Design of the High Street Ramp, Boston

The challenges of a confined site for a temporary highway exit ramp were met by supporting several of its piers on the substructure of a nearby office tower.

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The construction of one of the largest office complexes in downtown Boston, International Place, necessitated replacing the existing High Street ramp on the Central Artery. The main components of the complex are two cylindrical towers that were constructed at different times. The first tower, One International Place, was completed in 1988 and is 46 stories high. The second, recently completed tower, Two International Place, is 35 stories high. The location of the second tower required the removal of an existing southbound off-ramp from the elevated Central Artery, and thus the construction of a temporary new ramp to serve this portion of the Artery until the new depressed Central Artery is constructed underground.

In addition to carrying a heavy urban traffic flow, this temporary ramp had to be designed in order to accommodate the future construction of the depressed Central Artery. The design for this ramp was based on a sequence of construction that allowed the uninterrupted operation of the elevated Central Artery and the continuous use of the existing ramp until traffic could be redirected to the new ramp (see Figure 1).

Given the site constraints, five of the eight new ramp piers had to be supported on the substructure of the first tower of International Place. This type of support, and the resulting techniques used during construction, created some unusual challenges for both the designer and contractor.

Highway Design Considerations

The main challenge of this project was to position the new temporary ramp so that it would have minimal impact on the One International Place building and the future depressed Central Artery. In addition, the new ramp had to be designed with a profile and plan layout that would:

- Maintain a minimum pavement width of 22 feet;
- Maintain automobile and truck access to One International Place (see Figure 2);
- Maintain adequate roadway clearances over the city streets below;
- Provide acceptable gradient and stopping sight distance; and,
- Achieve acceptable depth to span ratios

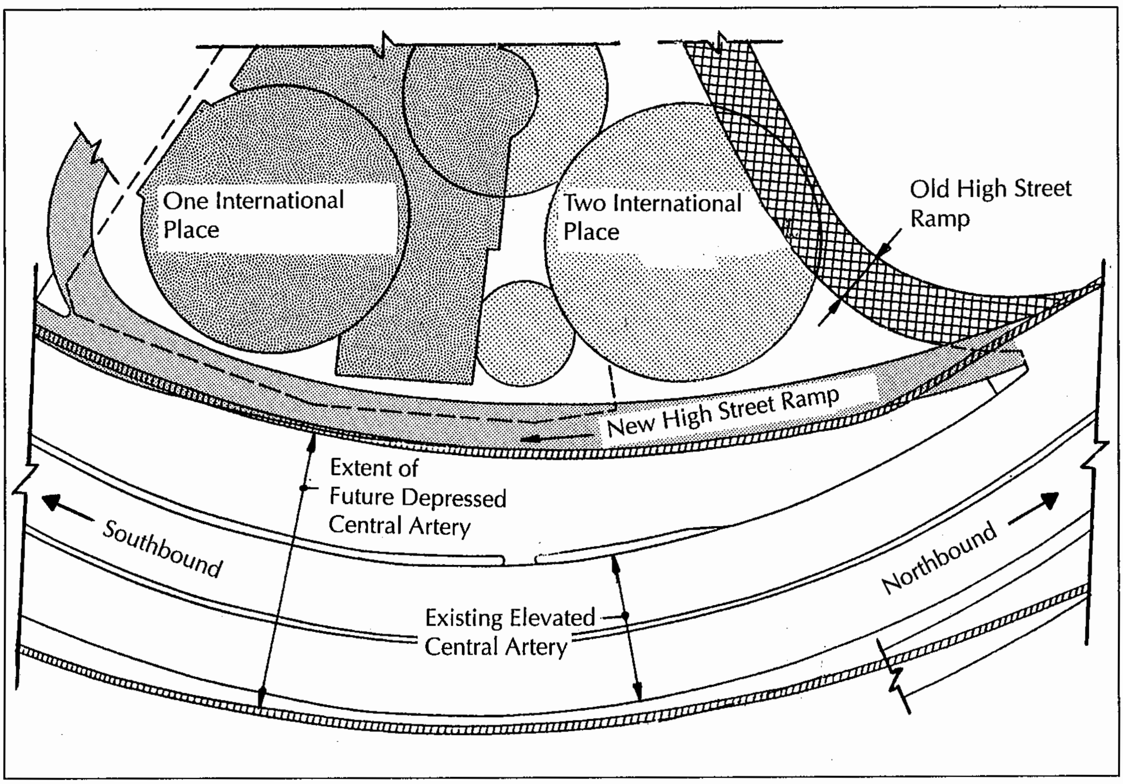

FIGURE 1. Site plan of International Place.

for the ramp girders while meeting all of the other demands.

Once these concerns were addressed and the ramp piers were located, a support scheme had to be developed for each pier that would minimize undesirable vibration and settlement effects on the One International Place building and that would accommodate the construction of the depressed Central Artery. The depressed highway will pass within five to 15 feet of the One International Place building's foundation wall.

After reviewing several different support schemes, it became evident that due to the lack of sufficient space for the new pier foundations, five of the eight ramp piers would have to be located within the basement of the One International Place building. The three remaining piers were supported outside of the building.

Structural Design Considerations

The three ramp piers outside the International Place building are supported on deep foundations. Reinforced concrete appeared to be the most appropriate choice of material for the construction of these outside piers since it is the alternative that requires minimum maintenance during the life of the piers. Each of the three concrete hammerhead piers is supported on six 42-inch diameter caissons that extend not less than 15 feet below the limits of excavation for the depressed Central Artery. These 90-foot long, heavily reinforced caissons were installed using the slurry caisson method. Each concrete pier was designed for the appropriate AASHTO loading requirements under two separate sets of conditions:

- The first was the *current condition* with soil present around the pile cap and the caissons (see Figure 3).
- The second was the *future condition,* when the excavation for the depressed Central Artery will have eliminated the soil that is the only means of lateral support around the caisson cap and caissons (see Figure 4).

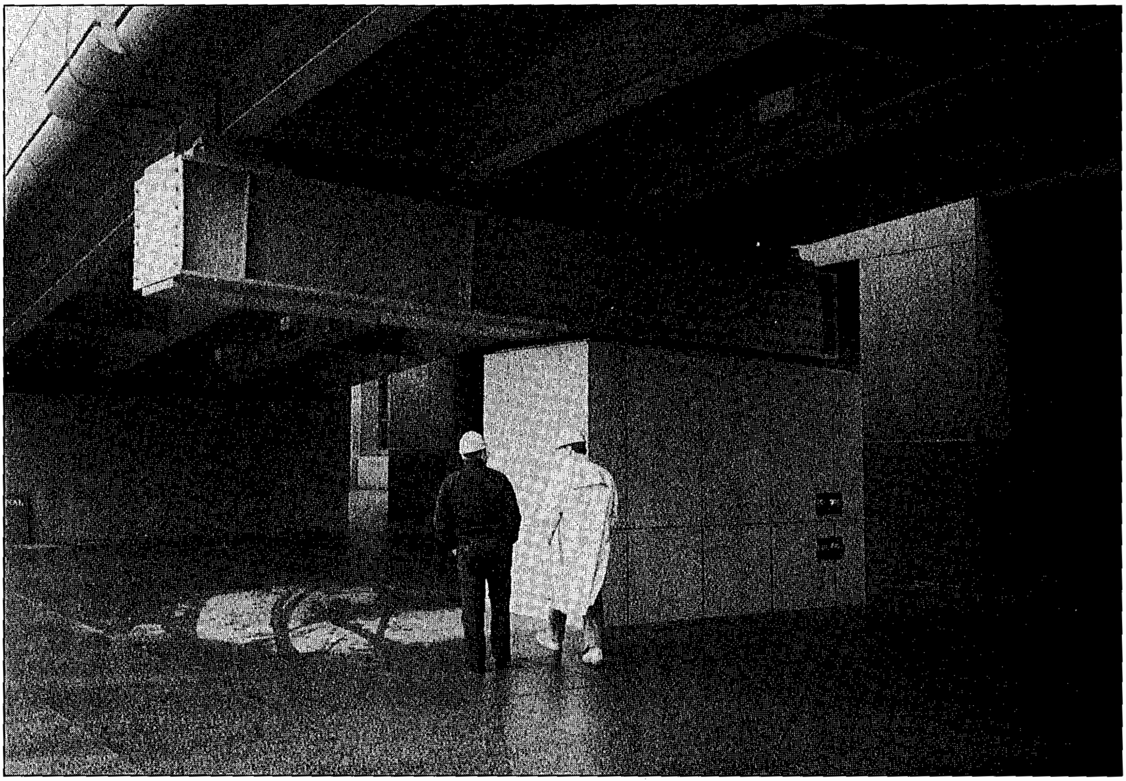

FIGURE 2. View of the ramp at the entrance to the garage at the One International Place building.

Based on the those criteria, each caisson was designed to withstand an axial compressive force of 400 kips, and a bending moment of 800 kip-feet.

For the first condition, a computer model was developed in order to simulate the lateral earth support. This computer model made use of spring supports around the caissons and the pile cap.

For the second condition, a bracing system was schematically designed in order to brace the caissons and the caisson cap. The bracing system will be installed in the future in a step-by-step sequence during the excavation of the depressed Central Artery (see Figure 4).

The remaining five piers were supported inside the One International Place building. In evaluating the possible use of reinforced concrete versus structural steel for these five piers, the following issues were considered:

- Construction schedule and cost;
- Minimum loss of space and disruption within the One International Place building;
- The ability to properly isolate ramp vibrations from the building; and,
- The least impact on the One International Place building during the future demolition of this ramp.

Based on the those considerations, a structural steel system was clearly advantageous. Four of the five steel piers consisted of a single box column supporting a cantilevered box girder (see Figure 5). The fifth pier required two columns. Each of the box columns is supported on a new spread footing bearing on a glacial till subgrade below the lowest level of the existing building. The new spread footings are of a type similar to those used for the existing One International Place building but were designed to function independently from the existing building foundations.

The design forces on the ramp created bending moments in the piers' cantilevered girder

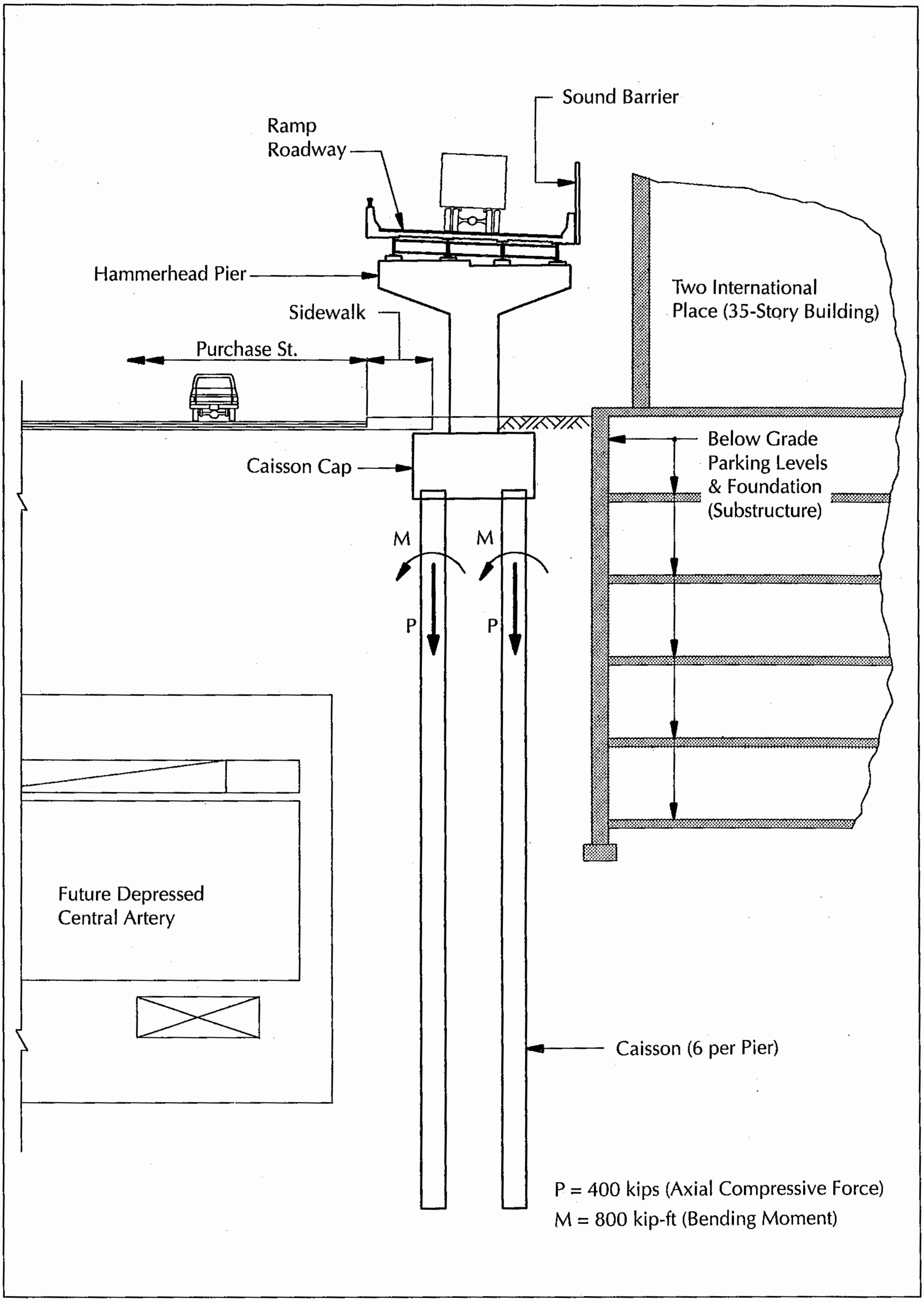

FIGURE 3. Typical cross section of the reinforced concrete pier.

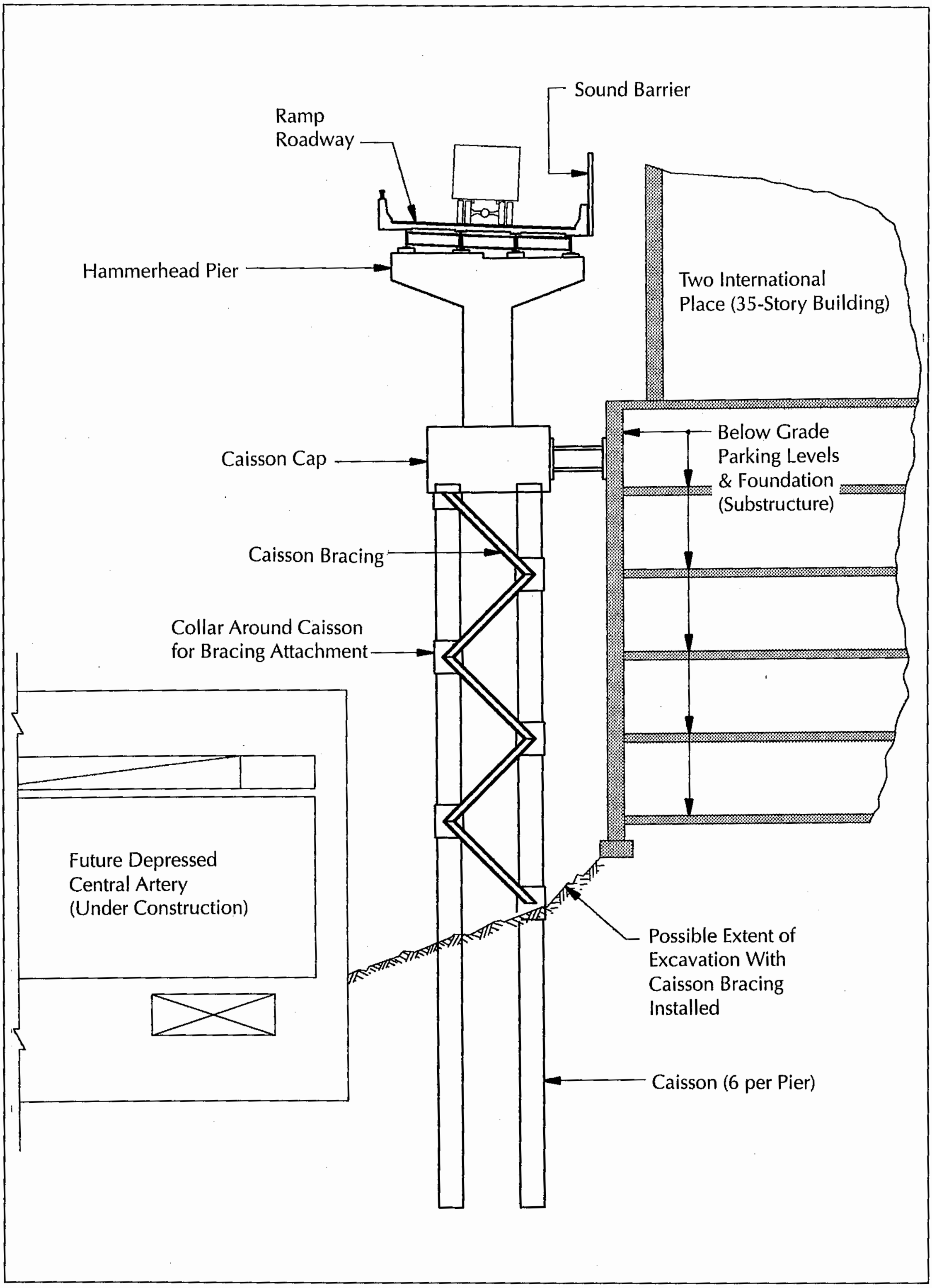

FIGURE 4. Cross section of the reinforced concrete pier during the construction of depressed Central Artery.

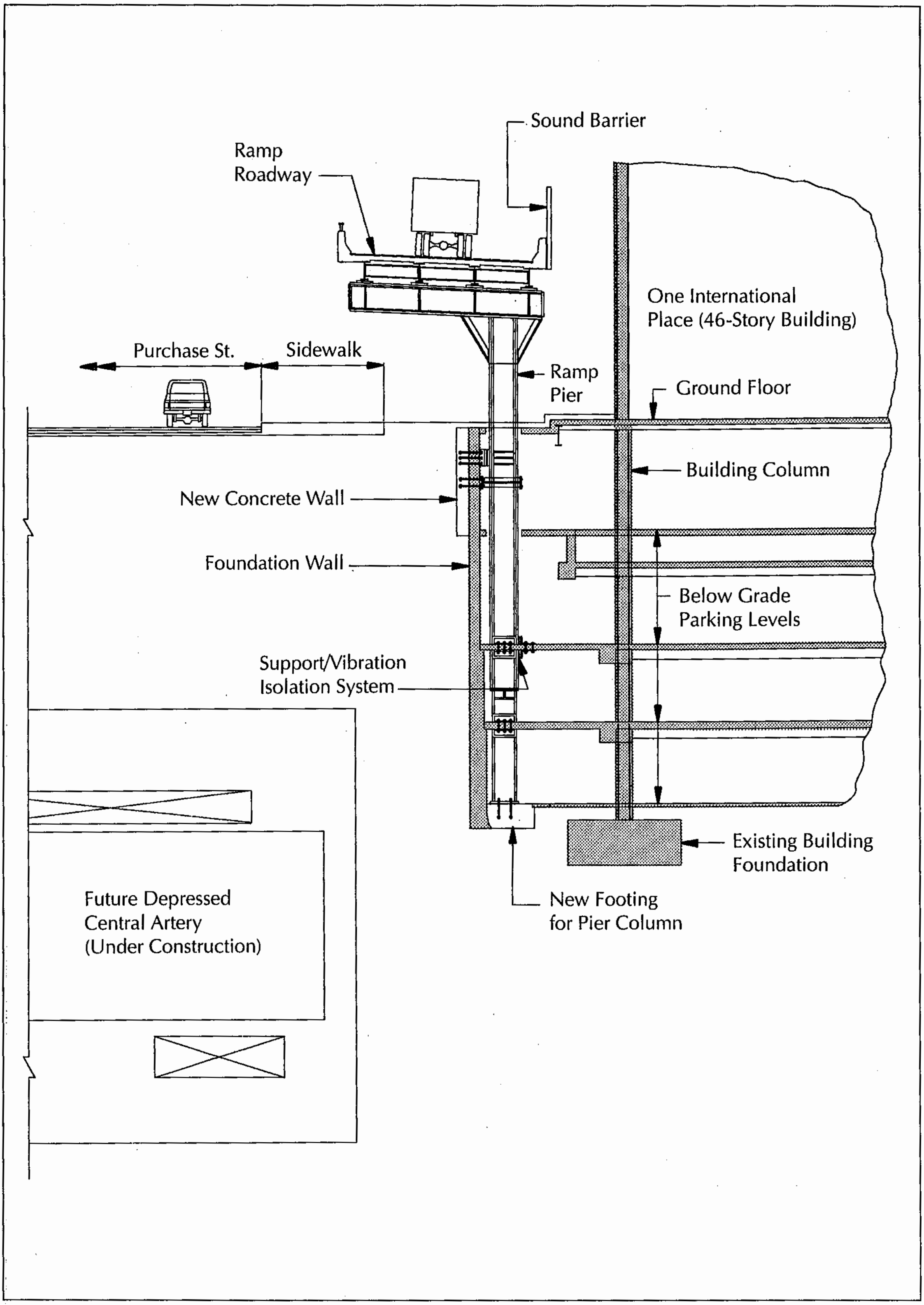

FIGURE 5. Typical cross section of the structural steel pier.

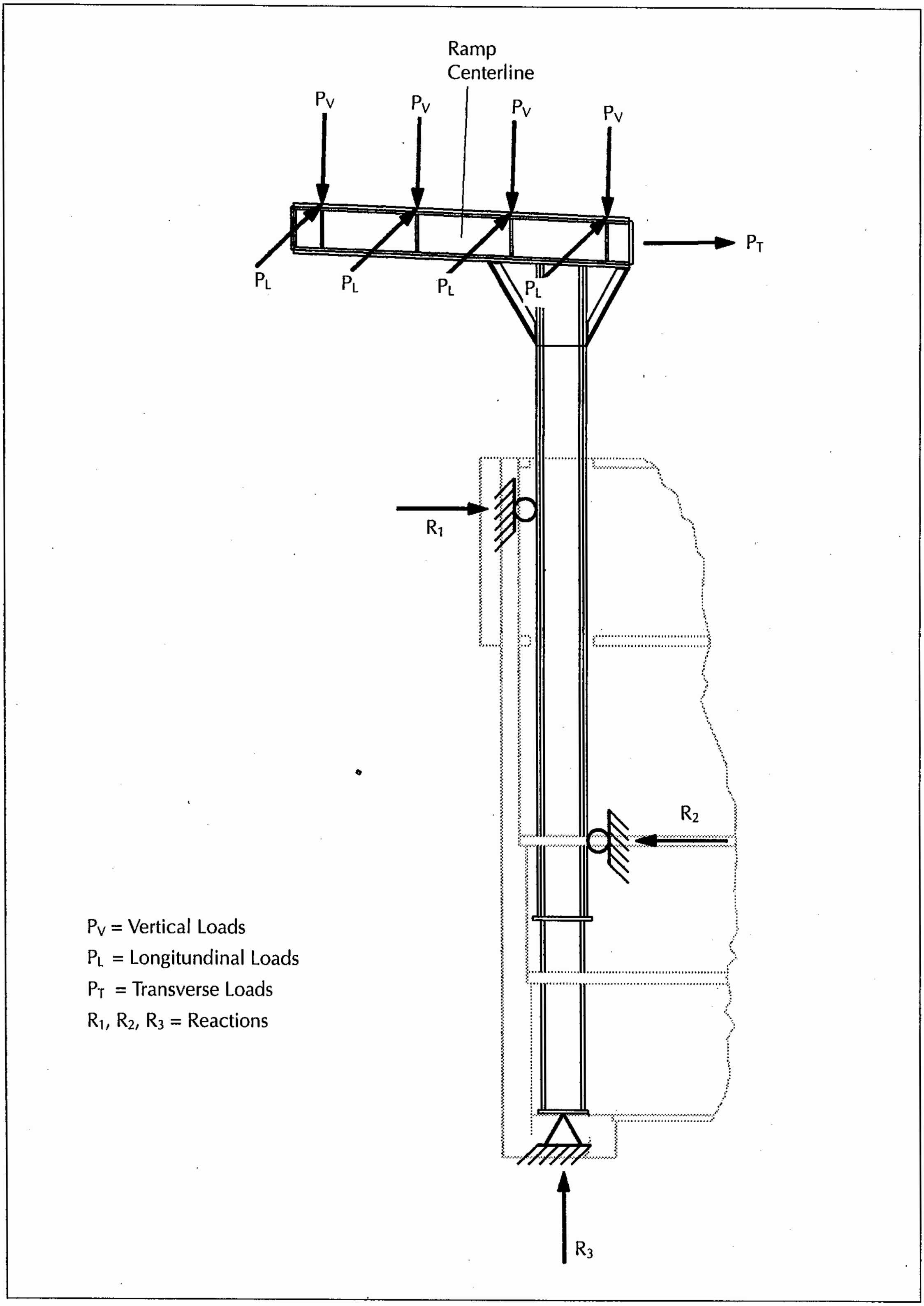

FIGURE 6. Model of the support system for the single column steel piers.

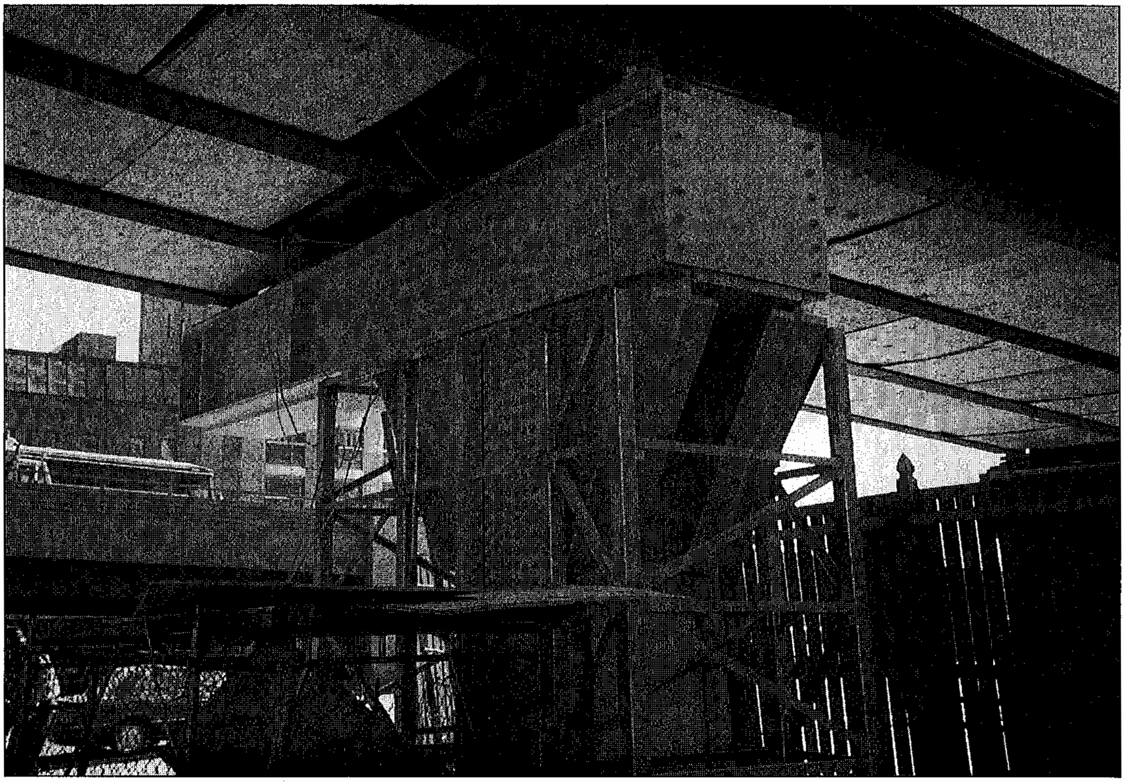

FIGURE 7. A view of a steel pier during construction.

and supporting columns. The moments in the columns were resisted by the garage floors and the foundation wall of the One International Place building acting as a couple (see Figure 6). The design loads creating these bending moments consisted of:

- Vertical loads — dead, live, and impact
- Longitudinal loads — live, seismic, wind
- Transverse loads — centrifugal, seismic, wind

The vertical loads and bending moments on the box column were resisted by the reactions — R_1, R_2 and R_3 — shown in Figure 6. The existing building's foundation wall was reinforced in order to develop reaction R_1, while the reaction R_2 was resisted by the existing garage slabs.

Of particular interest was the transmission of out-of-plane torsional forces from the box column to the garage structure. For these torsional forces, a special collar was designed that connects to the foundation wall and restrains the torsional forces of the box column.

All cantilevered box girders and box columns consisted of two W36 beams with 2.5-inch thick top and bottom cover plates. Many internal stiffeners were used in the box girders in order to increase the rigidity of the section against torsional warping. No field welding was permitted by the Massachusetts Highway Department (MHD) Standard Specifications since fracture-critical steel was used for all five of the steel piers. All field connections were therefore bolted connections that had been preassembled in the shop in order to ensure the proper fitting of all elements in the field (see Figure 7).

The Vibration Isolation System

The most important aspect of connecting the ramp structure to the building structure, however, was the design of the vibration isolation system. During the initial phases of this project, it became apparent that the ramp traffic creates an impact load on the piers that may be transmitted to the office tower through the building substructure. This transfer was completely un-

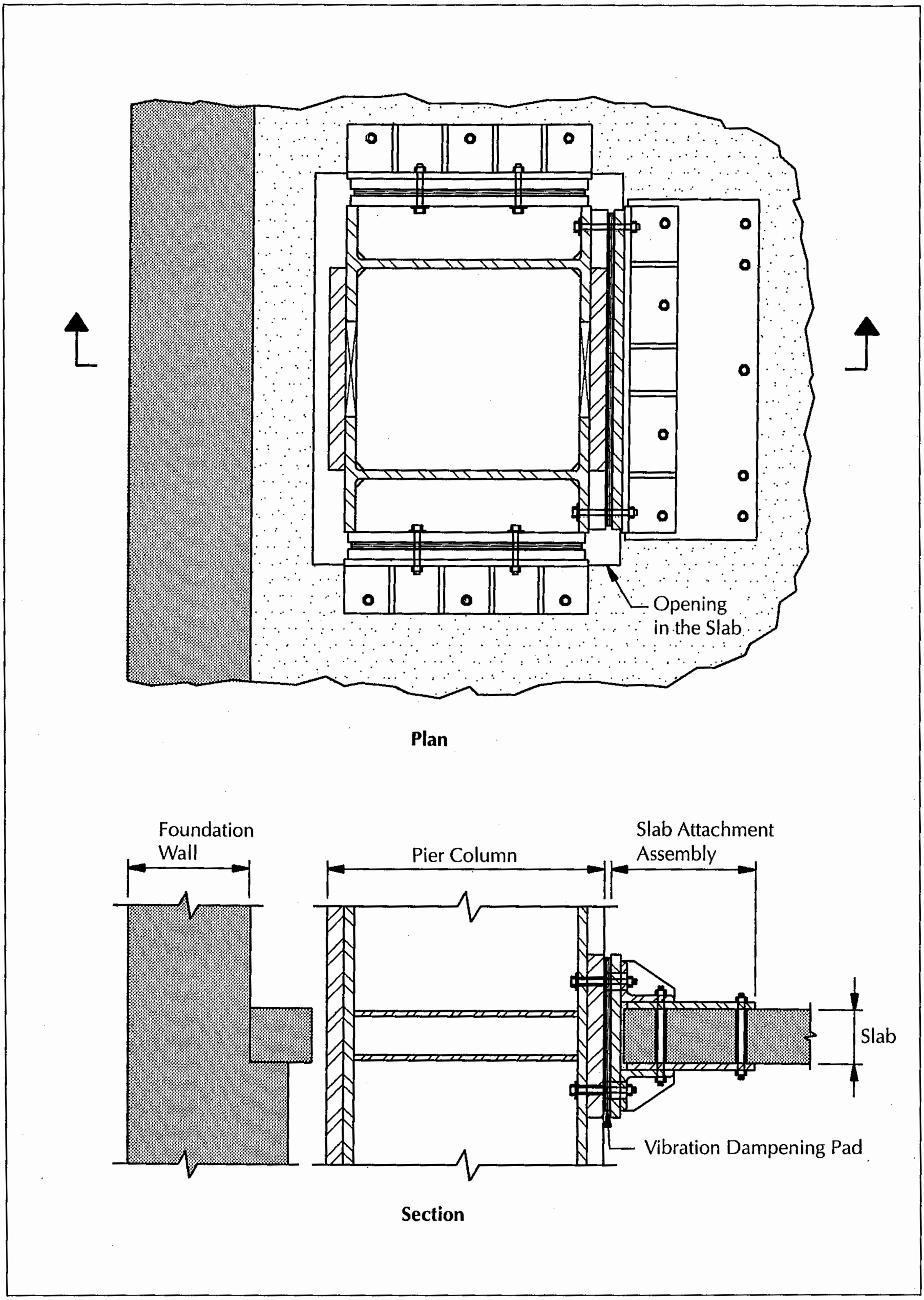

FIGURE 8. Typical steel pier lower support system against the parking level slab.

acceptable. The conventional design approach and common practice called for the separation of the ramp piers from the building structure, but the magnitude of the design loads and the physical restrictions inside the One International Place garage demanded that the ramp be supported laterally by the building.

A dynamic analysis of the ramp structure combined with the existing building was also impractical due to the complex geometry involved and the resulting highly complex computer model that would have been required. The dynamic analysis was therefore focused on the pier structure with rigid supports provided by the building. Different mode shapes and the natural frequency of this simpler model were determined in order to select the appropriate vibration system at the location of the piers' supports. The results of the analysis showed that the low frequency vibrations from the second mode shape was the most likely to excite the existing building structure. Using this information, a vibration dampening system was designed with vibration dampening pads (see Figure 8).

Shock and vibration absorbing bearing pads, washers and sleeves were used in addition to bearing pads in order to completely isolate the pier elements from the garage structure. Even though the design of the vibration isolation system was the result of intense effort, its actual behavior in the field could not be fully predicted by the theoretical models. It was only after the opening of the ramp that the full dampening effects of the isolation system became clear, and since its opening in April of 1990 there has been no report of ramp traffic-induced vibration in the One International Place garage or office building.

Construction Considerations

The last ramp pier inside the garage structure required two supporting columns rather than one — as had been the case for the other piers. The necessity for two columns in this pier was the result of a very long cantilevered box girder (see Figure 9). The dead load of the ramp structure created compressive forces in both box columns, but the live loads on the ramp created a net tension force in the rear box column. The design criteria set by the MHD did not permit the use of tension piles for the dead load of the ramp structure. Only live load tension forces were allowed to be carried by the tension piles. Therefore, in order to avoid the transmission of dead load forces into the tension piles, the following construction sequence was recommended to the contractor:

1. Install the tension piles and anchor into the bedrock.
2. Install the combined concrete footing for both pier columns.
3. Install the forward pier column and tighten all anchor bolt nuts.
4. Install the rear pier column but leave the anchor bolt nuts one inch above the top of the base plate to allow for vertical movement of the column.
5. Complete the construction of the ramp structure at street level.
6. After all dead loads are in place, hand tighten and secure the rear pier column's anchor bolt nuts, and grout under the base plate.

Summary & Conclusion

In summary, the relocation of the High Street ramp is notable for the following reasons:

- It is the first transportation project in the Commonwealth of Massachusetts to make use of drilled caissons and tension piles as a means of foundation support.
- The project's unique vibration isolation system prevented the transmission of vibrations from the ramp structure to the One International Place office building and garage.
- All ramp piers were located and designed so that the ramp could remain operational during the future excavation of the Depressed Central Artery.

It is likely that some of the solutions to the problems encountered during the design of this ramp are relevant to other temporary ramps that are currently under design as part of the depressed Central Artery project.

ACKNOWLEDGMENTS — *The authors wish to thank the following, without whom this project*

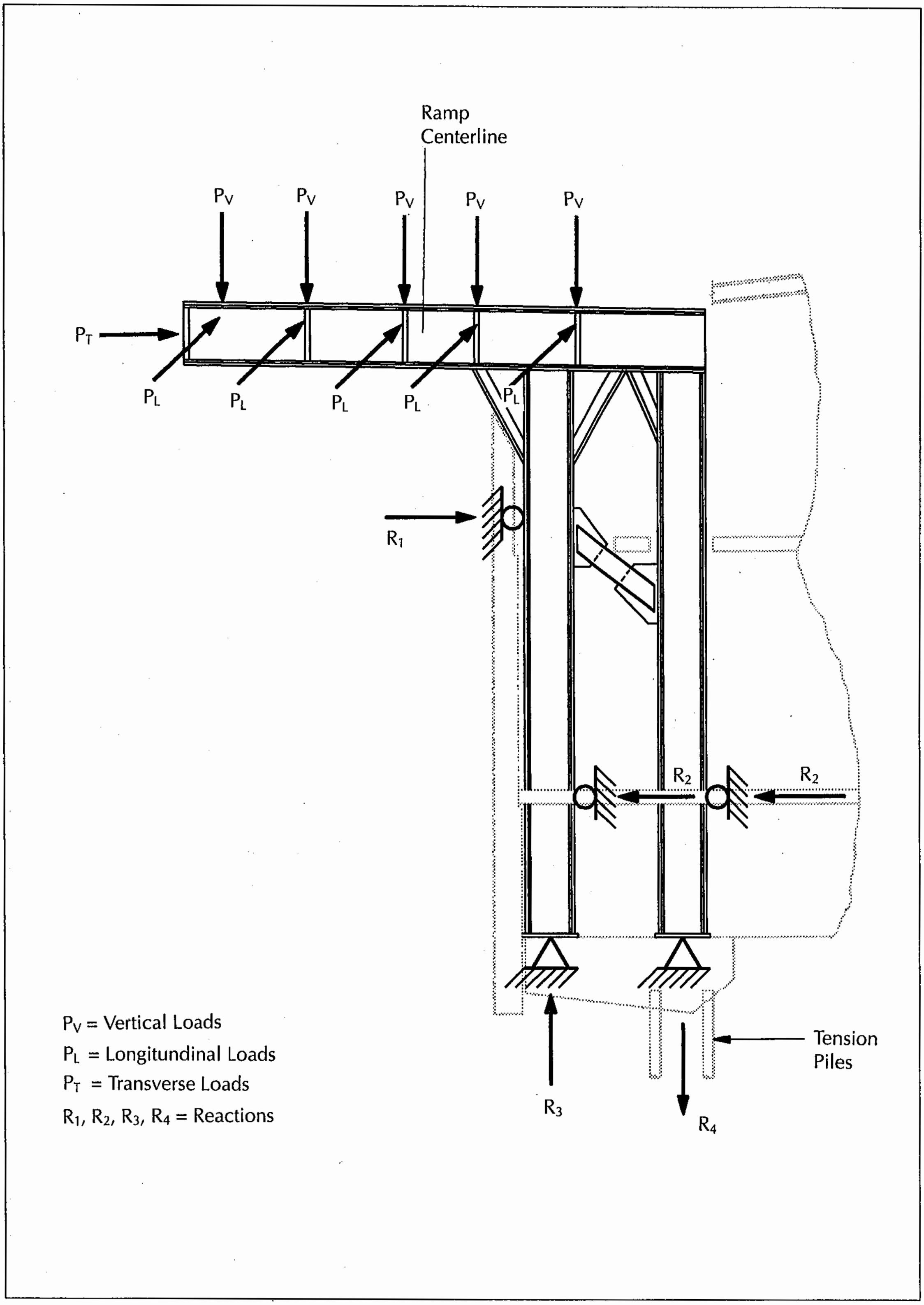

FIGURE 9. Model of the support for the double column steel piers.

would never have been brought to fruition: The Chiofaro Company — Developer of International Place; Massachusetts Highway Department — Owner; Vanasse Hangen Brustlin, Inc. — Civil Engineer; John Burgee Architects — Architect; Haley & Aldrich, Inc. — Geotechnical Engineer; Daniel O'Connell's Sons, Inc. — Contractor; Fabreeka Products Co. — Bearing Pad Manufacturer; and Bechtel/Parsons Brinckerhoff Joint Venture — Reviewers of the ramp design.

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