklin Street portals were designed to be, like
the system at 100 High Street, flush with the surface of glass but also, like the system at 1 Post Office Square, as light as possible. Supporting the doorways is a thin sliver of stainless steel that is supported by the glass fins. In this case, the integration of glass and steel is seamless. From a distance, the steel header blends into the bold silicone lines while up close the header matches the hardware of the doors themselves. Consistent with many other details on these projects, the 225 Franklin Street headers were designed and drawn conceptually during a meeting of the architects, the engineers, and the contractors. Once the design team had worked out the ramifications of this and other details in meetings with a significant number of stakeholders, few modifications were necessary for the final design.

The special character of each lobby and its existing building produced varying corner conditions. The 1 Post Office Square corners were required to extend out from the existing building and support a front glass surface that cantilevers beyond the return glass. The 100 High Street glass is flush with the building facade and so did not require special corner detailing. To avoid steel columns at the corners of the 225 Franklin Street facade, glass “minifins” were designed to be stabilized by a light tensioned steel structure that projects through the exact corner of the existing concrete facade above.

At 36 ft in height, the 1 Post Office Square corners were, in comparison with the 28 ft height of the corners at 100 High Street and the 22 ft height of the 225 Franklin Street corners, the tallest of the three lobbies. The loads on the corners were intensified by the extension of the front surface glass beyond the return walls (the wing or end walls). The design team’s early attempts to make the corner lites self-supporting were abandoned once it became clear that insulated glass would be required on the return lites. The time and expense required to develop special shear connections for the insulated lites would not fit within the project’s limits, so a slender corner column was designed instead. This 40 ft tall stainless steel circular HSS column is 10.75 in. in diameter with a wall thickness of 0.5 in. and is restrained only at the top, offering a high level of adjustability but low visual obtrusiveness. The column was connected back to the building with a built-up T section welded to the building’s existing column and integrated with the cantilevered fin supported by the same building column. The brackets supporting... (Continued on Page 86)
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(Continued from Page 75) The corner glass were attached to arm plates that were welded to the steel column. To provide sufficient adjustability to match the exacting glass tolerances with the less-stringent steel tolerances, a series of recessed stainless steel shims were installed between the arm plates and the glass hardware brackets. The brackets were fastened to these arm plates through holes that were drilled in the field after the column was fully installed. The consistency of the shims on both sides of the arm plates and their recess make it very difficult to recognize differences in shim thickness.

By far the most challenging corners to design and construct were those for the 225 Franklin Street project. The existing support structure in this area consisted only of light spandrel beams and a structural slab that lacked adequate capacity to resist corner loads. During design, the lack of information regarding the existing concrete facade and its relationship to the steel framing led to the conclusion that the facade might have to be cut by saw and replaced with drywall on the interior of the glass box. The design team felt very strongly, however, that such a move should be avoided if at all possible and determined, together with the contractors and the construction manager—Shawmut Design and Construction, of Boston—to solve the problem as quickly as possible once the area in question had been opened up.

Delaying the finalization of the design for the 225 Franklin Street corners until the construction phase afforded the additional advantage of having the construction manager, the steel fabricators, and the glass installers on board to make decisions about the potential installation of the glass brackets via surgical penetrations through the existing facade.

Once construction was underway and the existing conditions were documented, the design team determined that it would be possible to maintain the existing facade. At this point, with the glass shop drawings in production, the structural engineers worked directly with the glass fabricators’ engineers in both North America and the United Kingdom and with the glass installer for 225 Franklin Street to refine the connection details and have the fewest possible fastening points.

Finally, the design team and the contractors determined that a single stainless steel blade could be mounted through the corner of the existing facade of the 225 Franklin Street building and stabilized on either side by posttensioned stainless steel rods. As with the 1 Post Office Square corners, the blade brackets would have some room for recessed shims, but the stem of this blade could be made adjustable by shimming it 1 in. off of a complicated weldment just inside the building corner and drilling the connection holes in the field. The 1 in. shim provided significant adjustability but also created significant eccentric forces on the weldment. In its final condition, the weldment connection point was required to carry forces in five of the six degrees of freedom. The only degree of freedom determined not to be significant was torsion.

The supporting weldment was complicated not only by the complexity of the required load paths but also by the fact that it had to be installed within a very tight area and worked around both the existing building framing and the existing facade. Precise field measurements formed the basis of the final design, which was drawn by hand in a series of detailed sketches. Once the system had been designed, the structural engineers were concerned about the feasibility of actually constructing the system in such a tight space. Questions regarding which areas could be welded in the shop, which areas would have to be welded or bolted in the field, and which areas would require splices seemed almost impossible to answer without building a full-scale mock-up out of wood prior to finalizing the shop drawings.

The mock-up helped to determine how exactly to splice the heavy weldment and how to hoist it into place. The weldment mock-up also provided an opportunity to install a mock-up of the stainless steel blade prior to its fabrication. Once the process of installation had been finalized, the installation of the weldment and the blade and the posttensioning proceeded smoothly. The result of all that effort was to preserve the existing facade in place and to make the corner supports practically disappear in all except for one critical view. When one stands directly below the blade and looks up to the crenellated concrete facade of the 1963 tower, the blade assumes the role of tying together the kaleidoscopic lines of the facade and the glass. With its slightly offset angles, the blade holds a diverse group of elements together with a lively tension that is as visual as it is physical.

Upon completion of the three glass lobby projects, the owners were able to realize higher occupancy levels and higher rents in spite of the economic downturn, yielding a return on their investment of $8 million to $12 million per project. The presence created by the new lobbies has been well received and has benefited not only the buildings themselves but also the financial district as a whole.

The projects were also studied in the classroom and onsite by students in a steel design class at Tufts University. In particular, the students considered the interesting cantilever systems featured in these projects, came to understand the importance of simplicity and clarity in structural engineering calculations, and developed an understanding of the seriousness of removing the bracing from the existing columns in the 100 High Street building. They also learned that the
calculations themselves constituted only a small portion of the engineering. As a result, the story behind this design helped many students see the role of simple calculations in the creative process and develop a better understanding of assuming responsibility for structural design work.

Another major lesson learned by the design team was that close collaboration that transcends traditional discipline boundaries can help all of the stakeholders in a project achieve a higher level of design without a substantial increase in cost. Sometimes advanced design and planning technologies were able to support this process, and sometimes they got in the way. The key ingredients for success turned out to be the commitment and ability of the team members to work together through a host of difficult details that involved multiple trades and existing conditions.

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**PROJECT CREDITS**

**Owners/clients:** Equity Office Properties, Chicago  
**Architect:** CBT Architects, Boston  
**Structural engineer:** LeMessurier Consultants, Inc., Cambridge, Massachusetts  
**Construction manager:** Shawmut Design and Construction, Boston  
**Glass fabricator:** Pilkington Planar/W&W Glass LLC, Nanuet, New York  
**Glass engineers:** Glaswal Systems Ltd, Newmarket, Ontario, and Pilkington Architectural, St. Helens, United Kingdom  
**Glass installation:** Karas & Karas Glass Company, Inc., Boston (1 Post Office Square and 100 High Street), and Ipswich Bay Glass, Rowley, Massachusetts (225 Franklin Street)  
**Steel fabricators:** Berlin Steel Construction Company, Berlin, Connecticut (1 Post Office Square); Quinn Brothers Iron Works, Inc., Essex, Massachusetts (100 High Street); and DeAngelis Iron Work, Inc., South Easton, Massachusetts (225 Franklin Street)