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Use of reinforced fill structures in Hong Kong

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ABSTRACT : An overview is given on the use of reinforced fill structures in Hong Kong, including design and construction standards, geotechnical control, Endorsement Certificate System, usage, case histories, performance, and research and development undertaken by the Geotechnical Engineering Office. A total of 31 permanent structures have been completed so far, most of which utilise galvanised steel ribbed strips with concrete facing panels. All the completed structures have been performing satisfactorily, and little problem was encountered during construction under the local environment.

1. INTRODUCTION

Hong Kong has a total area of only about 1000 km^2, but it has a population of about 6 millions. The great demand on land for housing and transportation has necessitated much site formation works, involving the construction of slopes and retaining structures. The early retaining walls were all masonry. Nowadays, retaining walls are generally constructed in reinforced concrete. Other wall types such as reinforced fill structures, gabion walls and crib walls are sometimes constructed. The reinforced fill technique was introduced to Hong Kong in the late 1970's.

2. DESIGN AND CONSTRUCTION STANDARDS

In 1989, the Geotechnical Engineering Office (GEO) (the then Geotechnical Control Office) of the Hong Kong Government published the Model Specification for Reinforced Fill Structures (Geospec 2) (GCO 1989) to provide guidance on the design and construction of reinforced fill structures with a vertical or near-vertical face. In 1993, the GEO published GEO Report No. 34 (Wong 1993) to provide guidance on the design of reinforced fill slopes with an angle of face inclination exceeding 20° from the vertical. These two guidance documents have been adopted as Hong Kong standards.

Geospec 2 does not explicitly impose a requirement on the minimum length of reinforcing element, which is considered to be unnecessarily restrictive (Pang, 1990). Instead, the lengths of reinforcing elements are required to be determined from considerations of a range of external and internal ultimate limit states. For the design for external stability, viz. sliding, overturning and bearing failure, the recommendations given in the local retaining wall design guide (GEO 1993) are to be followed. Regarding internal stability, six modes of failure need to be considered as depicted in Figure 1. Detailed calculation methods and equations for checking against the six modes of failure are outlined in Geospec 2. A global factor of safety approach has been recommended for simplicity, i.e. a lumped factor is applied to the active earth pressure calculated from unfactored shear strength parameters, and no other factors are applied to the tensile strength of reinforcement, interface friction, etc. In preparing the calculation methods, reference was made to various national codes and to the results of centrifuge model tests by Bolton & Pang (1982).

For the design of reinforced fill slopes, limit state design with partial factors is recommended. The global factor approach is not appropriate for slopes because the active earth pressure calculated from unfactored shear strength parameters for a slope is relatively small and it is difficult to prescribe an adequate and consistent safety margin by the use of a lumped factor. Based on a consideration of the uncertainty associated with the shear strength of

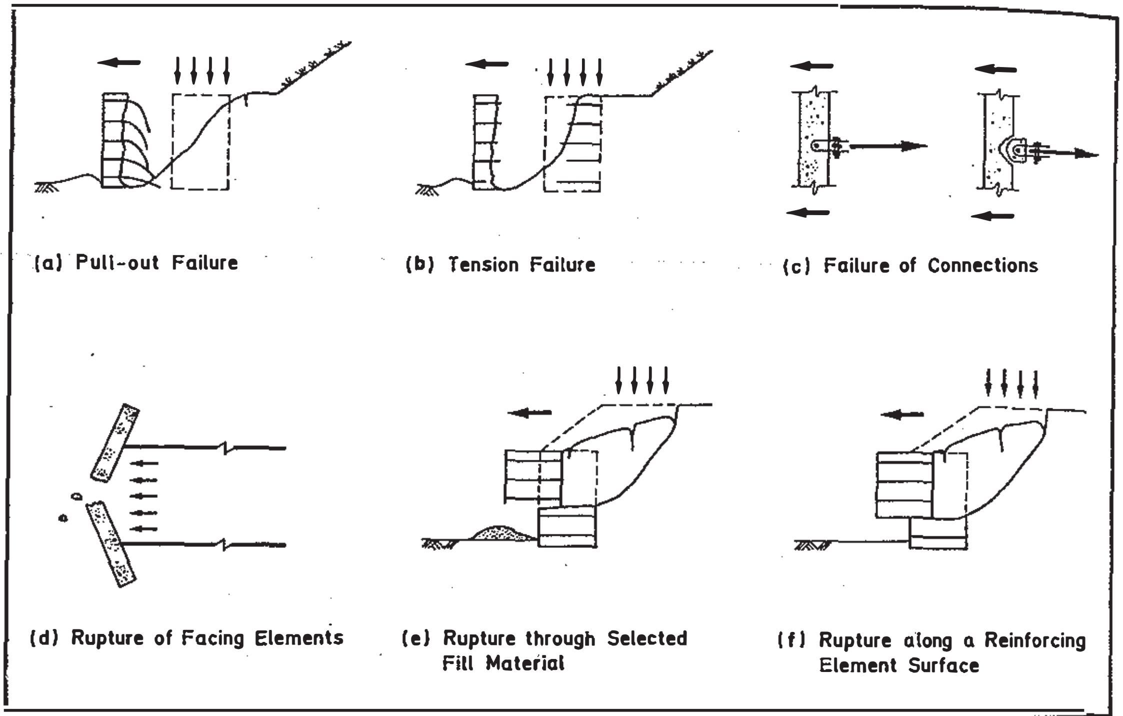

Figure 1 - Internal stability : modes of failure

common Hong Kong soils and other uncertainties, a partial factor of 1.2 on the shear strength of backfill is recommended. The partial factors on material strength and bond strength of reinforcement are considered individually for each material type.

Geospec 2 specifies requirements on material properties of the structure for reinforcing elements, facings, connections and fill, irrespective of the face inclination. It classifies fill materials into two categories, viz. frictional fill and cohesive frictional fill. The soil derived from the weathering of the common rocks in Hong Kong, e.g. completely decomposed granite, generally falls into the category of cohesive frictional fill. Crushed rock is generally used as frictional fill.

In Geospec 2, standards for compliance tests are given. British Standards with modifications to suit the local conditions are generally adopted. For example, in the determination of particle size distribution, the Geospec specifies that no dispersant should be added. The shear strength of the fill material and the coefficient of friction between fill and reinforcements are specified to be determined by direct shear tests using a 300 mm x 300 mm shear box. Following a detailed review by the GEO of soil testing standards in 1993, a number of modifications on standard soil test methods have been recommended (Chen 1994).

3. GEOTECHNICAL CONTROL

In Hong Kong, all permanent reinforced fill structures to be used in Government and private projects are required to be constructed generally in accordance with the requirements given in Geospec 2 and GEO Report No. 34. The Government project department or the designer for private development are required to make a geotechnical submission on the proposed works, including drawings, design calculations and the specification for the reinforced fill structure, to the GEO for checking to ensure compliance with the required standards.

Full-time site supervision are required to be provided during construction of reinforced fill structures. Direct shear tests in accordance with the Geospec 2 testing procedures are carried out to verify the shear strength of the fill material and the assumed value of coefficient of friction against sliding failure. Additional compliance testing on various properties of the fill materials and reinforcement products are ordered by the site staff in accordance with the specification.

In order to allow the GEO to carefully assess proprietary products intended to be used in permanent reinforced fill structures, which cannot be covered by the standard properties and general performance parameters specified in Geospec 2, an Endorsement Certificate System has been adopted (GCO 1989; Man & Pang 1992).

4. ENDORSEMENT CERTIFICATE SYSTEM

4.1 *Endorsement Certificates*

Since the introduction of an Endorsement Certificate System in 1989, four Endorsement Certificates have been issued. These certificates cover HDPE geogrids manufactured in the U.K., galvanized steel ribbed strips manufactured in Australia and South Africa, and galvanized steel meshes manufactured in Hong Kong. The assessment of five types of polymer reinforcement is currently in progress.

To facilitate application of the Endorsement Certificate System to Government projects, the Hong Kong Government publishes a list of approved suppliers of Endorsed Proprietary Products for Permanent Reinforced Fill Structures. The list is updated regularly.

4.2 *Problems Faced by Applicants*

The specific items which need to be considered during the assessment of an application for endorsement of proprietary products for permanent reinforced fill structures in Hong Kong have been described by Man & Pang (1992; 1994). Based on the past experience in assessing endorsement applications, two major difficulties are faced by the applicants, which are described below.

a. *Design Temperature*

Based on local field measurement data, the design temperature for both reinforced fill wall and slope has been taken as 35°C (Howells & Pang 1989; Man & Pang 1994). This design temperature has caused difficulty to the manufacturers of polymer reinforcements, who usually evaluate their products based on a design temperature of 10°C or 20°C in the temperate climates in the European countries. Tests on the creep behaviour, stress rupture and polyester hydrolysis need to be carried out at 35°C or higher temperatures to support the applications ir Hong Kong. Some of the above tests take a long time (at least a year) to complete.

b. *Fill Material*

Direct shear tests to determine the coefficient of friction between reinforcement and soil as well as site damage tests to determine the site damage factor have to be carried out to support an endorsement application. The test results would be used to derive preliminary design values to be stated in an Endorsement Certificate. The applicants could have difficulty in finding suitable fill material in their own countries with grading limits, and physical and mechanical properties which are similar to Hong Kong soils and which comply with Geospec 2 requirements. Arrangement of such tests to be carried out in Hong Kong is sometimes necessary.

5. USE OF REINFORCED FILL STRUCTURES

5.1 *Usage*

The first reinforced fill structure in Hong Kong was constructed in 1981. The structure is a wall up to 11 m high and 60 m long. Since then, a total of 31 permanent reinforced fill structures have been completed, and about ten more structures are either being constructed or construction is due to commence. The cumulative number of structures completed over the years is shown in Figure 2.

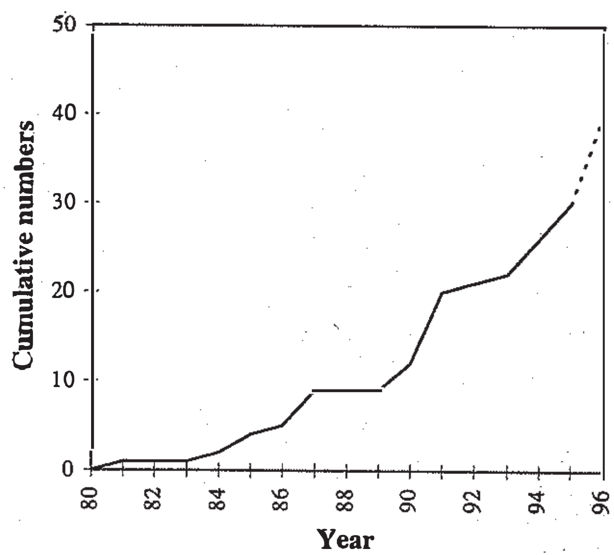

Figure 2 - Number of reinforced fill structures completed

Figure 3 shows the location of the completed reinforced fill structures in the territory. Many of the structures are situated in new towns such as Tuen Mun and Tsing Yi, which were developed in the 1980's to accommodate the increasing population of Hong Kong.

Some statistical data on the completed structures are shown Figures 4 and 5. It is not surprising that over half of the structures serve as either retaining walls or fill slopes in association with site formation

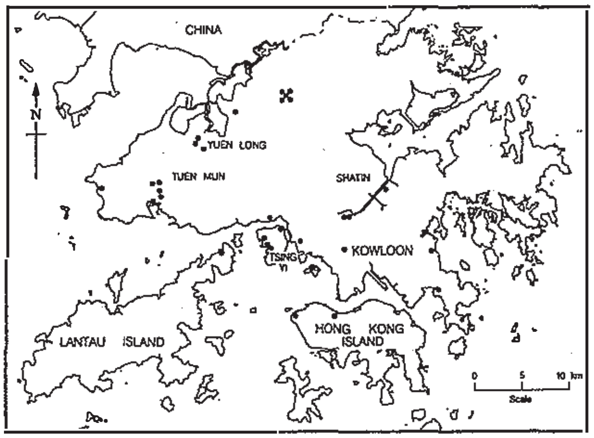

Figure 3 - Locations of reinforced fill structures in Hong Kong

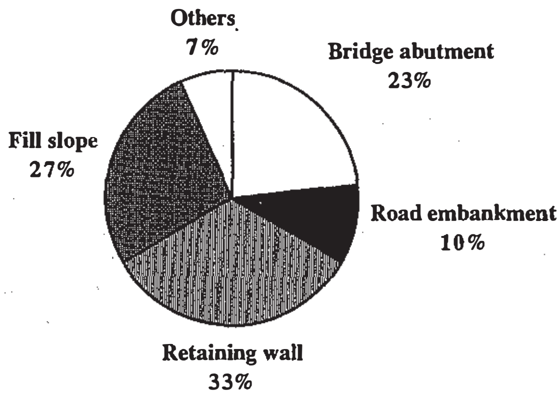

Figure 4 - Usage of reinforced fills structures

works. In the remaining ones, many are bridge abutments. Indeed, of the ten structures being constructed or due to commence construction, seven walls serve as bridge abutments. The heights of the completed structures are generally between 5 and 15 m, but the highest wall is up to about 40 m. The most common facing type is reinforced concrete panel.

The reinforced fill structures in the early days were all proposed by contractors as alternatives to the original design. The first reinforced fill wall was proposed by the contractor as an alternative to a bridge on an access road (Kennard et al 1982). The second and the third structures were replacements for a crib wall with a complex alignment and a piled bridge abutment wall respectively (Huddleston 1985).

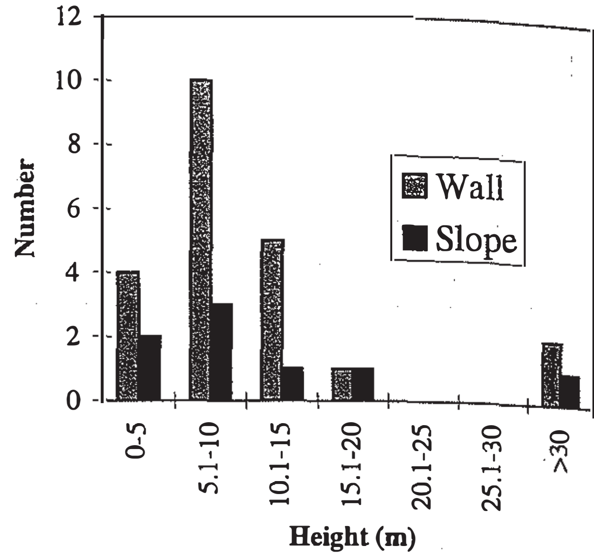

Figure 5 - Height distribution of reinforced fill structures

Most of the reinforced fill structures in Hong Kong are reinforced using galvanised steel ribbed strips. HDPE geogrids was introduced in the late 1980's. Following the endorsement of HDPE reinforcement in 1990, a total of six slopes utilising the product was constructed in 1991.

The type of backfill selected for a structure depends on the suitable material that is available near a site, e.g. completely decomposed granite. However, Hong Kong is a small area, and it is not too inconvenient to obtain fill material, e.g. crushed rock, from other places in the territory when required. The use of frictional fill is as frequent as cohesive frictional fill.

All reinforced fill structures constructed after 1989 have been designed to Geospec 2. Prior to the publication of Geospec 2, structures were generally designed in accordance with the UK Department of Transport Technical Memorandum BE 3/78 (1978). The first reinforced fill structure was designed to a combination of the French Ministry of Transport Recommendations (1979) and the UK Technical Memorandum BE 3/78 (Kennard et al 1992).

Apart from permanent structures, reinforced fill is sometimes used in temporary wall or slope construction. Ng & Mak (1988) reported the design and construction of two 14 m high reinforced fill structures for the bridge abutments of a temporary haul road to a borrow area. The abutments, with a facing inclination of 70°, was reinforced by HDPE geogrids. The facing was formed by the 'wrap round' method, and shotcrete was applied to the surface to prevent erosion.

5.2 *Construction Problems*

Much experience on the construction of reinforced fill structures has been acquired by the local contractors, and little problems have been reported. The most serious reported problem occurred in an area of the lower two tiers of a partially completed reinforced fill wall in a road project. During construction, the wall underwent severe panel displacement and loss of backfill material, as a result of a sudden built up of water pressure behind the wall during heavy rainstorm. Fortunately, the reinforcements did not suffer any significant deformation. The deflected facing panels were subsequently removed and replaced. Consequently, more emphasis has been placed on the method of control of temporary drainage behind partially completed reinforced fill structures during the course of construction.

In the early days of reinforced fill construction with the use of precast concrete facing panels, difficulties have been experienced in erecting the wall face to achieve the tolerances specified for vertical alignment (Price 1986). During construction of the first reinforced fill slope using polymer reinforcements in Hong Kong, which required wrapping back of the reinforcements at the slope face, control of the alignment of the slope face also caused some problems in the first few layers due to the lack of experience. This had resulted in some slight bulging appearance in the completed slope face. This problem was later solved by amending the construction method on site.

Soon after the publication of Geospec 2, some problems were encountered in meeting the specification on backfill material in a site formation project. The design engineer assumed in his design that the completely decomposed granite from a borrow area was a frictional fill material, based on some preliminary grading test results on the material collected from the borrow area. However, during construction, samples taken from the actual backfill on site was found to contain too much fines and the material fell into the category of cohesive frictional fill. The engineer had to review the design and carry out remedial measures.

5.3 *Performance*

The GEO keeps a record of all reinforced fill structures which it checks. Inspections of these structures were carried out annually by GEO staff until 1995. The local suppliers of endorsed products are also required to carry out an annual inspection and to provide an assessment on the performance of the completed reinforced fill structures using their products. So far, apart from minor cracking of some precast concrete facing panels in a wall due to poor detailing of the movement joints, no problem on the performance of completed reinforced fill structures has been found.

6. STUDIES

The GEO has been undertaking reviews on the behaviour of polymer reinforcements since 1989 in conjunction with the assessment of endorsement applications for polymer geogrids. The reviews on HDPE geogrids (Small & Greenwood 1993) and polyester geogrids (Greenwood 1995), which cover aspects of creep, stress rupture and hydrolysis, suggest that the geogrids can be used under the relatively humid and hot climate of Hong Kong, provided that an appropriate allowable design load is adopted.

The design temperature is a matter of concern. Temperature monitoring for reinforced fill walls with concrete facing panel and for sites with a grass cover is in progress. Having reviewed available data on soil temperature, Yeo & Pang (1996) have proposed to lower the design temperature for reinforced fill slope with a non-structural facing to 30°C.

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