

Caissons supporting a new tower on an old site had to divert its loads away from an active subway tunnel.

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# CAISSONS SKIRT A TUNNEL

**I**n Jersey City, things are on the rise again, this time with New Jersey's tallest building reviving its old transportation hub, where trains and buses still meet the PATH Tubes that carry commuters under the Hudson River daily to and from Manhattan.

Exchange Place Center is a 490 ft, 30 story office building that shares some features with its neighbors across the water, the World Trade towers: Both projects incorporate a PATH station and both were beset with foundation design problems caused by the presence of the PATH Tubes themselves. They also share superb views of the Statue of Liberty.

The Exchange Place foundation is above the tunnels of the PATH Tubes, and only limited loads from the building were allowed to be transmitted to the walls and roof of the tunnels. This required that the foundation loads be transmitted to the bedrock via drilled-in caissons installed adjacent to the tunnels.

The location of these caissons,

however, did not coincide with the location of the building columns, so concrete girders had to be cast in place to transfer the loads. Spanning up to 86½ ft, these girders are as deep as 15 ft.

The foundation engineers also had to contend with other artifacts below the surface of the site, which had once been occupied by a Pennsylvania Railroad terminal. Grades had been as much as 16 ft above the present grades, and footings and pilings of previous structures were encountered during geotechnical investigation for the project and during construction.

The subsurface consists of up to 27 ft of fill containing varying amounts of sand, silt, gravel and rubble. Under the fill is about 10 ft of soft river organic silt. Rock, typically at 32 ft beneath the surface, belongs to the Manhattan Formation, identified as micaceous schist and slightly weathered near the surface. In order to avoid penetrating the tunnel structures, the driller had to keep the hole plumb to within 1% of the boring depths, which varied from 60 to 120 ft.

All the rock cores were characterized by axial plane mineral fol-

iation ranging from about 10° to 45°, dipping to the north-northeast. The foliation is expressed by a preferred orientation of the mica flakes parallel to the axis of principal stress.

Rock cores tested for strength failed prematurely along the foliation. The average unconfined compression strength was 2,030 psi with a standard deviation of 766 psi. The average secant modulus at 50% ultimate load was  $457 \times 10^3$  psi with a standard deviation of  $249 \times 10^3$  psi. The average tangent modulus at 50% ultimate load was  $897 \times 10^3$  psi with a standard deviation of  $557 \times 10^3$  psi. Point load tests were conducted on seven cores yielding an average value of 91 psi.

Two foundation schemes were considered for supporting the structure: a mat foundation on rock and a deep foundation. The concerns for safety of the PATH tunnels, coupled with a cost analysis, indicated that a socketed caisson scheme was more feasible. The various underground structures limited the choices for constructing the deep foundations, and this led to an irregular caisson layout.

The caissons were designed to limit the stresses on the tunnel to the stress level that the underground structures had been subjected to in the past. However, this allowed new stresses as large as 1,600 psf to be imposed on the tunnel.

The stress transmission was controlled by (1) placing the bearing socket at predetermined levels so that the group effect of stresses from the caissons on the tunnels is acceptable; and (2) placing a corrugated shell as a bond breaker above the socket to avoid load transfer to the rock above its top.

The rock socket carries the load by both side resistance and end bearing. The proportion of the load transferred to the base depends on the length and diameter of the socket and the stiffness of the socket concrete compared to the stiffness of the surrounding rock. The ultimate bond resistance depends on tensile strength of the rock and, for this particular site, the orientation of the foliation.

A shear resistance of 700 psi along the foliations was estimated from the failure load of the laboratory-tested core and the failure plane observed in the laboratory. A design bond value of 145 psi was selected to maintain an adequate safety factor against excessive shear stress along the foliation and rock failure in tension. The socketed caisson loads varied between 3,230 kips and 8,863 kips, requiring socket lengths to vary from 13 to 38½ ft.

#### CONSTRUCTION PROCEDURES

Some of the 53 caissons, which are 44 in. dia., are within 4 ft of the tunnel walls. The deepest caisson is set 113 ft below the ground surface. Excavation for the girders and caissons intercepted the groundwater at the site. The contractor installed sheeting to control the groundwater flow.

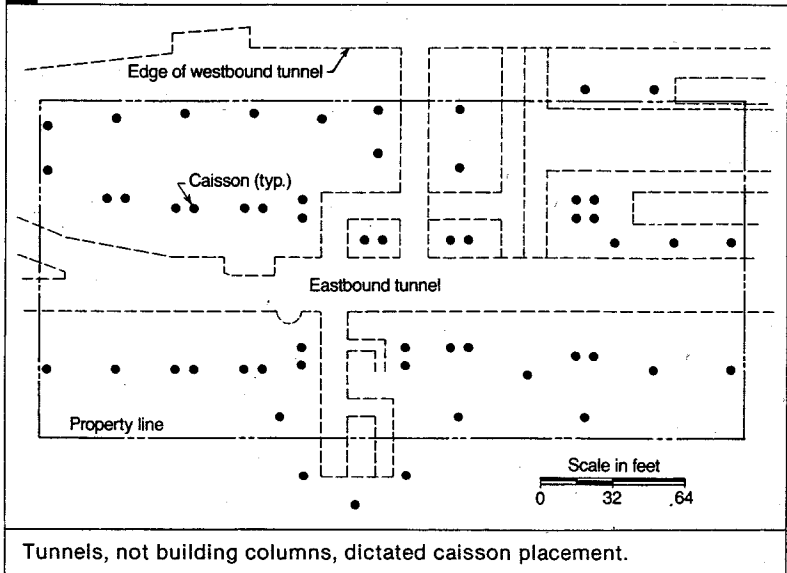
The installation procedure began with excavation by a large backhoe for a portion of the overburden consisting of timbers, old brick foundations and miscellaneous fill. A 5 ft dia. auger was used to drill to a depth of 15–20 ft. A 48 in. dia. steel caisson shell was then lowered into the hole.

The top of the casing was attached with a kelly bar, and the casing was drilled in to the top of



Exchange Place office tower rises over existing subway.

FIGURE 1.  
CAISSON PLACEMENT



rock. A soil auger was then lowered in the casing to remove the cuttings. A second auger having a toothed rock bit was lowered to drill the top few ft of weathered or soft rock. Finally, the caisson shell was drilled again and seated firmly in the rock.

After the caisson shell was well seated in bedrock, a large rock drill with rotary bits was lowered through it. The drill bit worked by compressed air and made a 44 in. dia. shaft. Water hosed into the hole kept the bits cool and formed a slurry of the rock cuttings, which was sucked into the top compartment of the rock drill for discharge outside.

After completion of rock drilling to the design depth, the final cleaning of the rock socket and the bottom was done by hand. A caisson crew, lowered down the hole in a bucket, removed all loose rock cuttings and water.

A plumb bob lowered from the top measured the final eccentricity of the caisson. The eccentricity of the center and plumbness at both the top and bottom of the caisson were recorded. Then a geotechnical engineer was lowered in a steel inspection cage to measure all seams and rock discontinuities. He also noted presence of gouge materials in seams and probed the base of the socket for seams and rock discontinuities, checked the level of rock surface at the base and hard-

ness of the rock at the socket, and searched for water seepage.

A 14-gage galvanized steel shell was installed inside the caisson to break the bond between concrete and rock socket above the designated pressure line. This was to eliminate stress on the path tunnel. Wood blocking and oakum was used between the shells and casing to serve as spacers.

A total of 522 tons of core steel were used in the caissons, installed after the socket was cleaned once again. Caisson cores are W14x109 to W14x730 (plus cover plates) ASTM A572 grade 50 steel. The largest core pieces, 730 lb/ft and 98 ft long, were brought to the site as full length single pieces.

After the steel was placed, 6,000 psi concrete with a 7 in. slump was poured through a 12 in. dia. tremie pipe. This was withdrawn after placing each 10 ft of concrete and the top one-third of the caisson was thoroughly vibrated. The caisson construction required 1,650 cu yd of concrete.

Twelve major foundation girders, each 10 ft by 13 ft 6 in., were poured to span the tunnels and transfer the building load from the columns to the caissons which skirted the tunnels. The maximum girder span between caissons was 86 ft 6 in. The individual girders required between 610 and 1,120 cu yd of concrete, and the total was 9,300 cu yd of concrete and 1,200

tons of rebar.

Since completion of the foundation system in May 1987, the Port Authority undertook to excavate a new escalator beneath the building (CE Jan. 1988) to serve the expanded and renovated PATH station. The escalator tunnel was excavated under controlled blasting, even though the wall of the tunnel is as close as 7 ft to one of the heavily loaded caissons.

Rock deformations were monitored by vertical, horizontal and inclined extensometers as the tunnel was advanced. There were no apparent adverse effects on the caissons as indicated by the small rock deformations.

The owners and developers of the Exchange Place Center, known as the Exchange Place Urban Renewal Associates (EPURA), have a long term lease on the land. The Port Authority, however, retains an underground easement. The Grad Partnership, Newark, are architects for Exchange Place, which will be completed in 1990 by general contractors Torcon Inc. Kaiser Engineers, Inc., New York City, are construction managers for the escalator tunnel.

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**After foundations were in, construction went up with building and down with access to subway station.**

