Caissons with prestressed rock anchors as soil retaining structures

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Caissons with Prestressed Rock Anchors as Soil Retaining Structures

Structures en caissons avec ancrages en rocher précontraints pour contenir la poussée des terres

Vorgespannte, felsverankerte Caissons als Erd-Sicherungs-Bauwerk

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SUMMARY
To overcome the difficulties of construction development in the hilly terrain of Hong Kong, a new form of soil retaining structure has recently been evolved. The retaining structure consists of caissons, either contiguous of spaced with laggings, tied back by temporary or permanent prestressed cables anchored into the solid rock stratum. The design principles and construction procedures are described in connection with an actual site for a tall building requiring such a solution.

RESUME
Afin de résoudre les problèmes qui se posent dans la réalisation de constructions sur le terrain accidenté de Hong Kong, une nouvelle forme de structure pour retenir les terres a été développée récemment. La structure de fixation est composée de caissons qui sont soit contigus, soit écartés avec des garnitures et ancrés par des câbles précontraints de manière temporaire ou permanente dans le rocher solide. Les solutions de procédés de construction donnés sont illustrés dans le cas d'un bâtiment élevé nécessitant une telle solution.

ZUSAMMENFASSUNG
Um die Schwierigkeiten bei Bauvorhaben in Hong Kongs hügeligem Gelände zu überwinden, wurde vor kurzem eine neue Methode zur Sicherung des Erdreichs entwickelt. Das Sicherungsbauwerk besteht aus Caissons, die entweder dicht aneinander gereiht sind, oder deren Zwischenräume ausgefacht sind. Die Befestigung erfolgt durch zeitweilig oder dauernd vorgespannte, in festen Felsschichten verankerte Kabel. Es werden die Entwurfsprinzipien sowie der Konstruktionsablauf anhand einer Baustelle für ein hohes Gebäude, welche eine solche Lösung verlangte, dargestellt.

1. INTRODUCTION

Hong Kong with a total land area of only 1,052 square kilometres is one of the most densely populated place in the world. The total estimated population at the end of 1978 was 4.7 million excluding refugees and illegal immigrants, making an average density of 4,500 per square kilometre with the high density of 25,000 per square kilometre in the urban areas and the low density of 500 per square kilometre in the suburb.

As the flat land in the urban areas is very scarce and very expensive, further development in recent years has spread to more and more difficult hilly terrain. Many site formations on steep slopes of residual soils pose precarious situation and some of them had caused minor and mojor landslides despite the usual measures being undertaken. Therefore, development in the hilly terrain has been hampered and the Government has imposed moratorium restricting new development in certain area. The pressure of land cost and population expansion creates the need to utilize even the 'undevelopable' land and to open up new towns in the suburb. This paper is concerned with the former aspect in which a newly evolved construction technique is used to make development possible in very difficult terrain.

2. SOIL RETAINING CAISSONS

2.1 Design Principles

Caisson has been used primarily for the transmission of vertical load to the deep strata. Unlike the ICOS wall which requires heavy machinery for excavation, the excavation for large-diameter caisson is carried out by hand-digging technique using simple tools to overcome varying sub-stratum from soft to hard, particularly when boulders are encountered. The excavation for caissons can, therefore, be carried out not only on flat ground for deep foundation transferring vertical load, but also on hilly terrain. This opens to the possibility of caissons being used as retaining members resisting horizontal earth pressure in bending.

However, cantilevered caissons can not resist much soil pressure especially in hilly terrain where there is large surcharge from the slope. In order to make the caissons capable of resisting considerable soil pressure as a retaining wall, they are tied back along the height by prestressed cables which are anchored into solid rock (Fig. 1). These rock anchors may be a temporary measure if permanent horizontal props (such as floor slabs) can be established later on, or they can be a permanent measure if permanent horizontal props can not be established such as in the case of a slope retaining caissons considered in the example shown later. With these rock anchors, the anchor heads on caisson become the supporting points and the caisson becomes a member resisting horizontal pressure in bending and in compression if there is vertical load.

There are two important aspects in the design of the caissons:
The first aspect is the earth pressure which directly affects the bending moment in the caisson. It is affected by the amount of the prestressing forces due to the soil-structure interaction. The problem is highly indeterminate which may require finite-element analysis together with on-site adjustments of the prestressing forces as relaxation might occur in the process of stressing sequence.
The second aspect is the direction and inclination of the prestressing cables which normally have to be steeply inclined downward in order to anchor them into the rock. This will produce eccentric vertical components of the prestressing forces at the anchorage heads with the resulting increases in bending moment.

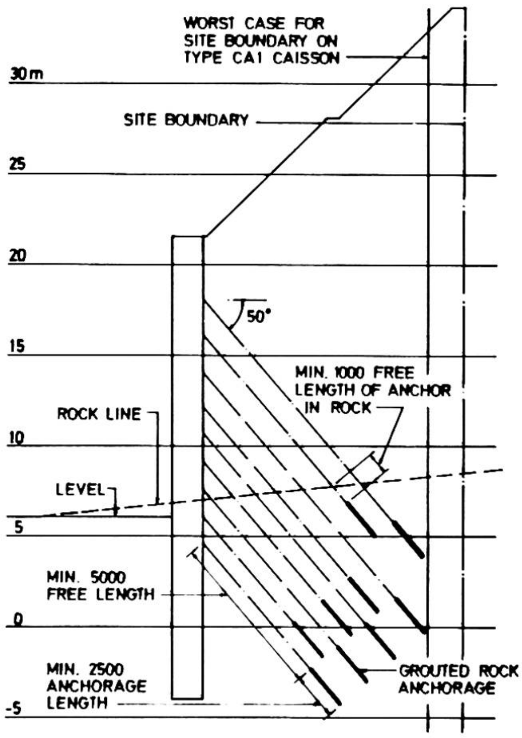

Fig. 1 Cross-Section Through Retaining Caisson

2.2 Construction Sequence

The construction sequence described in the following is related to an actual site. Before the excavation for the caissons, the first stage site formation (Fig. 2) started with slope cutting and temporary drainage in order to facilitate the construction of the caissons, the delivery of materials and transportation of spoils. The excavation for each caisson was carried out in stages of one metre deep approximately, followed by the casting of concrete ring. While excavation deepened, these concrete rings formed the shield of the shaft. Boulders were broken up whenever they were encountered by the use of neumatic drill. Having formed the shaft down to bed rock, the caisson reinforcement was lowered into the shaft and lagging starter bars were fixed through drilled holes in the shaft. Steel pipes, bearing plates, anchor block spiral reinforcement and box-out blocks were positioned from the inside of the shaft. The caisson was then concreted using tremie tube.

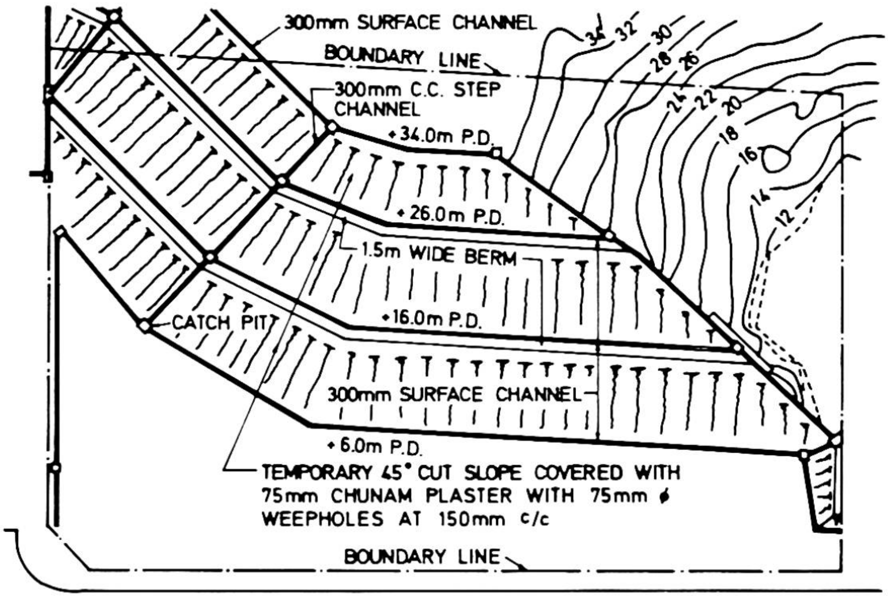

Fig. 2 First-Stage Site Formation

The second stage site formation, (Fig. 3), followed the completion of caissons. The soil was excavated on the outside of caissons which were exposed to the first level of anchorage positions and the anchorage pockets were made good. Using the embedded steel pipes as alignment guides, (Fig. 4), the anchor holes were drilled into the rock. The tendons, with their free length coated with grease and wrapped with polythene tape, were placed in positions and grouted for the required length in rock for bond (Fig. 5). Water test was carried out to ensure each grouting had been properly carried out and no leakage occured. The tendons were then stressed to the predetermined forces and locked at the anchorage heads. The process from excavation to stressing of tendons was repeated until the full depth was reached.

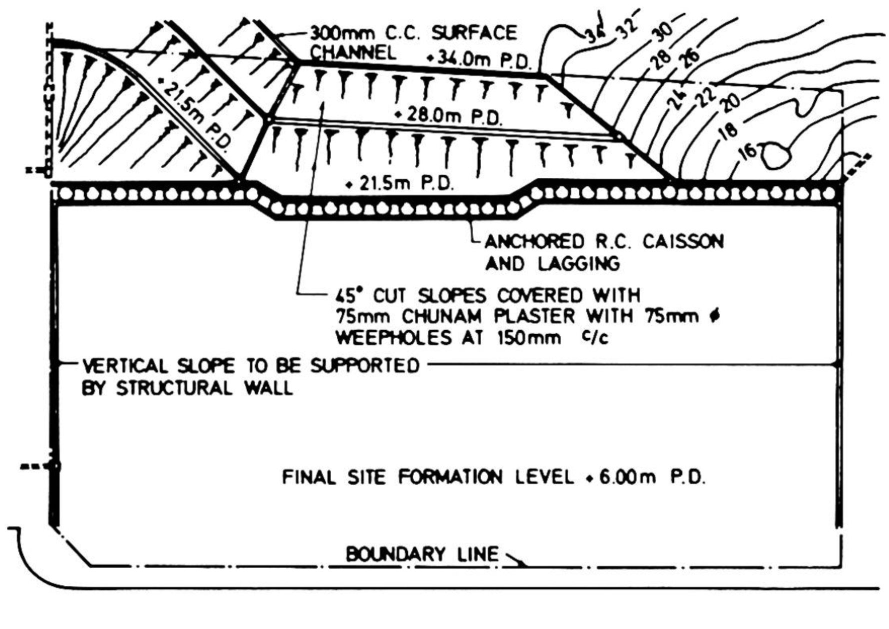

Fig. 3 Second-Stage Site Formation

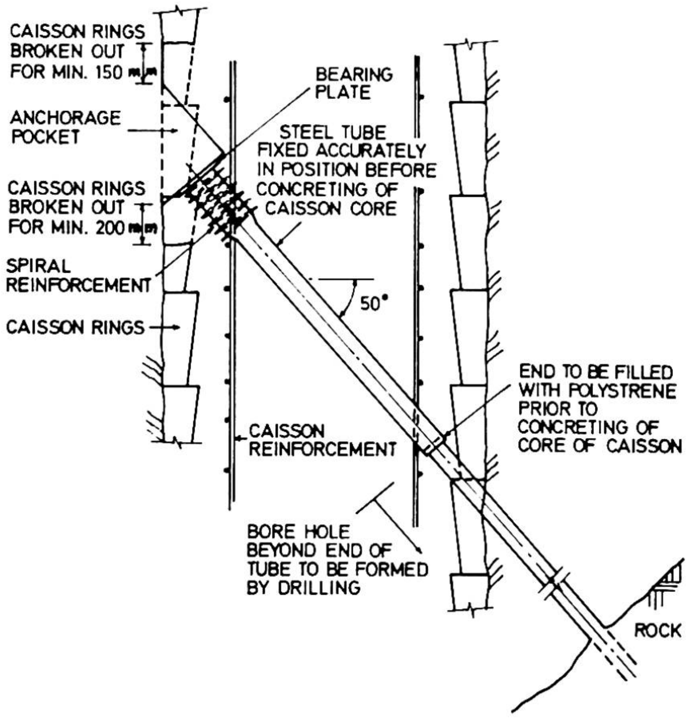

Fig. 4 Upper Portion of Rock Anchor

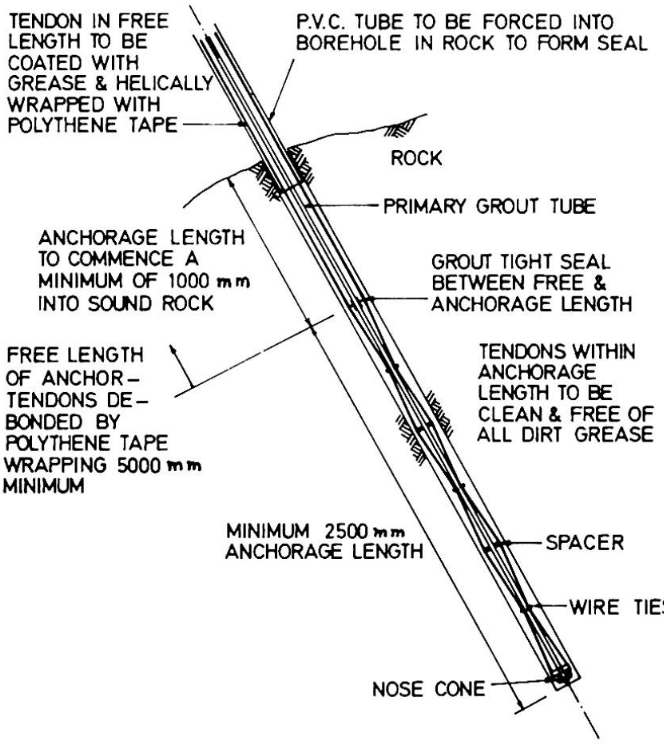

Fig. 5 Lower Portion of Rock Anchor

3. FIELD INSTRUMENTATION

Because of the importance of the retaining structure to the project and the lack of information regarding soil-structure interaction of this nature, field instruments were installed to collect and monitor field data in order to check the design parameters and assumptions, and to observe any sign of abnormality so that steps can be taken early to rectify dangerous situation if it arises.

The field instruments installed on site (Fig. 5 & 6) are briefly described as follows:

(a) Piezometers: installed around the site to monitor pore water pressure in the soil for the evaluation of slope stability.
(b) Inclinometers: plastic casings were installed in the retaining structure, from the top of which the sensor can be lowered into the casings for the measurement of slope deformation of the structure.
(c) Earth pressure cells: installed at different levels and locations behind the retaining structure to monitor the actual earth pressure on the structure.
(d) Load cells (annular ring type): installed between the anchor heads & bearing plates of some anchorages to monitor the variation of cable forces.

The actual field data collected through these instruments provide the basis to correlate the loading on the structure with the effects, and enable the checking of the design and safety of the structure.

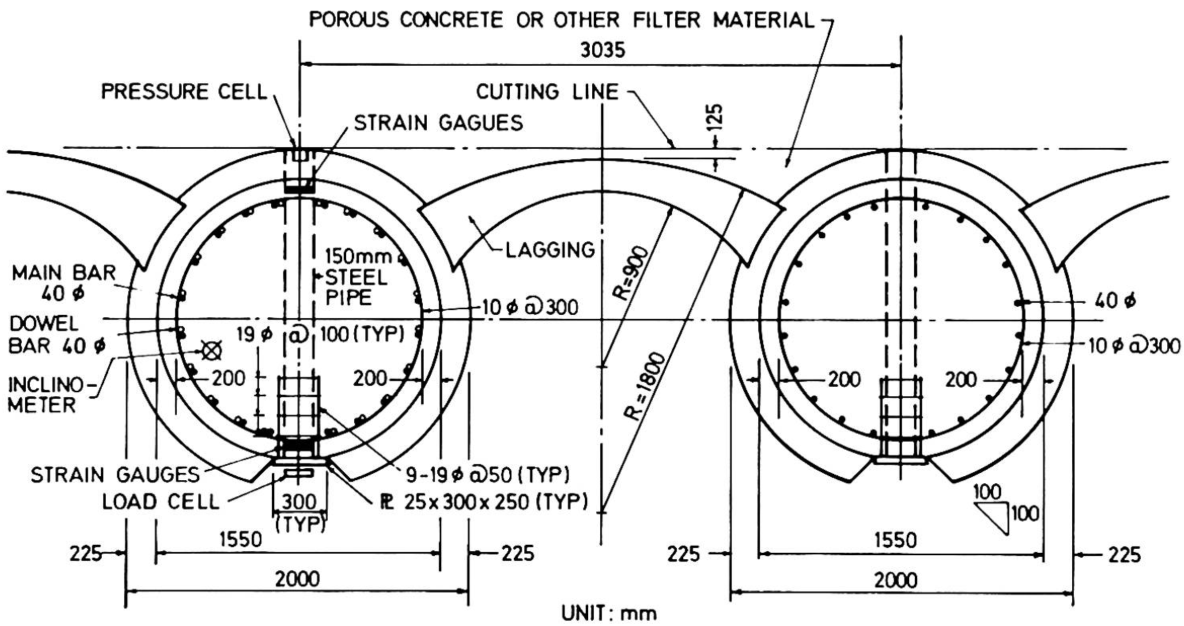

Fig. 6 Locations of Field Instruments

4. CONCLUDING REMARK

A type of soil retaining structure has been evolved in the form of caissons tied back by prestressed cables which are anchored into solid rock. The use of such retaining caissons enables the formation of difficult site in the hilly terrain where heavy machinery can not be employed. Field instrumentation produces useful data which in turn provide the confidence in the design and safety of the structure.