Structural Renovation & Expansion for the Hynes Convention Center

A successful renovation requires a thorough evaluation of the building's condition, as well as an appreciation of its condition, in order to determine the design plan.

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THE UPGRADING of the Hynes Auditorium into a convention center required nearly doubling the original building's floor space for exhibition areas and meeting rooms. This requirement could only be reasonably met by increasing the envelope of, and renovating, the existing structure. The old structure was expanded to the north and east. In addition to expanding the building's footprint, another floor was added to the structure.

The renovation and expansion of the existing structure was constrained and shaped by the restrictions imposed by:

- the existing foundation system;
- work required within areas of limited access and within rights-of-way where traffic could not be seriously impeded; and,
- upgrading the existing structure for seismic loads.

These constraints posed architectural and structural challenges to the project's successful completion. *(See "Foundation Considerations for the Expansion & Renovation of the Hynes Auditorium" on pages 35-62 for a discussion of the foundation system and its expansion — Editor's note.)*

Existing Structural System

Located adjacent to the Prudential Center Complex in Boston, the original Hynes Auditorium was designed in 1962, and construction was completed in 1964. It included a basement loading dock, mechanical mezzanine, two levels of exhibition halls, offices and public facilities. Figure 1 presents a site plan of the original structure.

The structure was designed to live load capacities of 250 pounds/square foot (psf) for the loading dock and exhibition areas and to 150 psf for other public spaces. Building codes in use at that time did not require an evaluation of the structure for earthquake loads. The foundation for the structure consisted of steel HP14 piles and 16-inch diameter pipe piles

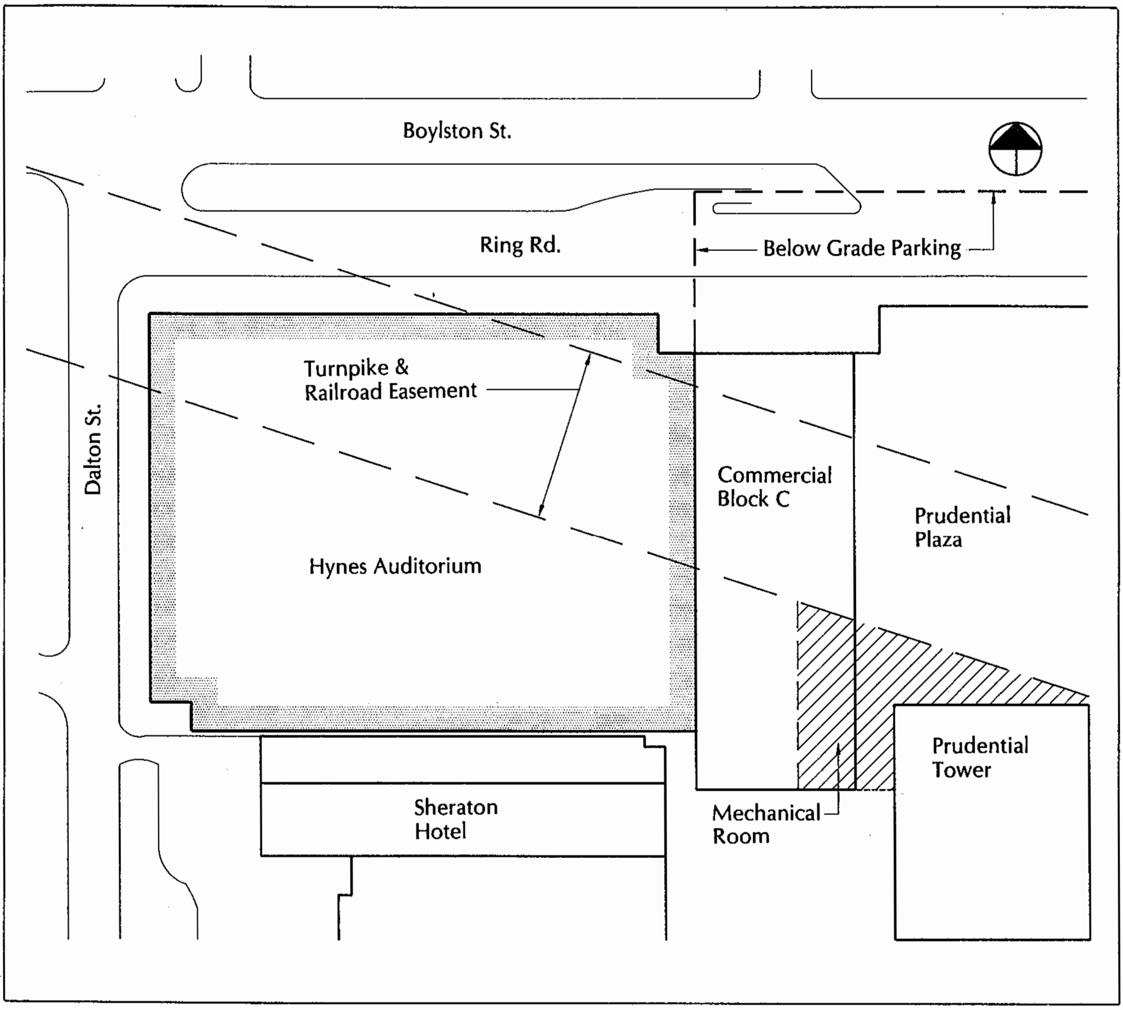

FIGURE 1. The site plan of the original Hynes Auditorium.

supporting reinforced concrete caps and end-bearing on bedrock. The main portion of the building's Prudential Plaza and second levels were constructed of two-way concrete grid flat slabs (waffle slabs) and concrete columns in 30-foot square bays. The mechanical mezzanine above the second level and the roof structures were constructed of structural steel. The area of the Prudential Plaza level directly above the Massachusetts Turnpike and a railroad right-of-way included structural steel framing and plate girders for the transfer of loads from the concrete columns.

In addition to the Hynes Auditorium, the Prudential Center Complex included a tower (the Prudential Tower) and four one-level commercial blocks. The turnpike and railroad rights-of-way cut across the entire complex. Commercial Block C, the complex area directly to the east of the Hynes Auditorium, was constructed on a mat foundation except for the area above the rights-of-way. Within the median strip of the turnpike, and between the turnpike and the railroad, cast-in-place concrete corrugated steel shell (Cobi) friction piles were used. The framing of the street level north of the turnpike consisted of concrete beams and one-way flat slabs. South of the turnpike, the street level was framed with two-way concrete flat slabs. The plaza level and roof structures were constructed using structural steel framing. As in the construction of the auditorium, a system of steel plate girders was used for the transfer of column

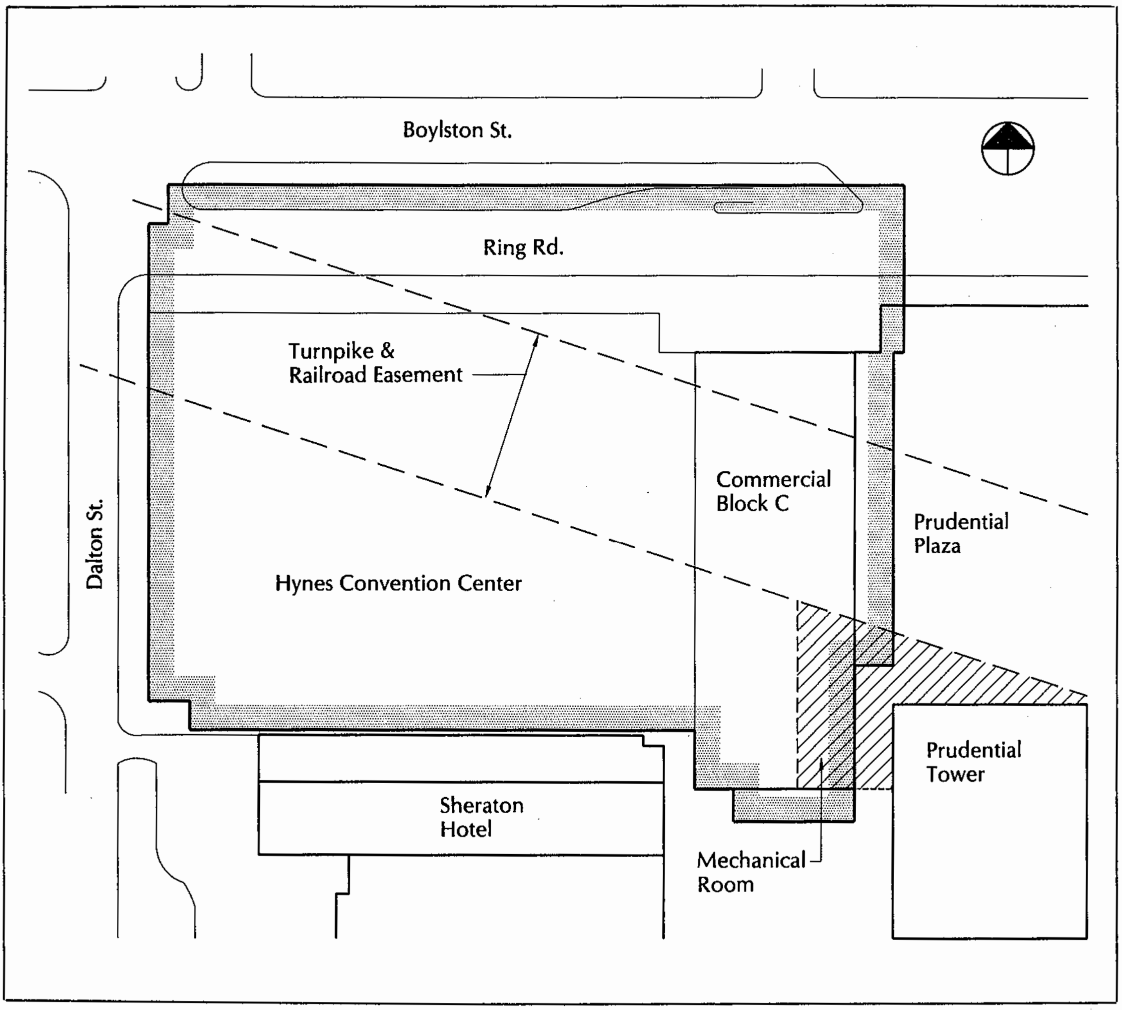

FIGURE 2. The site plan of the renovated Hynes Convention Center.

loads above the turnpike and railroad rights-of-way.

Design Issues

The old structure was to be expanded to the north into the Ring Road area towards Boylston Street and to the east into Commercial Block C (see Figures 2 and 3). The evaluation of initial studies of possible structural systems for the convention center indicated that before incorporating the original structure in the new design, several problems would need to be addressed. The overall design load of the superstructure in the Commercial Block C area would be increased at least 100 percent over the existing design, and the design load of the superstructure in the existing auditorium area would be increased by approximately 50 percent. The capacity of the existing columns, foundations and transfer grids over the turnpike/railroad rights-of-way were of particular concern. Design checks of the existing columns within the auditorium indicated that sufficient capacity was available. However, the transfer girders over the rights-of-way varied greatly in their existing capacities and it appeared likely that many of them would require reinforcing.

The foundation system for the auditorium consisted of rock-bearing steel HP14 piles and steel pipe piles. A key design concern for the steel piles was the loss of cross-sectional area due to corrosion. Design standards in use at the time of initial construction required that

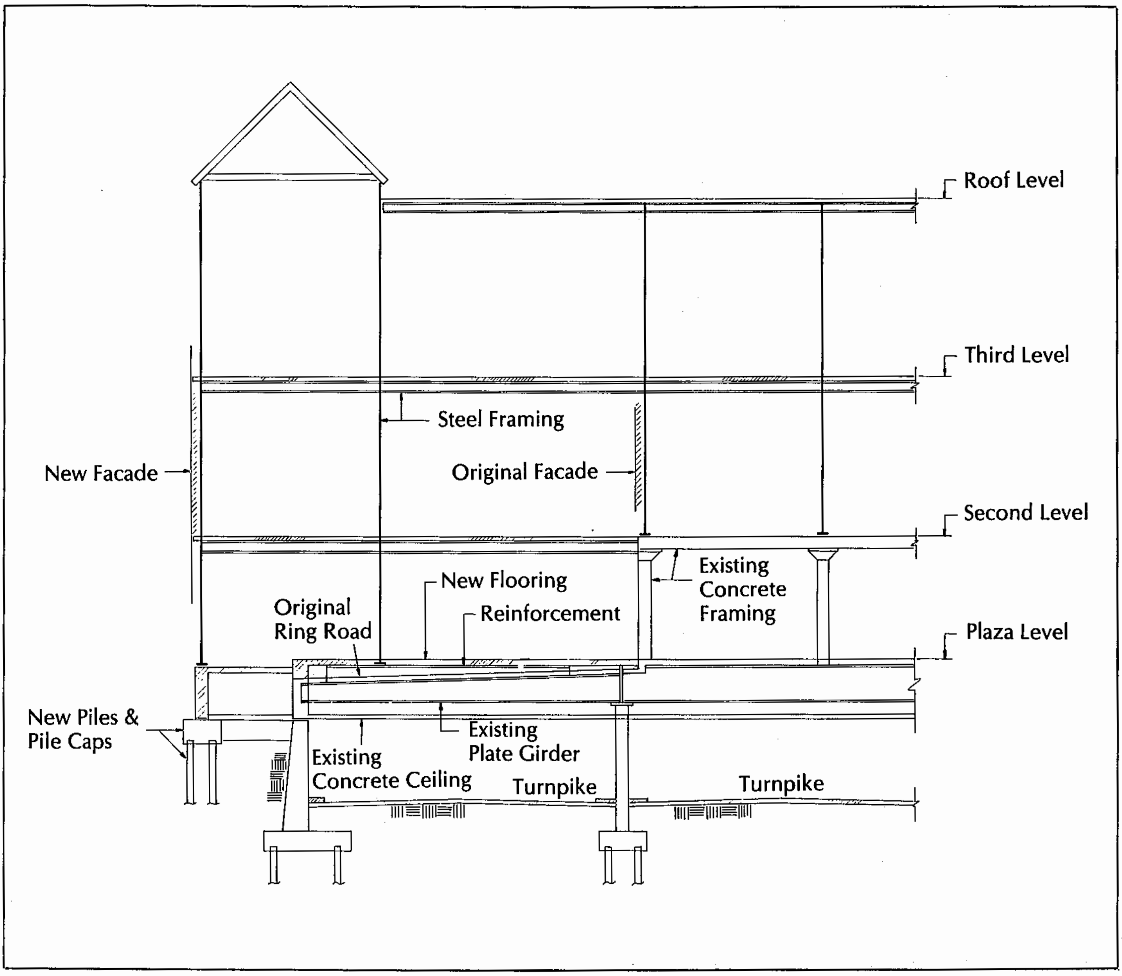

FIGURE 3. A cross-section of the Hynes expansion to the north into the Ring Road area and towards Boylston Street.

the capacity of the steel piles be partially reduced because of the possibility of corrosion. Current design standards do not require the same reduction provided that measures are taken to resist possible corrosion.[1] When the original building was constructed, the piles were coated with a corrosion-inhibiting substance and cathodic protection devices were also used.[2] A number of test pits were excavated to allow visual inspection of the piles in order to study their condition with respect to corrosion and to evaluate their capacity. The cathodic protection was found to be functional and the piles were found to be uncorroded. In addition, a load test was performed on an existing pile of each type. As a result of these investigations and the change in design standards, the rated capacities of both pile types was increased by approximately 50 percent.

The concrete mat foundation for the Commercial Block C area was investigated for a 100 percent increase in loads. The mat's limited capacity and the long-term settlement of the new structure due to the compression of the subsoil were of major concern. In order to accommodate the new higher loads and to have settlement characteristics compatible with the adjacent auditorium foundation, a rock-bearing pile was desirable for this area. The pile that would be selected would have to offer a high capacity with low soil displacement and would have to be capable of being installed in limited headroom. The pile selected was a unique drilled-in steel pipe that provided a 250-ton capacity and was capable of being installed in headroom as low as 10 feet. The total installed length of the pile was approximately 160 feet.

The plaza and second levels of the auditorium that housed the main exhibition halls in the original building would be utilized as much as possible in the new design. A full third floor and a partial mezzanine were to be added to the structure. The building's original mezzanine above the second level as well as the roof structures were evaluated for incorporation into the new design. The elevation of the original mezzanine and the majority of the roof framing were found to be incompatible with the new design. The remainder of the roof framing was evaluated for compliance with the current state building code requirements.[1] The roof was found to be underdesigned for current snow drifting design criteria. Therefore, it was recommended that the auditorium be demolished down to the second level.

The original Commercial Block C framing at the street level north of the turnpike was designed for street traffic. The structure was, therefore, of sufficient capacity for use in the renovation. However, the elevation, slopes and column grid could not be incorporated into the new design. The elevation of the existing plaza and roof levels did not correspond to the adjacent auditorium framing levels. The new design required that the majority of the existing superstructure be demolished to the mat level.

The only portion of the Commercial Block C plaza level area that was salvaged in the final design was the roof of the basement mechanical equipment room that served the Prudential Tower. This room, which happened to be located within the area required for the Hynes Auditorium expansion, would be permanently leased back to the Prudential Tower owner. Since this room actively serviced the tower, it had to remain operational throughout the construction process. In order to support the new superstructure above the room, new drilled-in pile foundations were installed through the space and new piers and columns erected. This work required an intensive coordination effort between the Massachusetts Convention Center Authority (owners of the Hynes Auditorium) and the design team as well as the cooperation of the owners of the tower. The mechanical equipment room remained in operation throughout the project.

New Structural Systems

The structural systems for the expansion were designed to overcome the constraints imposed by the following conditions:

1. The existing auditorium structure was of limited capacity, therefore the weight of the new framing systems and architectural finishes was critical.
2. Building loads, column locations and column spans had to be balanced throughout the design process.
3. The speed of erection was also a major consideration since the auditorium was to be closed throughout the construction process. To limit the loss of convention business, an aggressive construction schedule was mandated by the owner. The work above the turnpike/railroad rights-of-way within the Commercial Block C area further impacted on the duration of the construction period since these rights-of-way could not be totally impeded during construction (for example, construction work access to the turnpike was limited to not more than 2 of the 3 lanes in each direction and only during periods of off-peak traffic).

A structural steel system was found to meet these considerations. The weight of the structural steel system selected was approximately one-third of the weight of the concrete grid flat slab system used for the original auditorium while possessing the same design strength. A structural steel system can also be erected quickly and from above, thus requiring only a very limited presence within the turnpike/railroad rights-of-way. In addition, structural steel permits greater flexibility in accommodating unequal spans, high loads, concentrated loads and long span roof structures.

The structural steel system utilized a common construction technique that permitted an overall cost-effective design and maximum speed of construction. The system included a concrete floor slab on a deformed metal deck and permitted composite action between the concrete floor and steel framing members. The metal deck would act as reinforcing for the concrete slab and serve as a form during construction. Only minimal additional reinforcing would be required. The composite section, including the concrete slab on the metal deck and the steel framing members, was considerably stronger than the steel member alone. The use of composite action allowed the weight of steel to be reduced significantly, thus reducing cost.

The new main entrance for the Hynes Convention Center was located in the area of Commercial Block C north of the turnpike. This area, known as the Rotunda, consisted of two large vertical cylinders: an inner and outer drum. These architectural shapes and other design considerations made the Rotunda suited to the use of a cast-in-place concrete structural system. The cylinders were designed as concrete shear walls and were used for the lateral stability of this portion of the structure. The floor system was a two-way concrete flat slab. Since the Rotunda was not located over the rights-of-way and the foundation system consisted of new piles specifically designed for the new loads, the weight of the structural system and the capacity of the existing structural elements were not major concerns.

New Transfer System

Commercial Block C was to be constructed from the top of the existing mat foundation. The new construction was to be of structural steel except at the Rotunda. The new foundation system in this area consisted of drilled-in, end-bearing steel piles. The piles were installed in low headroom conditions using small sections of pile length connected with a threaded coupler. In the areas of the mechanical equipment room and the turnpike/railroad rights-of-way, there was insufficient space to maneuver the pile drilling rig. In these areas, piles that were required to support the new superstructure could only be installed from above. For this reason, the original plaza level framing was not demolished immediately, but was saved for use as a temporary drilling platform for pile installation. Piles were drilled through the mechanical room from the plaza level with only the protective shell around the pile posing any interference with operations in the room. Likewise, piles were installed from above in the turnpike's median and in between the turnpike and railroad.

Since the original Commercial Block C was designed on a 30-foot square bay, the new space was designed around the same grid system (see Figure 4). The original foundation under the turnpike and railroad area consisted of concrete piles with limited capacity and could not be reused. New piles could not be installed in this area to match the 30-foot grid since their installation would have damaged the existing concrete piles. Damaging these piles would have put the pile drilling rig at risk since it was supported on framing that was supported on the same concrete piles (see Figure 5). To avoid undermining the rig, it was necessary to offset the new pile groups from the main grid. Due to this offset, the main building columns on the old grid would not align with their foundations in either direction. A two-way system of transfer girders was designed at the plaza level to solve this problem.

The transfer system consisted of 27 welded plate girders approximately 6 feet deep. The heaviest of these girders weighed 20 tons and was 60 feet long. The size and weight of these members necessitated erection from the turnpike surface. This intense presence within the roadway was only possible during off-peak traffic hours. Once the transfer system was in place only minimal interference within the turnpike and railroad was required to complete the plaza level framing and the remainder of the structure above.

Reinforcing Existing Plate Girders

Within the footprint of the original building, the transfer girders over the turnpike/railroad rights-of-way experienced a modest increase in loads due to the addition of the third level. North of the original footprint, the existing girders supported Ring Road. The girders in this area were not designed to support columns. The addition of three levels of fram-

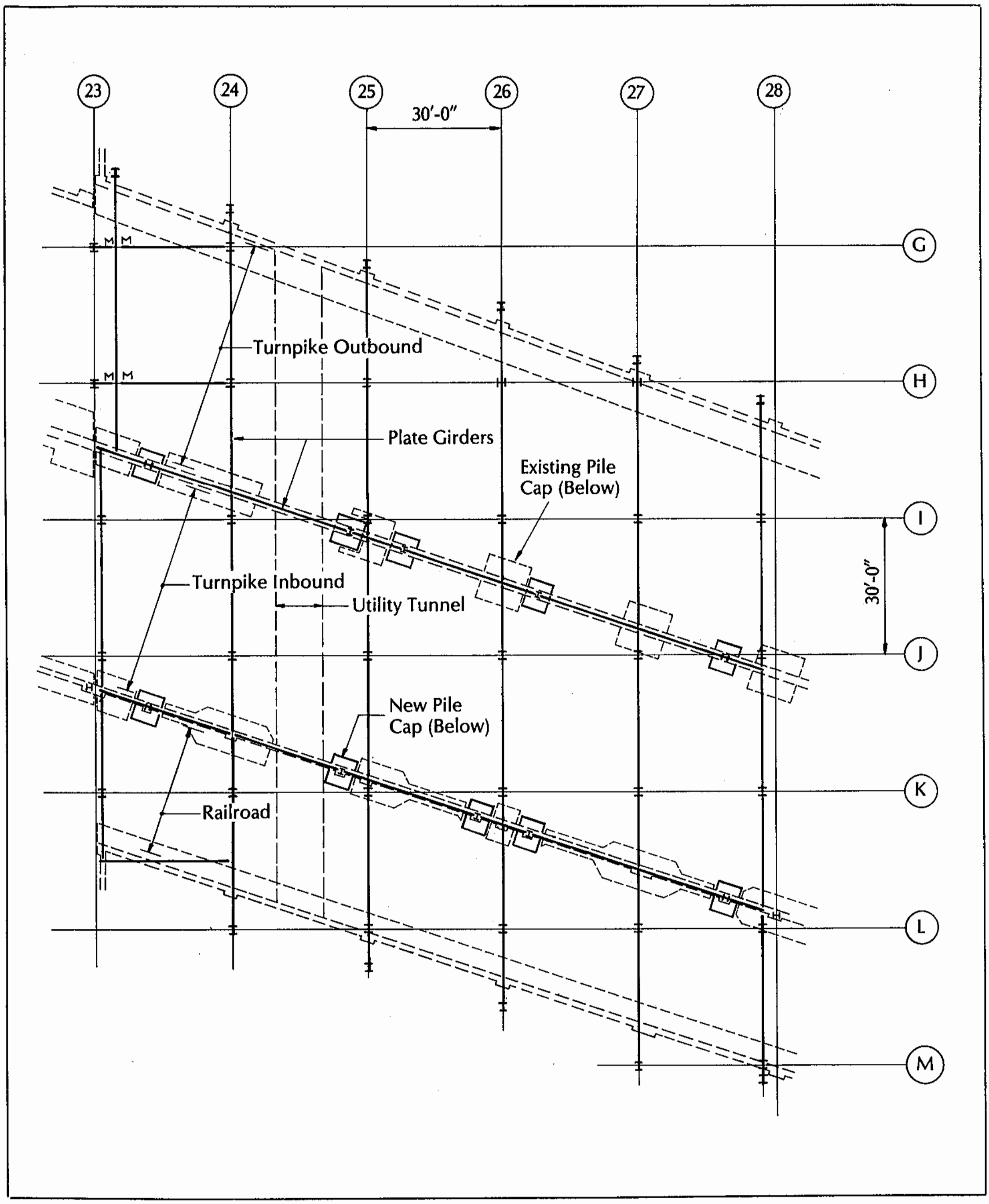

FIGURE 4. A plan of the new foundation and transfer systems within the Commercial Block C area over the turnpike/railroad rights-of-way.

ing above the plaza level subjected these girders to a significantly increased loading.

Several steps were taken to reduce the new loads and limit the impact of the new loading conditions on these girders. A new mechanical room mezzanine (a partial fourth level) was restricted to the area south of the turnpike and railroad. In order to more uniformly distribute the loads to all of the existing girders, the new spaces that were created had

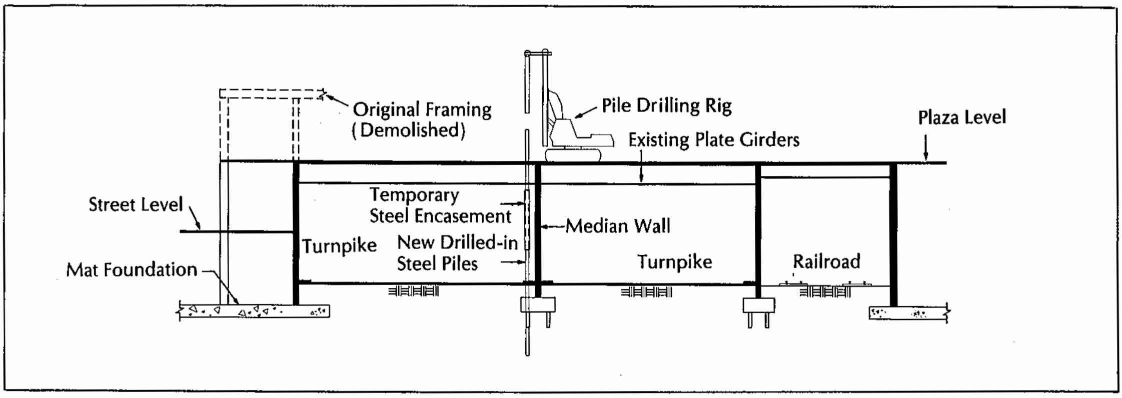

FIGURE 5. The installation of new piles within the Commercial Block C area over the turnpike.

to be restricted to uses that would accommodate the complex's 30-foot grid. This grid system was most easily accommodated for use as meeting rooms, providing the added benefit of assigning a 100 psf live load design requirement for the area, compared to the 250 psf live load required of the exhibition spaces. In addition, the structural steel system that was chosen for the project was based, in large part, on weight. The weight of all architectural partitions and finishes considered for the structure was a key factor in their selection.

Despite these efforts to reduce the new loads, an analysis of the girders for the new loading conditions revealed that all the girders within the Ring Road area would be overstressed. However, only a portion of the girders within the original footprint would be overstressed due to the new loads. In order to retain these girders for use in the renovation, the girders would need to be reinforced. The original auditorium was to be demolished to the second level. For the duration of the project, the minimum load on these girders would be the dead load of the second level slab and the plaza level or Ring Road area framing. Therefore, the system of reinforcing as well as the construction method needed to accommodate the girders under load, with existing columns and framing in place.

The section properties of the existing steel plate girders could be increased simply by adding plates to the existing flanges and web without changing the depth of the members. Since this method is most effective when the top and bottom flanges are reinforced equally, there must be access to both flanges. The girders were enveloped in a space approximately 7 feet high. This space was created by the concrete floor slab above the top flange and a hung concrete ceiling below the girder. An evaluation of the ceiling revealed that it was adequate to support minimal foot traffic at best. The concrete floor slab was a one-way flat slab that was supported on the floor beams transverse to the girders. Therefore, the top flange was accessible simply by removing the narrow strip of concrete above the flange. However, in order to access the bottom flange, large openings in the floor slab were required. It was also clear that working within the envelope would be restrictive and, therefore, time consuming and costly. For this reason, it was necessary to limit the reinforcing work to the top flange whenever possible. Unfortunately, for a given depth of girder, the addition of plates to only one flange has little effect on increasing the section modulus. In the case of the girders within the area of the original building that needed reinforcement, there was no choice but to work on both the top and bottom flanges.

Another option was available for reinforcing the girders in the Ring Road area. The elevation of the roadway was dropped with respect to the interior floor elevation, plus the Ring Road area sloped away from the original face of the auditorium. The new floor in the Ring Road area would have to be built up to match the existing floor elevation. The tops of the existing girders were from 1 to 2.5 feet below the new floor elevation, allowing the depth of the girders to be increased. This added girder depth required that work be performed only to the top flange of the girder and would result in significant increases in section properties. The added depth was accomplished via the use of "tee" sections. The "tee" section, in effect, extended the web of the existing girder and added another top flange.

The additional plates and "tee" sections were connected to the girders by welding. However, the quality of the welded connections was diminished when the connecting members were under stress. Unfortunately, the girders remained under load from at least the existing second and plaza level structures. The stress level induced by the minimum existing loads was high enough to cause concern. Furthermore, a differential in stress level between the base steel and the added steel limited the effective use of the added steel. Therefore, a construction method that relieved the stresses in the original member during the installation of the reinforcing plates and "tee" sections was required.

Investigations of the existing girders indicated that under minimum load a significant additional capacity was available. In order to relieve the load on one girder, it was possible to safely transfer the load to adjacent girders (see Figure 6). The contractor developed a system of movable temporary transfer girders for this purpose. The temporary transfer girders were located above the girder that was to be reinforced and were designed in such a way that they would span to the adjacent girders. High capacity tension rods connected the temporary girders above to the existing girder below. The tension rods were then jacked to a specified level, effectively unloading the girder. This system for the release of stresses was custom-tailored for each girder loading condition and stress level.

Seismic Design

Building codes and design standards in use at the time of the original Hynes Auditorium and the Prudential Center Complex did not require accommodation for seismic loads. The current building code in Massachusetts requires that all new structures be designed for seismic loads.[1] Existing structures are not required to be upgraded to the current standards. However, new additions to existing structures are required to be designed for seismic loads, but the existing structure itself is not generally required to be upgraded. The renovation of the auditorium included massive additions. Therefore, it was deemed necessary to upgrade the entire existing structure to current standards. North of the original auditorium and within the Commercial Block C area, the construction was all new and was designed for seismic loads. A system of new and existing expansion joints was designed to separate the completed building into five independent structures, two of which constituted the original auditorium.

The basement level of the auditorium was restricted to the area south of the railroad right-of-way. The basement walls were constructed of concrete and were investigated for use in the design of the lateral load resisting system. These walls extended from the foundation to the plaza level. From the plaza level to the second level there were no existing structural elements available that could be used to resist seismic loads in compliance with current standards. Therefore, a new system of lateral load resisting elements was required from the plaza to second levels. The new steel structure above the second level was designed for seismic loads. An analysis of the basement walls and lateral capacity of the existing piles indicated that the existing structure below the plaza level was more than capable of resisting the anticipated seismic loads.

A lateral load resisting system consisting of bracing or shear walls was considered since the existing structure was constructed of cast-in-place waffle slabs and columns on a 30-foot square grid. A steel bracing system offered such advantages as speed of erection and lightweight construction. However, because of the magnitude of the forces, no feasible means of connecting the steel bracing and the concrete could be developed.

A system of concrete shear walls was then considered. The new walls could be in-

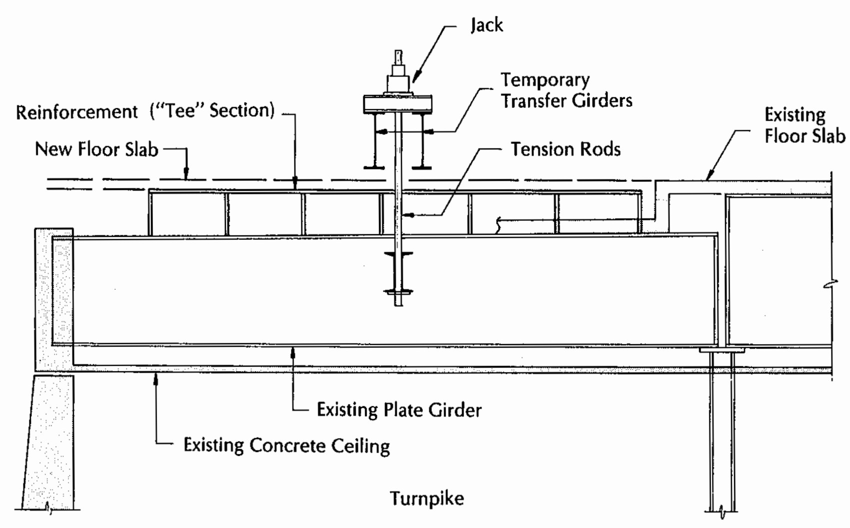

FIGURE 6. Section for reinforcing existing plate girders over the turnpike/railroad area showing the use of temporary transfer girders and jack.

filled between the existing columns on the 30-foot grid and between the plaza and second levels (see Figure 7). The infill wall system had to be capable of resisting the building shear forces and moments created by the lateral loads. The existing columns and slabs would act as the boundary elements to the wall panel. To allow the wall system to act as a unit, the existing concrete elements and the new wall panels were interconnected so that vertical and horizontal shear forces could be transferred. The shear forces could be resisted by concrete-to-concrete bearing by the use of shear keys or through a reinforced connection by the use of shear friction.

The concrete was placed from above the second level through new access holes. The wall filled the existing waffle slab on the underside of the second level, creating a natural shear key connection. The other edges of the panel were cast against the smooth surfaces of the columns and the floor slab. Since it was felt that the labor required to create shear keys in the columns and slab would be prohibitive, the use of shear friction was considered. Shear friction depends on reinforcing steel transverse to the joint. Development of the required reinforcing steel was effected by drilling and grouting with a high-strength, non-shrink grout.

The ability to develop the shear forces for the boundary conditions permitted the existing structure to be fully upgraded to current seismic standards. As an added benefit, the capacity of the system to resist seismic forces greatly exceeded requirements for resisting wind forces.

Conclusions

The success of any renovation effort starts with an appreciation of the original structure. Recognition of the strengths and limitations of the original structure must guide the entire design process. The original Hynes Auditorium was well designed and solidly constructed. A critical factor in its renovation was the capacity of its pile foundations. Reuse of the original foundations would not have been possible without a beneficial change in the state building code that permitted the inspection and testing of the piles and then permitted their use at a rated capacity 50 percent

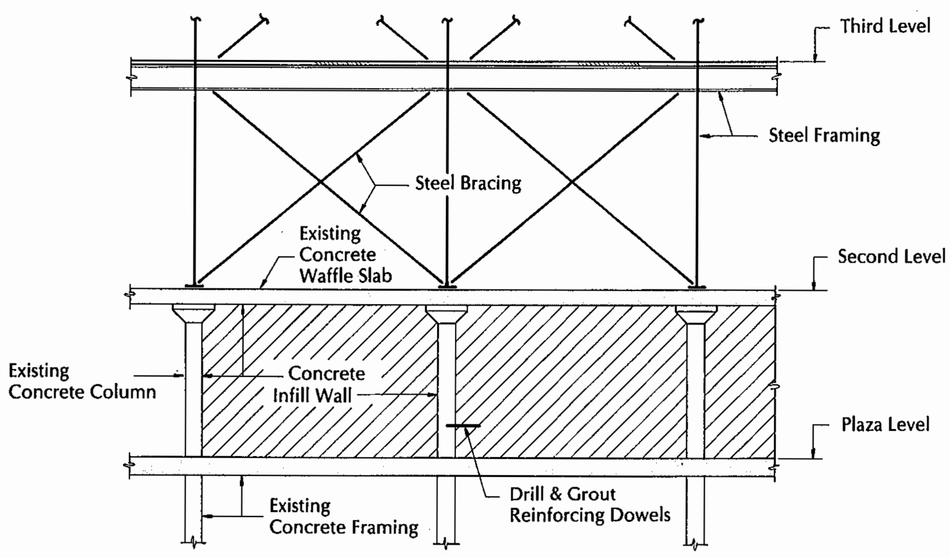

FIGURE 7. The lateral load resisting system used to upgrade the existing concrete frame to current seismic standards.

greater than the original capacity.[1]

The increase in the rated capacity of the existing foundation system and the given capacity of the other structural elements formed the boundaries for the new design. The building's owner and the project's architect were determined to live within these boundaries whenever possible. The limitations affected aspects of architectural design, from the layout of meeting rooms and exhibition space based on live load considerations and column spacing, to the selection of materials based on weight.

A design that recognizes the limitations of existing conditions must also be constructable at a reasonable cost. The work over and within the turnpike/railroad rights-of-way was recognized as a sensitive area because of limited access into this area. The intensity of work required to reinforce the existing plate girders over the turnpike was of special concern. In order to limit the work required, the use and construction of the spaces above the turnpike were affected. Even within the Commercial Block C area, the original structure affected the final design despite the fact that the structure in this area was new from the foundation and up. In order to construct new foundations within the turnpike/railroad rights-of-way, the original structure was maintained as a drilling platform for the installation of the new piles, requiring the development of a two-way transfer system.

The design process of a completely new building generally starts with posing the question, "Given the program requirements, what does the building want to be?" The process ends with the question, "How will the building be constructed?" For a renovation, the design process must start with posing two questions: "What is the building's existing condition?" and "What is constructable?" If the program and the design requirements can be accomplished within the existing constraints, the renovation will be a success.

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