UNDERGROUND BASEMENT CONSTRUCTION ADJOINING HISTORICAL MONUMENT  
BY SOIL NAILING – A CASE STUDY

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ABSTRACT: Construction activity close to historical monuments is a tricky issue due to several restrictions imposed by Archeological Survey of India (ASI). Mostly such monuments had either raft foundations or stepped foundations. Alongside Alambagh gate in Lucknow, an underground basement of double storeyed has been constructed. ASI agreed only for the soil nailing method at the site as it allows negligible detrimental effect to the structure, the monument being only 7m away from edge of proposed parking. On the basis of insitu pull out tests, the nail length, spacing, dia etc. were determined. The overburden surcharge (on account of traffic load) and seismic parameters were also incorporated in analysis. The paper discusses the design and construction details of the 6m deep basement designed by authors using soil nailing techniques. The nailed construction cost came out to be 60% of conventional underground construction techniques.

INTRODUCTION
Amid the noisy street-market of Chander Nagar, Lucknow, stands the Alambagh Gate, a grim reminder of the heavy bloodshed during the first war of independence. A large number of mutineers were hanged from this Gate, that's why it is also called Faansi Darwaza. The nawab of Awadh, Mohd. Wajid Ali Shah had constructed the two-storeyed structure for the palace of his queen Alam Ara during 1847-1857. The gate served as the entrance to the Alambagh Palace.

Alambagh is one of the busiest commercial areas of Lucknow. Presently due to inadequacy of definite parking space, the newly proposed double storeyed underground parking shall accommodate approximately 300 vehicles and would have green covering on the top. The construction proposed was at a distance of just 7m from the historical Alambagh gate. Complicacies involved are the safety of the historical gate and the abutting commercial roads on front of gate. It was proposed to construct a double basement underground parking at a distance of around 7m from the gate. Concept of such structures is simple but due to presence of historical monument nearby, the site conditions are a little touchy. Being a historical monument duly protected by Archeological Survey of India, the latter was concerned about the safety of the foundation of the monument as without availability of foundation drawings of the monument, it was believed that it might be having either a full raft or stepped footing which might be up to the boundary line of the proposed basement. The agency was also concerned about the safety of the sub structure and thereby the super structure also, particularly during excavation work of the basement which might involve heavy machinery that could generate vibrations and uncontrolled cutting of the soil underneath.

SOIL NAILING
The basic concept of soil nailing is to reinforce and strengthen the existing ground by installing closely spaced steel bars, called "nails," into a slope or excavation as construction proceeds from "top to down." This process creates a reinforced section that is itself stable and able to retain the ground behind it. The reinforcements are passive and develop their reinforcing action through nail ground interactions as the ground deforms both during and following construction.
PULL OUT TESTS
Pullout tests were performed to determine the soil nail lateral friction. To compute the apparent coefficient of friction between soil and the nail, the pull out test is the only possible and reliable method. Grouted nails were tested at four different locations. To account for any variation in the soil properties, if any, and overburden pressures four different locations were selected for testing. At each location the nails were buried into the excavation at different depths. The average apparent coefficient of friction was obtained as 0.45.

Table 1 Details of Nail Dia and Surcharge conditions along four walls of the underground Parking

<table>
<thead>
<tr>
<th>Wall</th>
<th>Surcharge (kPa)</th>
<th>Grouted Nail dia, (mm)</th>
<th>Nail length, (mm)</th>
<th>Nail Spacing, Sv (mm)</th>
<th>No of nails</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>100</td>
<td>4000</td>
<td>1200</td>
<td>5</td>
<td>Gate Side</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>75</td>
<td>4000</td>
<td>1200</td>
<td>5</td>
<td>Highway Side</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>100</td>
<td>4000</td>
<td>1200</td>
<td>5</td>
<td>Highway Side</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>75</td>
<td>4000</td>
<td>1200</td>
<td>5</td>
<td>Highway Side</td>
</tr>
</tbody>
</table>

DESIGN OF NAILED CUT
At Alambagh site, the stratum is cohesive which has poor drainage facility. Safety of any retaining wall depends on good drainage system. The grouted nails improve the drainage system of cohesive soil mass due to insertion of granular mass. The grouting material shall also make a good bond with cohesive soil all around. Conventionally, soil nails are designed by an analytical approach which is based on ground models established from ground investigation and soil shear strength parameters obtained from laboratory testing. Many different analytical and numerical methods are available [1,2,3,4] for assessing the stability of natural or manmade slopes. In IIT ROORKEE, a software MSNAILS has been developed by the authors for the design of nailed slopes which has been tried at some sites successfully. In present analysis also that software has been used.

DESIGN DETAILS
The soil at the site is cohesive under the classification as CI/CL. The average values of soil parameters were:

\[ \gamma_s (bulk \ density \ of \ soil) = 16, \ c (cohesive \ strength \ of \ the \ soil) = 70\text{KPa}, \ \phi \ (angle \ of \ internal \ friction) = 16^\circ, \ \text{LL (liquid limit)} = 41\%, \ \text{PL (plastic limit)} = 24\% \]

The four walls (1 to 4) of the basement have been defined in Fig. 2.

On all the four sides of proposed basement, vehicular movement shall be regular. Hence suitable values of surcharge (q) have been taken in the analysis (Table -1).

According to IS: 1893-2002, the seismic coefficients taken into analysis were \( \alpha_h = 0.16 \) and \( \alpha_v = 0.08 \)

![Fig. 2 General layout of proposed basement](image)

The fascia wall of basement of height 6.5m (including 0.5m bottom raft) was designed as a vertical cut. Grouted nails of either 75mm or 100mm dia (Table 1) were used according to surcharge load along four walls of the basement.

The grout and shotcreting proportion was taken as 1:1 (cement/sand). The shotcreting shall be carried out in 2 stages, each of 37.5mm thickness, thus making a total of 75mm (3"). A wire mesh of aperture 100mm held by U-hooks of 6mm steel bars was placed on the cut face. To facilitate quick drainage of pore water pressure, if, any 100mm dia drainage pipes were provided at 5m c/c horizontally along the length of the basement (Fig. 3). The nails and shotcrete are shown in Fig. 4.

![Fig. 3 A cross section of Nailed cut in zone 1, 2 and 3](image)
DRAINAGE
Drainage is an important issue in all retaining walls and structures. Therefore drainage pipes were also provided at suitable intervals (Fig. 5). The drainage pipes were perforated PVC pipes which were duly wrapped around by geosynthetic cloth so that only clear water enters the pipe and not the soil particles. The drainage pipes are provided at a slope outward (Fig. 5), so that water comes out under gravity without any blockade. The drained water thus, was collected in a sump through a common header pipe, from where it will be pumped out. A completed view of 6m deep basement showing nails and drainage pipes in shown in Fig. 6.

COST
The cost is a relative issue. Sometimes even the higher cost is indispensable in view of site limitations. At this site, other solutions could be retaining walls or sheet piling. But both these solutions were very expensive. Normally the cost of soil nailing (though design specific) comes out Rs. 4500/- to Rs. 9000/- per square metre. At this site, the cost of soil nailing worked out to be 60% of the conventional construction techniques generally adopted for underground basements.

CONCLUSIONS
The soil nailing technique proved to be an effective solution to this site in view of safety of the historical monument at the site with respect to the space available and sensitivity involved while excavation. Nailing is the most economical technique of all the underground constructions.

REFERENCES