DESIGN AND CONSTRUCTION OF A HIGH RETAINING SCHEME

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SYNOPSIS A multi-storey factory building is proposed to be built on a site 90 m long by 50 m wide, in a congested industrial area in Kowloon, Hong Kong. The site situates at the bottom of a hillside with a highway at the mid-level of the hill. In order to maximize the utilization of the site area, it is necessary to have very steep cut along the backside of the site. A retaining scheme consisting of anchored caissons and curved laggings was designed. Due to the difficult site condition, instrumentations including inclinometers, piezometers, pressure cells and anchor load cells are installed for construction control and long term monitoring. This paper presents the results of site investigation, design and construction of the retaining scheme which is currently in progress. The total cost of the site formation and retaining scheme is estimated to be around US$2.4 millions.

INTRODUCTION

An eighteen-storey factory building is proposed to be constructed on a rectangular site, about 90 m long and 50 m wide in Kowloon, Hong Kong. The site is located at a hillside and is bounded by a highway on the north up-slope and a street on the south side. The hill descends from the highway at a slope of about 25 degrees to a cliff about 5 to 16 m high along the street. The maximum difference in elevation between the two road levels is about 28 m.

The ground floor level of the proposed building is to be at the same level as the lower street. In order to utilize the maximum site area, it was necessary to have very steep cut slopes along the north, east and west boundaries. The cut slope along the north side is about 90 m long and the maximum height is approximately 28 m. Special retaining structures are required to support the slopes. This paper describes the geotechnical investigation, design and construction of the retaining scheme, and instrumentation of the supporting structure. At the time of preparation of this paper, the construction is still in progress.

SITE AND SUBSURFACE CONDITIONS

The site is located on the lower slope of a fairly steep ridge. The ridge extends northernly from the highway to a 30 m high cut slope formed at 50 degrees. Information obtained from site investigation indicated that the site is covered with a thin layer of colluvium varying in thickness between 1 to 2 m. Underlying the colluvial mantle are weathered granitic rocks in various degrees of weathering. The completely weathered zone which consists of dense silty sand is about 4 m thick. The underlying highly weathered zone is about 6 m thick and consists of dense silty sand and gravel.

Soft rock formation classified as highly to moderately weathered granite was encountered at a depth of about 14 m below the level of the highway. This formation has extremely high resistance to the penetration of sampler and is very difficult to core. The parent rock formation of slightly weathered granite which is typically a coarse grained Hong Kong Granite, was found at 22 m to 30 m below the highway, and 3 m to 7 m below the lower street level. The core recovery in this formation generally exceeded 95% and the rock quality designation (RQD) normally was higher than 85%.

In the area near the foot of the existing cut slope north of the highway, the slightly weathered granitic bedrock was found at a much higher elevation. The surface of bedrock in this region therefore appears to dip in an easternly direction.

At the time of site investigation, the groundwater level was found at about 18 m below the highway and dipped toward the south to about 2.5 m below the lower street level.

A total of 15 boreholes was drilled at the site. Figure 1 shows the topography of the site and the locations of the boreholes.

ANALYSES AND DESIGN

For the proposed development, there are four requirements of prime concern:

(i) Maximum utilization of the site area for floor space.

(ii) Stability of cuts along the entire north boundary and part of the east and west boundaries.

(iii) Stability of the highway above the site both during and after construction.

(iv) Permanency of the retaining structure.

The most critical part of the site development of

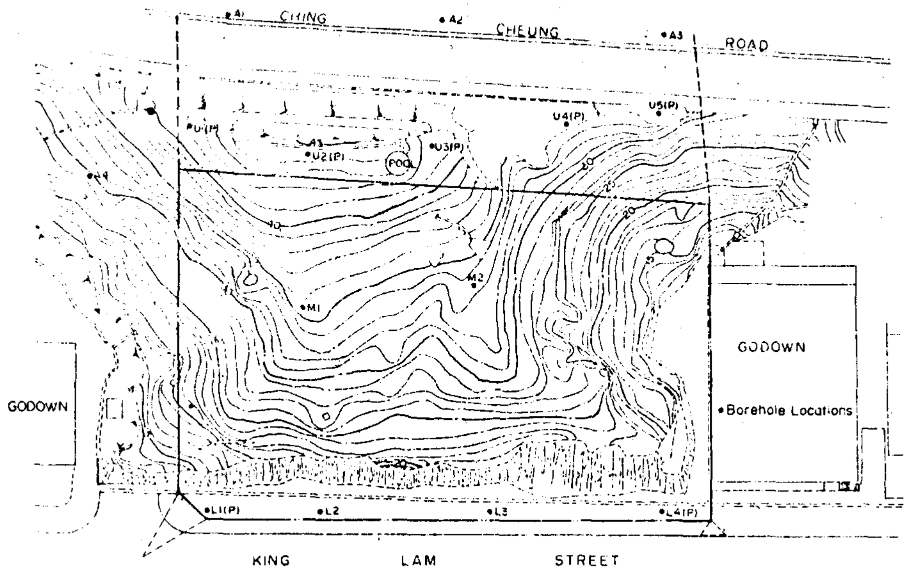

Fig. 1 Topography of the Site and Locations of Boreholes

this project is the selection of the retaining scheme along the north boundary since the stability of this structure will not only affect the stability of the highway located above the cut but also the safety of the proposed building itself. In the past decade, numerous landslides have occurred at hillside developments in Hong Kong. The Government of Hong Kong is therefore particularly concerned with the safety aspect. Furthermore, the design scheme will also affect the total area available for the construction of the proposed building. This is another critical consideration for this development in view of the high land cost in Hong Kong.

Considerations were given to the possibility of utilizing the building structure to retain the cut. This possibility was abandoned during the early stage of analysis for safety reason. Among many types of retaining schemes studied, four schemes were considered feasible and were given detailed analysis. Figure 2 presents schematic sketches of the four schemes. They are:

(i) Scheme A – anchored slurry beam and lagging.

(ii) Scheme B – slope with anchored wall.

(iii) Scheme C – counterfort retaining structure with anchored wall.

(iv) Scheme D – anchored caissons with laggings.

On the basis of the analysis, a preliminary estimate of the construction cost and time required for the various schemes were made. Scheme C is least expensive and would require shortest construction time. However, this scheme would occupy the largest amount of site area which can not be used for building construction. Cost for excavation, drainage and instrumentation were essentially the same for all schemes. After discussion with the owner, architect, and structural engineers involved, it was decided to adopt Scheme D for the primary reason of maximum usage of the site area.

The design of Scheme D involves the construction of a series of vertical caisson-lagging system retained with rock anchors. The anchors are to be extended into the slightly weathered or fresh rock formation situated under the highway north of the building site. Under this scheme, practically all possible space within the building site can be utilized. However, due to objection of the Government Agencies concerned, all the construction facilities must be confined within the site boundaries even though the proposed rock anchors would penetrate into the fresh rock formation more than 30m below the highway. With this restriction, a portion of the site area must be sacrificed.

The final scheme adopted involves a 12 m high cut slope at an angle of 45 degrees from the highway level and a vertical caisson-lagging-anchor system below the cut slope as shown in Fig. 3.

Based on test results as shown in Fig. 4, the effective angle of shearing resistance, ϕ', for the weathered granitic soil varied from 37.8 to 38.9 degrees depending upon the degree of weathering. The effective cohesion intercept, c', was near zero in all cases. In view of the variable nature of the weathered granite, the ϕ' value used in analysis was taken as equal to 35 degrees. The average unit weight of the weathered granite was taken as equal to 2 mg/m^3. A surcharge of 11.5 kN/m^2 was used to represent the load from the road above.

The caisson system consists of a series of 30 reinforced concrete caissons of 1.7 m diameter at 3.0 m spacing center to center. Due to restriction of the extension of the anchors, the centerline of the caisson row is moved southward to approximately 16 m

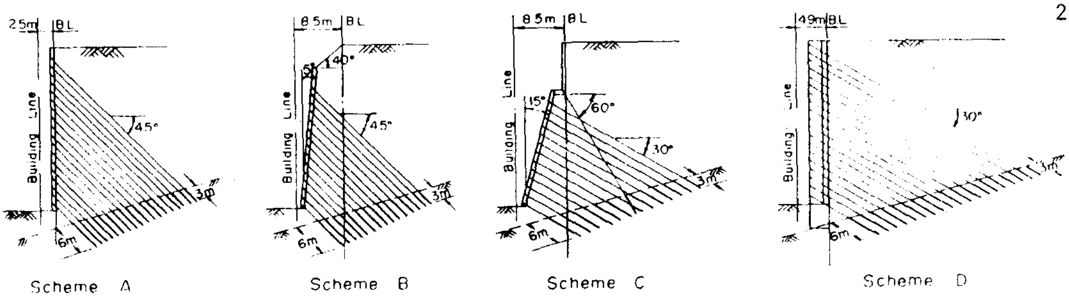

Fig. 2 Schematic Design of Retaining Structure along Northern Boundary

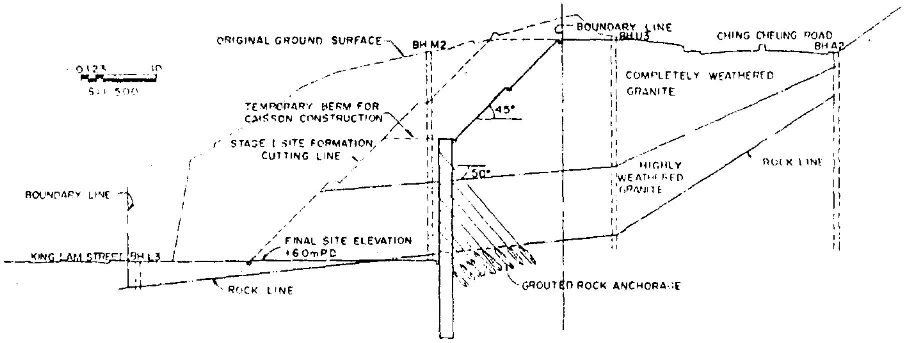

Fig. 3 Section Showing the Retaining Scheme Adopted for the Northern Boundary

from the north boundary. All caissons are to be extended to a sufficient depth into the slightly weathered or fresh granitic bedrock for bearing. All caissons are to be retained by rock anchors extended into the bedrock formation. The anchors are designed with an inclination of 50 degrees from the horizontal. In analyzing the anchoring system, both bending moment and eccentricity of anchor load were taken into consideration. A detailed anchor design was later provided by a nominated specialist contractor according to anchor specifications.

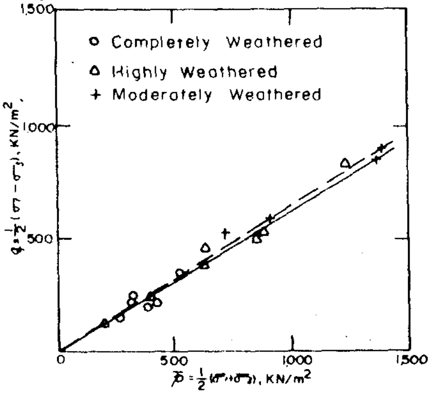

Fig. 4 Strength Test Results of Soils and Rock Formations

The ground between the caissons are to be retained by laggings. The laggings can be either rectangular or curved in shape. A curved section was adapted as it can transmit majority of the earth pressure which retains onto the caissons by compression with minimum shear stress. Furthermore, curved laggings would give a better appearance. The laggings, which are to be keyed into the caissons during cast-in-place construction, are to be constructed in sections approximately 97.5 cm in height and separated by a 2.5 cm gap for drainage purpose. In order to provide the best drainage, which means greater safety, a layer of porous concrete is to be placed between the concrete lagging and the earth. Figure 5 shows the plan view of the retaining scheme.

CONSTRUCTION

The site formation work for the building is to be carried out in two stages. The first stage includes preliminary excavation and the forming of a temporary slope. The area between the north boundary and the highway was excavated to the same level as the highway. The temporary slope was made in the central part of the site at 45 degrees with 1 m wide bench at every 10 m of height. Temporary drainage system was provided along the top and toe of the slope and along each bench. All exposed slopes were covered with 50 mm thick chunam plaster which is a mixture of hydrated lime, cement and sand. A schematic drawing of the site formation work is shown in Fig. 3. The first stage work took approximately two months to complete. The second stage site formation started

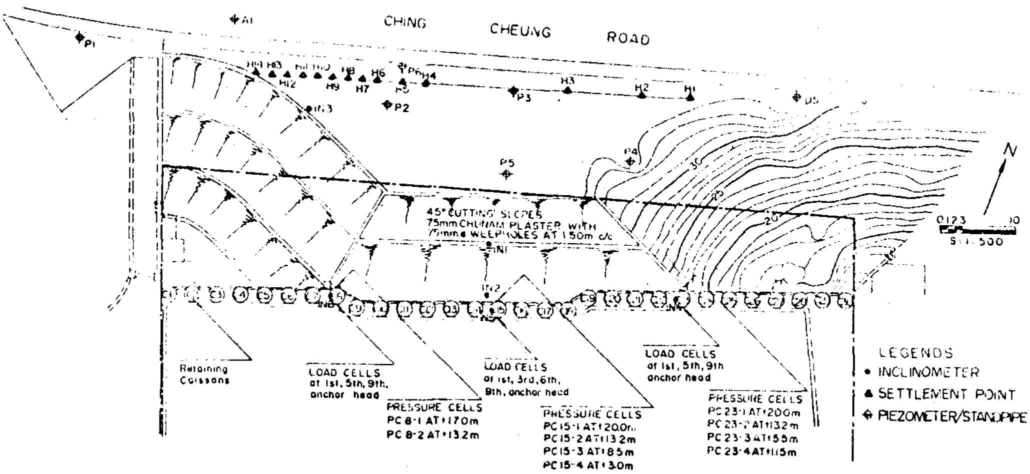

Fig. 5 Plan View of the Retaining Scheme along Northern Boundary

immediately after the first stage work. This stage of work involves the cut of the 45 degree slope from the north boundary and the construction of the caisson-lagging retaining structure.

All caissons were manually dug in sections of 1 m and extended into the underlying slightly weathered or fresh bedrock formation as determined by the consultants. A total of 30 caissons was constructed in a period of eight months. During construction, the size of the caisson was increased to 1.8 m diameter by the client for extra safety reason. This in fact had somewhat dampended the balanced appearance of the caisson-curved-lagging system. At the time of preparation of this paper, three rows of anchors and laggings have been constructed. It is estimated that the entire site formation work including the retaining structure will take approximately 12 months to complete.

INSTRUMENTATIONS

To ensure safety and economy of the project, field instrumentations were designed to be incorporated for construction control and long term monitoring. Instrumentations to be installed include the items listed below. The locations of the instrumentations are shown in Fig. 5.

(i) Testing requirement for anchors – Since the anchorage system is of permanent nature, all anchors are required to be tested under a specified testing program. In addition, load cells (Soil Instruments, Ltd., U.K.), ten in total, are to be installed for long term monitoring of the tensions in the anchors.

(ii) Monitoring of groundwater fluctuation – It is well known that stability of a cut slope depends greatly on the porewater pressure variation. A series of six piezometers was installed at the site for both construction and long term monitoring of groundwater pressure.

(iii) Monitoring of movement of retaining structure – Because of the height of the cut to be retained and also the existence of the highway above the cut, it is necessary to monitor any possible movement of the retaining structure both during and after construction. A total of 6 inclinometer well (Slope Indicator Co., U.S.A.) was installed with 3 of the wells installed in the caissons, 1 on the laggings and 2 on slopes.

(iv) Monitoring of ground movement – Possible ground movement, particularly the existing cut slope and the highway located above, due to construction is monitored periodically by using a precision transit on a total of 27 survey points distributed along the north boundary.

(v) Instrumentation for earth pressure measurement – Methods for computation of earth pressures against retaining structures up to the present are still semi-empirical. Actual earth pressure data from full scale measurements are scarce. Ten total earth pressure cells (Soil Instrument Ltd., U.K.), four of which incorporating cell type piezometers, were installed on the backface of the caissons for the purpose of determining and monitoring the actual lateral pressures acting on the caissons.

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