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ABSTRACT

This paper presents a case history on the failure of an excavation bracing system. The engineering project involved the construction of the New World Plaza in Changchun, China. The plaza building had a 3-story deep basement which supported an 8-story building together with a 42-story main tower. The excavation area was surrounded by streets on three sides and an on-going 8-m deep excavation along the fourth side. The excavation varied from 15 m to 16 m in depth and was braced with 157 anchored cast-in-place reinforced concrete piles. The bracing system failed as soon as the design depth was reached. Primary causes of the bracing failure included improper installation of the tieback anchors, inadequate stiffness and strength of the wales, and adverse effects of freezing temperatures. It was remedied by reducing the mat foundation area together with the installation of short piles against the load bearing wall.

KEYWORDS


INTRODUCTION

For construction of the New World Plaza in Changchun, China, a 15-16 m deep excavation was made over an area of 105 m by 80 m. The excavation was braced with 157 anchored cast-in-place reinforced concrete piles. When the excavation reached the design depth of 16 m at the area of the mat foundation, several tiebacks cracked and collapsed. This paper presents the details of the engineering project, subsurface condition, bracing system, causes of failure, and remedial measures.

PROJECT DESCRIPTION

The New World Plaza building in Changchun City, China, has a 163 m high 42-story main tower with the rest of the building only eight stories and 41.4 m high. The basement is 3 stories deep. The main tower portion of the building is supported by a mat foundation and the rest of the building is supported by pile foundations. The floor plan of the building is 101 m by 76 m, and the area of the foundation excavation is 105 m by 80 m. The elevation view of the building is shown in Figure 1, while the tieback layout and foundation plan view are illustrated in Figures 2. Three sides of the excavation area are surrounded by streets and the fourth side is bordered directly against an on-going construction of a building which has an 8 m deep foundation excavation. The ground surface dips gently from southwest corner to northeast corner of the excavation area for about 1.5 m.

SUBSURFACE CONDITION

A total of 19 borings were made to determine the subsurface condition. Six of these borings were 40 to 50 m deep. The soil layer composition and their engineering properties are presented in Table 1. The ground water table was at 2.4-4.0 m below the ground surface.

EXCAVATION

The depth of vertical excavation varied from 15 m in the west
at the pile foundation area to 16 m in the cast at the mat foundation area. Along the periphery of the excavation were installed 28 wells, 10-15 m center-to-center spacing, to lower the ground water table. Each well had a diameter of 600 mm and a depth of 26-27 m. In addition, four pumping wells and one observation well were installed around the center of the excavation area.

**BRACING SYSTEM**

The excavation was braced with 157 anchored cast-in-place reinforced concrete piles. The pile layout is shown in Figure 2. Each pile had a 1.0 m diameter, 19.5 m length with 2.2-2.6 m center-to-center spacing. They were tied back using two anchors at the center between two adjacent piles on the wales, one at 5.0 m and the other at 10.0 m below the top of pile. The anchor was designed and constructed according to the soil anchor design and construction specifications (ADRIMMC, 1991). The anchor was installed in a 150 mm diameter hole dipping 15°-22° into the ground. The tendons were 32 mm diameter threaded steel rods; the anchored and unanchored lengths were 13.5-14.5 and 3.0-5.0 m, respectively. The anchor grout was a cement paste having a water-cement ratio less than 0.4. The design anchor pullout strength was 25 MPa. The anchors were prestressed to 310-350 KN.

*Fig. 1 Sectioned elevation view of the building*

*Fig. 2 The tieback layout and foundation plan view*
BRACE FAILURE

When the excavation reached the design depth on February 17, 1994, the wale at the east side between No. 46 and 47 piles broke; subsequently, 8 piles in the vicinity collapsed. In the meantime, the wales and piles in the west side underwent considerable deformation and cracking. Despite rapid deposition of soil in front of the piles, No. 70 through 76 piles collapsed on April 14, 1994. No. 79 through R6 piles also severely deformed. As a result, the excavation work was halted for several months.

CAUSE OF FAILURE

Immediately following the incident, an investigation was undertaken to determine possible causes for the failure of the bracing system. In the investigation, details of the design were carefully reviewed and the field construction process was also examined. The following were identified as the primary causes of the failure:

1. Improper installation of the tieback anchors -- A great majority of the lower anchors were too close to the upper ones; some of them were even 1 m higher than the design elevation. The higher than the design location could cause an over-stress in the lower anchor. Meanwhile, although the anchors were designed to be installed at the centers between two adjacent piles, some of them were found too much off-centered. As a result, the wale could be severely over-stressed causing excessive wale deformations.

2. Inadequate stiffness and strength of the wales -- The wales were made of old rails whose strength was lower than the required value. Additionally, possible effect of fatigue incurred during the service life of the rail was not properly considered.

3. Adverse effect of freezing temperature -- In Changchun, the mean lowest temperature was about -25°C; the freezing period lasted about four months; and the frost depth was about 1.7 m (CNSST, 1989). As shown in Table 1, the soil at excavation was mostly a silty clay with considerable water content. Such a soil under freezing temperature could undergo considerable swelling. Since the excavation was covered only by a layer of textile fabric, the soil between tiebacks bulged severely indicating the serious frost effect on the stability of the bracing system.

REMEDIAL MEASURES

Based on the results of the investigation, it was decided that the excavation be discontinued. Instead, the foundation area was reduced, and the 2-m wide of the mat foundation which extended beyond the load bearing wall was removed and replaced with smaller piles. The smaller piles had 0.8 m diameter and 8.0 m length which penetrated 4.0 m below the base of the raft, and were located at 2.0 m in front of the large tieback piles. The smaller piles were also cast in place and were fastened to the building wall. The 2-m space between the small and large piles was filled with soil to enhance the stability of the tieback bracing system. A schematic illustration of the pile configuration is shown in Figure 3. The volume of concrete needed for construction of the smaller piles was about equal to that of the removed portion of the mat. Since no additional effort is needed for improving the

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Soil Strata</th>
<th>Unit Weight (KN/m³)</th>
<th>Cohesion (KPa)</th>
<th>Internal Friction Angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2~2.4</td>
<td>Miscellaneous Fill (mixture of construction debris, coal ash &amp; soil)</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>3.7</td>
<td>Soil Fill</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>11.3</td>
<td>Silty Clay</td>
<td>19.6</td>
<td>46.6</td>
<td>19.7</td>
</tr>
<tr>
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<td>108</td>
<td>12.1</td>
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<tr>
<td>16.6~17.3</td>
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<tr>
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<td>133.5</td>
<td>16.1</td>
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<td>Coarse Sand</td>
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<tr>
<td></td>
<td>Moderately Weathered Shale</td>
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<td>----</td>
<td>47.7</td>
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</table>
The existing bracing system, considerable saving in time and cost was resulted from the measures taken.

![Fig. 3 Schematic illustration of pile configuration](image)

**SUMMARY AND CONCLUSIONS**

A case history on the failure of an excavation bracing system was presented. The excavation had an area of 105 m by 80 m with a depth of 15–16 m and was braced with 157 tiebacks. The tiebacks were cast-in-place reinforced concrete piles with two levels of anchors installed on the wales at the centers between two adjacent piles, one at 5 m and the other at 10 m below the pile top. The bracing system at the mat foundation area failed when excavation reached the design depth of 16 m. The bracing failure was attributed to improper installation of the tieback anchors, inadequate stiffness and strength of the wales, and adverse effects of freezing temperature. The failed bracing system was corrected by installing 8 m long piles against the load bearing wall and also back-filling the space between the piles and the tiebacks. Meanwhile, the portion of the mat foundation which extended beyond the load bearing wall was removed. This remedial measure caused little delay in project completion date with no substantial increase in construction cost.

It is concluded that a successful bracing of deep excavation requires a sound engineering design with a careful construction operation that closely follows the design. Meanwhile, possible adverse environmental effect must be duly taken care of. The remedial measure appears to be efficient and cost effective.

**REFERENCES**
