# COLUMN BACKFILL BEHAVIOR DURING TOP-DOWN CONSTRUCTION

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## ABSTRACT

This paper presents a case history of column backfill behavior during top-down construction. The steel columns were installed in slurry-excavated trenches called load bearing elements (LBE's) prior to general excavation. The columns were embedded into tremie-placed concrete foundations below the lowest floor level. The column backfill above the foundation was bentonite slurry mixed with Portland cement. The partially embedded columns were laterally supported by the backfill. The stability analysis of the columns was based on extensive field and laboratory testing of the cement-slurry backfill properties. The results of the stability analysis allowed the contractor to plan safe construction and excavation sequences.

## DESCRIPTION OF PROJECT

The Post Office Square Parking Garage, located in the financial district in downtown Boston, Massachusetts, was built in 1989 using the top-down method. The general contractor was J. F. White Contracting Company of Newton, Massachusetts. GEI Consultants, Inc. (GEI) provided consulting services to J.F. White during construction. The owner of the project is The Friends of Post Office Square. The owner's design team was lead by Parsons, Brinckerhoff, Quade & Douglas.

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The 7-level underground structure covers a full city block with an area of about 60,000 square feet per level (Fig. 1). The structure consists of reinforced concrete floors supported by steel columns (LBE's). The walls of the structure consist of cast-in-place slurry walls.

## Top-Down Construction Method

The top-down construction method used on this project consisted of the following steps:

1. Install perimeter slurry walls.

2. Install columns in LBE slurry trenches. Tremie place concrete foundation for the columns and backfill the LBE trenches to grade.

3. Excavate and place roof level slab.

4. Incrementally excavate and place lower floor slabs which provide bracing for the slurry walls and columns.

The contractor selected several construction techniques which influenced the stability of the columns during construction, including:

1. Tremie backfilling the LBE's with a mixture of desanded bentonite slurry and Portland cement. The objective was to solidify the slurry to the consistency of the natural clay to allow easy removal of the mixture from the column surfaces and to provide lateral support to the columns equal to the clay soil.

2. Placed the floor slabs on forms hung from the columns (Fig. 2). The forms required an additional 4 to 5 feet of excavation below the bottom of the floor slab under construction.

3. Excavation of a wide trench at the center of the site to allow the excavation equipment to remain in the excavation during slab placement.

These construction techniques allowed an aggressive construction schedule despite the potential restrictions needed to maintain stability of the columns.

## Column Stability Analysis

The primary effect of the construction techniques were to increase the unbraced length of the partially embedded columns beyond the conditions assumed by the design engineer and to apply large bending moments from the suspended form work.

The top of each column section at each stage of construction was assumed rigidly attached to the completed concrete floor. The point of fixity at the base of the columns embedded in LBE backfill was estimated using published recommendations for building of partially embedded piles[5, 6] The total length from the concrete slab level above to the assumed point of fixity in the LBE backfill was used to estimate the allowable column load.

The column stability analysis was further complicated by the following:

1. Bending moments applied by unbalanced loading of the formwork and concrete. The forms were suspended by steel rods attached to the columns. Loads during concrete placement typically resulted in 38-kip loads eccentrically located up to 2 ft. from the column. Unbalanced loading occurred simultaneously on the strong and weak axis of the column in some locations.

2. Dead loads due to slabs, walls, mechanical equipment, etc. were considered and increased as construction proceeded downward.

3. Live loads due to construction equipment operating on the completed roof slab included a 260-kip back-hoe, HS-20 truck loading, and miscellaneous equipment and materials.

4. Plumbness of the columns for analysis purposes was assumed to be within the tolerances of the AISC specifications. This was checked and verified as excavation progressed and the column was exposed.

**LBE BACKFILL TESTING**

The equivalent depth to fixity in the backfill is related to the column flexural rigidity (EI) and the subgrade modulus of the backfill. The relationship between backfill shear strength and elastic modulus required extensive testing of the backfill, including dilatometer tests, field vane shear tests (ASTM D2573), and standard penetration tests (SPT's) at two LBE locations. Additional field testing included an ongoing program of hand-operated field vane shear tests (similar to ASTM D2573) as the excavation progressed.

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[5]Davisson, M. T. and Robinson, K. E., "Bending and Buckling of Partially Embedded Piles," *Proceedings 6th Int. Conference SM&FE*, Vol. 2, 1965.

[6]ACI-543, "Recommendations for Design, Manufacture and Installation of Concrete Piles." *Manual of Concrete Practice*, 1987 Part 4.

The dilatometer is a flat, stainless steel blade, with a circular expandable steel membrane on one side. Tests were performed at approximately 9-in. vertical intervals. The data obtained from the tests included small strain elastic modulus and estimates of soil type and shear strength.

Laboratory triaxial shear tests and vane shear tests were performed on undisturbed samples of LBE backfill to evaluate the shear strength and elastic secant modulus values. Index tests including water, cement, and bentonite content were also performed to evaluate uniformity of the backfill. The composition of the LBE backfill, the shear strength, and elastic modulus values measured in the testing program are summarized in Tables 1 and 2. The extreme variability in strength, elastic modulus, and composition indicated that the slurry-cement backfill was difficult to mix and place uniformly.

The modulus values obtained from the testing were used to evaluate the buckling capacity of the columns using a beam on elastic foundation analysis. The results of the analysis were used to evaluate the assumptions regarding the embedded depth to a fixed-end condition. A table of allowable excavation depths at each level was developed for selected values of backfill shear strength. The contractor was then required to use the hand-operated vane shear apparatus to field measure the backfill shear strength. The vane test were performed on the LBE backfill at most columns as excavation was advanced.

**SUMMARY**

The field and lab testing of the backfill correlated shear strength and subgrade modulus. These correlations gave the contractor a method to evaluate the safety of each column at every stage of excavation by making simple in-situ measurements of the backfill shear strength and to correct unsafe conditions prior to critical loading conditions. Backfill which did not meet minimum strength criteria was excavated and replaced with a lean concrete prior to the critical loading conditions.

**TABLE 1**

| Location | Sample | Elevation | $\gamma_b$ pcf | Water Content (%) | % Bentonite by Dry Weight | Bags Cement per 4 cu yd | Cement/Water Ratio |
|---|---|---|---|---|---|---|---|
| K13 | UF1 | 4 | 22.1 | 230 | 68.3 | 8.0 | 0.14 |
| K13 | UF3 | -27 | 26.9 | 193 | 61.9 | 11.8 | 0.20 |
| M15 | UF1 | 0 | 17.5 | 324 | 67.7 | 2.8 | 0.10 |
| M15 | UF2 | -32 | 20.7 | 270 | 64.6 | 8.4 | 0.13 |

**TABLE 2**

| | | | Peak Undrained Shear Strength psf | | | Elastic Modulus psf | |
|---|---|---|---|---|---|---|---|
| Location | Sample | Elevation | Triaxial Tests | Lab Vane | Field Vane | $E_{50}$ Triaxial Tests | $E_d$ Dilatometer |
| K13 | UF1 | 4 | 107 | 53 | 92 | 1,500 | Approx. 0 |
| K13 | UF3 | -27 | 480 | 600 | -- | 7,900 | 60,000 to 180,000 |
| M15 | UF1 | 0 | 170 | -- | 580 | 2,500 | 4,000 |
| M15 | UF2 | -32 | 520 | 730 | 1,550 | 20,000 | 35,000 |

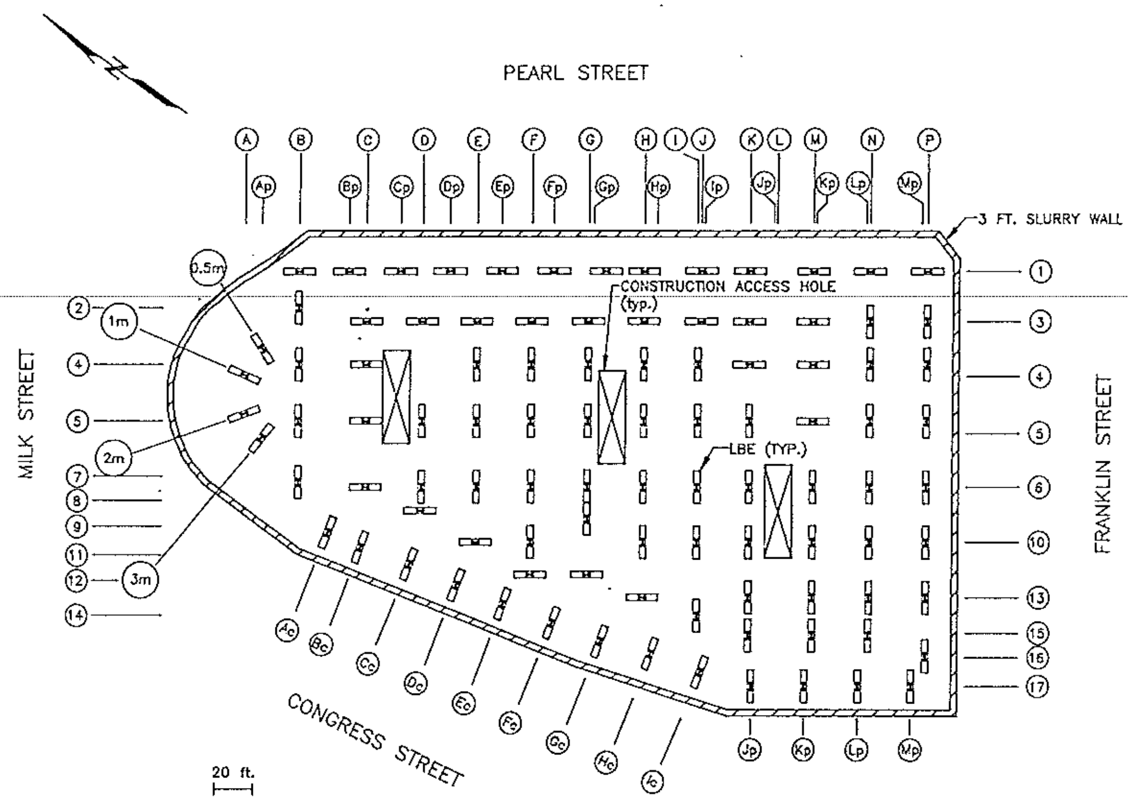


FIG. 1 SITE PLAN

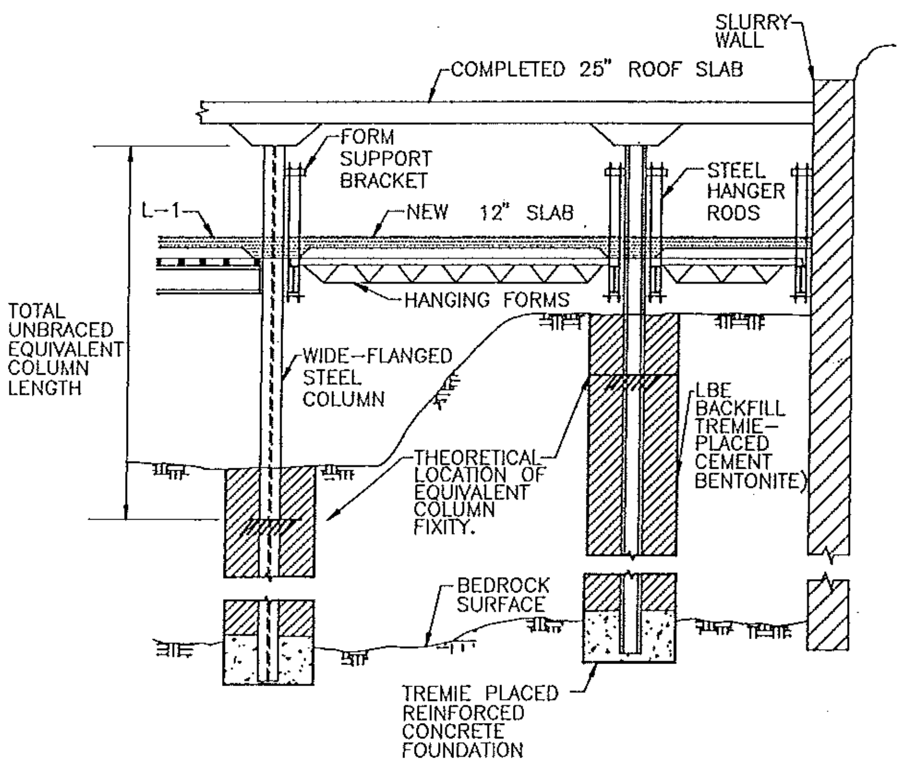


FIGURE 2 TYPICAL SECTION THROUGH LBE'S