LAND RECLAMATION GUIDELINE (LRG)

LAND RECLAMATION GUIDELINES OVER SOFT GROUND PART 1: SITE INVESTIGATION

1. INTRODUCTION

In the recent years, undredged reclamation has become the most favourable option due to its environmental benefits from the reduced quantity for disposal of dredged soil and additional need of sand fill material. This document discusses the reclamation design suitable for undredged reclamation over Soft Marine Deposits in Hong Kong.

The main purpose of this guideline is to develop a common understanding of design, construction, buildability aspects, quality control and assurance procedures between owner, engineer and contractor. The guideline Part 1.0 - Site Investigation includes these main topics:

1. *Identify key aspects for the Site Investigation to facilitate reclamation design;*
2. *Discuss key factors for the successful investigation, sampling and testing of the ground, based on prior experience in Hong Kong and overseas; and*
3. *Recommend best practice for design and quality control of the ground investigation.*

For reclamation purposes, the main objective of Site Investigation is to assess the following in the compressible stratum:

1. The extent and soil properties of the compressible stratum and drainage boundary;
2. Of the compressible stratum, the stress history and soil strength; and
3. The hydraulic conductivity and compressibility properties.

2. HISTORY

(Reclamation key points)

- **The geological maps present information of superficial deposits, solid geology and geological lines which provide relevant information .**
- **API can understand previous reclamation history such as location of existing / buried seawalls, filling and reclamation of the area.**
- **The literature review provides information for geotechnical parameters such as coefficient of consolidation, compression and recompression indices, etc. which are useful for reclamation design.**
- **As-built records provide information to consider in design in terms of reclamation**

2.1 Geological Map

The 1:20 000 scale geological maps are published by former Geotechnical Control Office (GCO), and edited by Geotechnical Engineering Office (GEO). The geological maps present information of superficial deposits, solid geology and geological lines. Maps are able to provide general understanding of the formation of superficial deposits (ie. Marine Deposit & Alluvium) of the surrounding area, and indicate brief information of geological history. In addition, the geological maps show the approximate isopach trend of superficial deposits (ie. thickness of superficial deposits). The ground models can be refined with existing and site-specific ground investigation data to facilitate reclamation design.

Indication of Paleo-drainage network can provide some indication of cobble / coarse materials at the Alluvium / MD interface which can be taken into account reclamation design and subsequent works.

2.2 Aerial Photographs

Aerial photographs can assist in the general assessment of the geology and development history of the site. During site investigation and desk study stage, a preliminary aerial photograph interpretation (API) survey can provide a timeline of reclamation history and extent and the location of existing / buried seawalls. Although photographs below sea level are not captured, the stereoscopical photographs of nearby ground surface can be used to identify and delineate specific ground and geological features, such as photolineaments.

(Special thanks to Clayton Chan, SW Lee, Roger Lee and SL Chiu for preparation of this guideline)

Aerial photographs taken in a time sequence can provide reference for the development history, for example, to determine the location and extent of previous filling and reclamation of the area and existing seawall. The actual extent of fill materials can then later be verified by additional ground investigation works.

2.3 Literature Review

A summary of past projects and studies can be obtained by readily available literature prepared by industry specialists and practitioners. The review provides snapshots of Hong Kong past experiences which have taken into account the ground conditions, sampling methods, operator nuances and lessons learnt.

The review also provides justification of the stratigraphy and adds to the sample size of the notable geotechnical parameters such as coefficient of consolidation, compression and recompression indices, overconsolidation ratio, fill creep, drained/undrained shear strength, soil stiffness, permeability, Poisson's ratio, Atterberg limits etc.

The following papers / journals are suggested sources of literature review:

1. Technical Papers of case histories of past reclamation projects such as Siu Ho Wan, Tuen Mun, TMCLK, Penny's Bay, Lai Chi Kok, Castle Peak; & Site preparation for the new Hong Kong International Airport, Edited by Plant. G.W., Covil, C.S. and Hughes, R.A. (1998)
2. Design Manuals: Portworks Design Manual, Canadian Foundation Engineering Manual, Geotechnical Manual for Slopes, Federal Highway Administration;
3. Proceedings of Conferences: International Conference of Soft Soil Engineering, International Conference of Soil Mechanics and Foundation Engineering, Southeast Asian Geotechnical Conference, International Conference on in-situ Measurement of Soil Properties and Case Studies; and
4. Geotechnical Journals and Institution Libraries: ASCE Journal of Geotechnical Engineering, Canadian Geotechnical Journal, and proceedings of the Institution of Civil Engineers-Geotechnical Engineering.

2.4 As-built Records

As-built records provide valuable information of existing seawall, piers & ports, culverts, channels, and outfall utilities which can be taken into account with reclamation design. The stratigraphy, dredging extent and formation of existing seawalls can help designers establish a ground improvement extent, and ensure that existing outfalls are not obstructed during filling works. With regards to a sloping seawall, the extent, orientation and composition of the core, underlayer and rock armour can be incorporated in the stability checking during removal / reclamation filling works.

3. EMPRICAL METHOD & REFERENCE

(Reclamation key points)

- **Groundwater monitoring records from existing piezometers and standpipes may assess the dissipation of excess pore water pressure with time in Clay during past reclamation. The monitoring helps verify the groundwater conditions for design and construction planning.**
- **GEO's published documents and public literature provide different empirical methods to estimate soil strength, stiffness, permeability, and consolidation conditions, useful to determine a range of geotechnical parameters.**

3.1 Water and Wave Conditions

3.1.1 Ports Works Design Manuals

For the design stage of reclamation works, environmental conditions, such as tide, water levels, bathymetry, wave and currents at study area should be considered. Particularly, water and wave design conditions are significant for assessing permanent and temporary stabilities of marine structures. Issued by CEDD, 'Port Works Design Manual' (PWDM) offers us guidance on the design reference based on local conditions and experience for marine works and structure constructions. Also, the PWDM provides useful data (such as wind data and extreme water level) for design reference.

Figure 1, Port Works Design Manual

(Special thanks to Clayton Chan, SW Lee, Roger Lee and SL Chiu for preparation of this guideline)

3.1.2 Wave Modelling

Hydraulic study should be conducted to determine design wave, current and water level parameters for the design of kerbing structures confining the reclamation, viz, breakwaters, seawalls and temporary construction structures. 2D Wave modelling, such as SWAN or Delft3D, can be used to simulate wave and storm surge conditions at study area to determine the extreme design wave conditions for reclamation, breakwater and temporary construction structures' stability design.

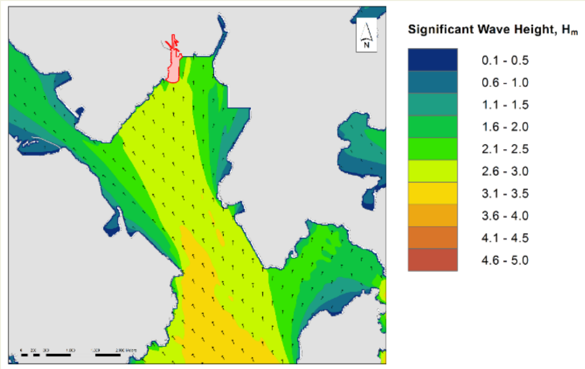


Figure 2, Wave Agitation with Typhoon Condition at Tseung Kwan O

3.1.3 Rainfall Data

Rainfall records can be obtained from the HK Observatory website. When rainfall is superimposed with groundwater monitoring data, trends observed can give indication of response magnitude and time. The tidal lag magnitudes can be assessed and subsequent reclamation design can be fine-tuned to local conditions. As the designer is made aware of groundwater trends from rainfall, the combined effects of soil permeability and site / reclamation activities on groundwater response can be distinguished to enable further investigation.

3.1.4 Tidal Levels

Predicted and recorded tidal levels can be obtained from the HK Observatory website. For design of reclamation, the designer is able to predict the draught with time to envisage vessel access to site. The designer's selection ground improvement type can take into account vessel accessibility due to draught and the construction programme can be estimated closer to site conditions.

3.2 Soil Strength

3.2.1 Skemption's Method

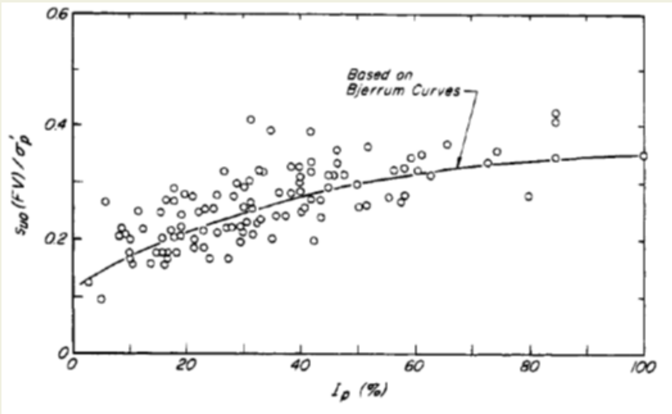
To estimate the undrained shear strength of normally consolidated marine clay prior to in-situ testing, an empirical correlation proposed by Skempton (1954b) can be used. The approximated clay shear strength can be assessed with effective overburden pressure and plasticity index as follows:

$$C_u/\sigma_v' = 0.11+0.0037I_p$$

where I_p is the Plasticity Index (%) and
σ_v' is the effective overburden pressure (kPa)

A typical empirical derivation can be adopted to estimate the undrained shear strength of normally consolidated marine deposit clay with only effective overburden pressure (Terzaghi et al, 1996). It can be used to obtain a quick estimation and comparison of the soil strength obtained from site investigation.

$$C_u=0.22\sigma_v'$$



3.2.2 GEO, HKSAR guidelines

Table 12 of Geoguide 3 provided a reference for soil description based on the undrained shear strength. With the approximate value of undrained shear strength obtained by field testing, the consistency of the marine clay can be described as following:

Soil Type	Consistency Term	Undrained Shear Strength (Cu) (kPa)
Slits and Clays	Very Soft	< 20
	Soft	20-40
	Firm	40-75
	Stiff	75-150
	Very stiff or Hard	> 150

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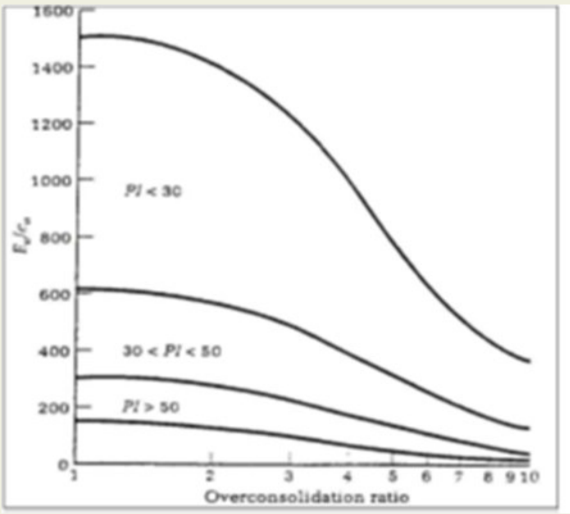
3.3 Soil Stiffness

3.3.1 Jamiolkowski

The undrained modulus (E_u) can be derived from the undrained shear strength of clay depending on plasticity and the overconsolidation ratio proposed by Jamiolkowski et al., 1979.

E.g., the soil stiffness for slightly overconsolidated Clay in the undrained conditions is E_u (MN/m^2) = 400c_u.



Extracted from Meigh (1987)

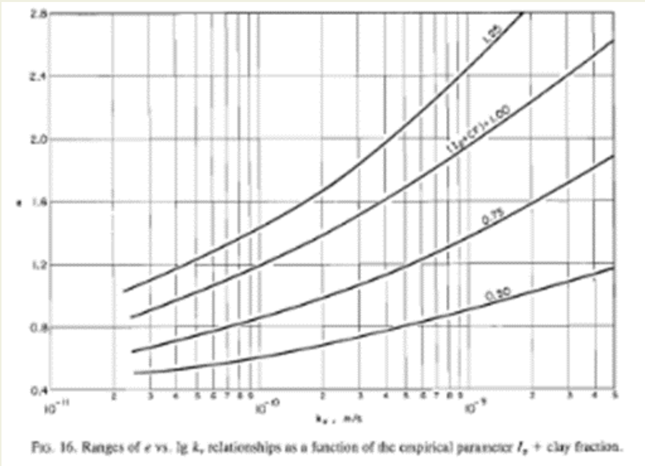
3.4 Permeability

3.4.1 Published Literatures or GEO's Technical Documents

Typical range of permeability values for compacted fill, colluvium and completely decomposed rock in Hong Kong can be found in Table 8, GEOGUIDE 1. Large quantities of site investigation and laboratory testing data for soils under Hong Kong waters were made available during the course of site preparation for the Chek Lap Kok airport (Plant et al, 1998). Though the range is wide due to soil variability, the reference information is useful for propose of preliminary design or engineering appraisal of a seepage problem, when site-specific soil property data is unavailable. For soft clay of the Hang Hau Formation, since its geotechnical properties throughout Hong Kong are fairly similar, the previous documented work can be referenced for indicative design permeability value, e.g. Plant et al (1998) and Yeung & So (2001). Alluvial deposit of the Chek Lap Kok Formation has high degree of small-scale sedimentary variability (e.g. cross-bedding, cross-cutting, channelization, etc.) and comprises layers of various grading, but when considered over a larger area, it can be sufficiently regular to adopt a single permeability value for design of larger-scale reclamation work. A detailed account of the properties of the Chek Lap Kok Formation is given by Lo & Premchitt (1998, 1999).

3.4.2 Emprical Method

Several equations were proposed to relate the permeability of granular soil to parameters commonly including effective grain size, void ratio and uniformity coefficient, e.g. Kozeny (1927), Carman (1937, 1939), Amer and Awad (1974), Chapuis (2004). Thus, for using these equations, a grain size analysis should be carried out. The empirical correlation proposed by Samarasinghe, Huang and Drnevich (1982) can be used to estimate permeability of normally consolidated clay from void ratio. This equation involves two constants that should be back analysed by curve fitting to experiment permeability test data. Tavenas et al (1983) studied the permeability characteristics of intact natural soft clays of Canada and of Sweden; and found that the variation of permeability with void ratio is best represented in terms of a linear e vs log k relationship as a function of the empirical parameter I_p and clay fraction.



After Tavenas et al 1983.

3.5 Consolidation Characteristics

3.5.1 Literature Review

For the consolidation characteristics of soils in Hong Kong, Lo & Premchitt (1998) and Premchitt, Ho & Evans (1996) have carried out studies on clays from the Chek Lap Kok Formation and published some data. CEO (2002a) also presents the typical range of various engineering properties of Marine Deposit (Clay). In addition, Chung (2015) mentions the typical range of various consolidation properties of soils in Hong Kong such as the coefficient of volume compressibility, compression index, coefficient of consolidation and the ratio of secondary compression index to compression index.

3.5.2 Settlement Monitoring

During reclamation works, monitoring will be required to provide data for assessing the settlement and the strength gain of compressible later as a function of time as well as the stability of the reclamation fill and the

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soils underneath. In general, 3 parameters are essential to be monitored, namely dissipation rate of excess pore water pressure, vertical settlement and extensometers can be adopted to monitor the surface and sub-surface movement respectively. Lateral deformations are monitored by installation of inclinometers. In active works area, monitoring data shall be taken at least daily.

The location of the monitoring instruments shall be carefully planned with considerations of the working sequence, plant operations, areas with critical geology etc. Very often, the monitoring instruments require vertical extension and protection (e.g. fenced off) as the reclamation works in progress.

The monitoring data obtained shall be used to verify the reclamation design and ensure safety on site. Various plots can be prepared with the monitoring data for different uses. For example, the excess pore water pressure can be plotted against time and changes in the vertical stress to monitor the stability of the reclamation fill while maximum height of fill can be determined by relating the lateral deformation to the filling height and time.

4. FIELD TESTING

(Reclamation key points)

- **Cone penetration tests are commonly used to identify extent and thickness of Alluvium layers. CPT also provides information for DCM and PVD ground improvement designs necessary for reclamation, along with prediction of consolidation settlement.**
- **SPT 'N' provides data for soil classification and correlation with stiffness and strength.**
- **Field testing such as vane shear test and SPT "N" value are useful to determine the undrained shear strength of fully saturated clay and the geotechnical engineering properties of subsurface soils respectively. Such field tests are complimented with laboratory triaxial compression test data and would be adopted for assessing the stability during reclamation works.**
- **Pressuremeter test can provide in-situ soft Clay stiffness parameters required to predict movement during the reclamation filling works.**
- **Constant head test and falling head test are widely used to determine the in-situ soil permeability. The soil permeability is useful for design or engineering appraisal of a seepage problem in reclamation.**

4.1 Drillhole Logging

In the initial stages of design, it is necessary to investigate and sample the ground by direct physical means such as marine drillhole logging. Various geophysical information can be obtained by this investigation method in the soil strata to form the ground models and acquire undisturbed samples for laboratory testing. The key factors for successful reclamation are to spread the sampling rationally at both pre-reclamation, during reclamation and post-reclamation stages. The stratigraphy encountered are comparably uniform throughout the site consisting of Marine Deposit Sot Clay underlain by Upper and Lower Alluvium and Saprolite. The quality and reliability of the drillhole logs is to verify its consistency with the previous ground models and CPT soil classification. The drillhole density can be tuned to further investigate the changes in stratigraphy from man-made activities such as dredging and backfilling.

To assess the sample quality, we recommend adopting $\Delta e/e0$, which is the ratio between change in void ratio measured during the test for consolidation stages up to the in-situ stress level and the initial void ratio (Lunne et al, 1997a). An indication of oedometer test sample quality can be determined and categorized to a 'very good' to 'very poor' range, indicating the degree of sample disturbance or consistency of the Clay structure.

4.2 Geophysical Survey

Application such as mapping of subsurface material interfaces, locating buried man-made objects (e.g. cables and pipelines), condition of the existing seawall, etc can be accomplished by different geophysical survey techniques such as echo sounding or side scan sonar and seismic reflection for bathymetry, seafloor topography, and sub-seafloor stratigraphy respectively (Randolph & Gourvenec, 2011). The technique of echo-sounding has been widely adopted to determine the water depth in civil projects. However, the environmental elements such as sewage-rich seabed layers and naturally gassy marine mud deposits might critically limit the effectiveness of a geophysical survey. Another major purpose for the survey is to determine the seabed level, water draught and sub-seafloor stratigraphy.

Although the precision of the survey is limited, a large data sample set can be obtained within a short period of time with relatively good frequency. Subsequently,

(Special thanks to Clayton Chan, SW Lee, Roger Lee and SL Chiu for preparation of this guideline)

seabed contours and verification with the ground model will further enhance designer's confidence of the data. Signs of heave or deep seated slip planes can be identified through geophysical survey.

4.3 Grab Sampling

Some marine deposit Soft Clay may be dredged to facilitate construction of the existing seawall or marine utilities. To determine the dredge extent, seabed material on and up to 3m below the seabed is retrieved by grab sampling. Samples, although are disturbed, are used for classification, chemical, biological screening, elutriate testing and further refining the ground model. Normally, approximately 8L of grab sample would be sufficient for laboratory testing purpose. This sampling method is carried out quickly and can cover a larger plan area to identify the change of seabed stratigraphy due to man-made activities. Or the grab sample can verify seabed obstructions identified by initial geophysical surveys.

4.4 Piezocone Penetration Test

4.4.1 Ground Model and Soil Classifications

The CPT method is widespread used mainly for the determination of soil classification in onshore and offshore areas where large amounts of data is obtained with depth. The testing cone is pushed into the ground at a constant rate and continuous data is collected from the resistance and porewater pressure. The CPT provides net cone resistance (q_n), pore water pressure (u) and when adopted the empirical cone factor (N_{kt}), the c_u is estimated with depth. The determination of N_{kt} involves theoretical, experimental and statistical correlation with laboratory test data (Lunne et al. 1997). The value of N_{kt} suggested by past studies ranges from N_{kt} = 10 to 20. Use of CPT results precisely defines the interface between Marine Deposit and Alluvium, and Upper and Lower Alluvium. The termination criteria for Deep Cement Columns (DCM) adopts also a q_n requirement. This ensures that the DCM toe terminates within competent material. CPT results also identify locations and thickness of sand lenses within the Alluvium and is taken into account in the PVD design and consolidation settlement predictions.

4.4.2 Soil Strength

Meigh (1987) reported that the piezocone penetration test (CPT) is an in-situ testing method used to determine the geotechnical engineering properties of soils and assess subsurface stratigraphy, relative density, strength and net water pressures. Besides, CPT results are often used for evaluations of soil parameter, for instances, soil stiffness, effective strength parameters and shear wave velocity (Mayne, 2007). CPT allows for measurement of excess pore pressure generated during the cone penetration. The CPT is regularly used in geotechnical investigation for reclamation works and examination of the efficacy of ground improvement works due to its efficiency and precision.

The use of CPT provides an excellent method for estimating continuous profiles of in-situ undrained shear strength (S_u) and over consolidation ratio (OCR). Estimation of su of Soft Clays using CPT results is made from a widely used correlation:

$$q_t = Nk * su + s_{vo}$$

where Nk is cone factor and s_{vo} is the total vertical stress.

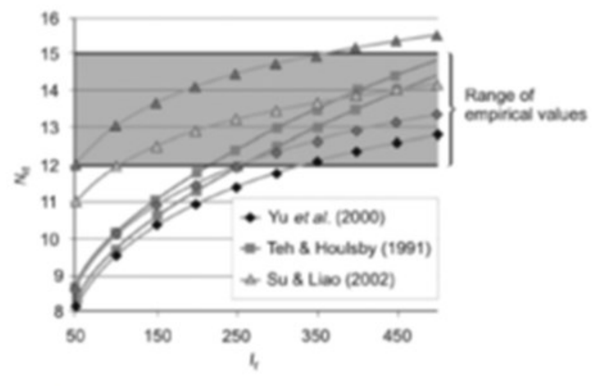


Figure 3.16 Theoretical and empirically predicted N_{kt} factors.

Extracted from Schnaid (2009)

Values of Nk range from 8 to <20, influenced by various factors including soil plasticity, OCR and the test from which su has been established (Lunne et al, 1997). Schnaid (2009) reported comparisons between theoretical and empirically predicted Nk factors which are shown above for Ir ranging from 50 to 500 and strength anisotropy ratio of 0.5 to 0.9.; where Ir is rigidity index being the ratio of shear stiffness (G) to shear strength (Su) of the soil.

It is always necessary to double check the cone porewater pressure readings from errors due to air bubbles or plugging of the cone penetrometer. In addition, it is recommended to confirm the net area ratio (coefficient of Penetrometer) as this varies with the employed ground investigation specialist contractor. As a designer, you must ensure that data is provided in proper AGS format to accommodate the large sample set and wide range of readings which are illegible with typical PDF formats. Readily available software may also be used to read, generate, interpret and report CPT readings from AGS format such as C-Petit.

Further development is recommended in future on the Penetrometer test by adopting recent development of Ball Penetrometers and/or T-bar Penetrometers (Randolph and Gourvenec, 2011).

(Special thanks to Clayton Chan, SW Lee, Roger Lee and SL Chiu for preparation of this guideline)

4.4.3 Consolidation Characteristics

The CPT dissipation test is done by measuring the dissipation rate of excessive pore pressure during a pause in the penetration. With this test, the horizontal coefficient of consolidation, c_h, can be estimated with the following formula (Robertson and Cabal, 2015):

$$c = \left(\frac{T_{50}}{t_{50}}\right) r_0^2$$

Where T_{50} = theoretical time factor; t_{50} = measured time for 50% dissipation; r_o = penetrometer radius

Sufficient number of dissipation test shall be carried out so as to provide a reasonable estimate of the coefficient of consolidation. It is also recommended to carry out the test to full dissipation to obtain the equilibrium pore pressure.

4.5 Standard Penetration Test

4.5.1 Ground Model and Soil Classifications

The application of SPT provides information to determine the classification of the ground and correlation with stiffness and strength. The reason for its wide use is that SPT is simple and inexpensive. A small disturbed soil sample would be obtained when the split barrel sampler is used. Although the sample obtained is not suitable for laboratory triaxial tests, it provides an indication of strength through the SPT "N" value.

SPT is especially useful when carried out in Fill and Alluvium for reclamation design purposes. Similar to SPT carried out on land, data should be sorted, graphed and outliers should be neglected before a suitable design line is set out. Should design strength be a function of depth, the SPT 'N' values should also be graphed vs depth below seabed level.

4.5.2 Soil Strength

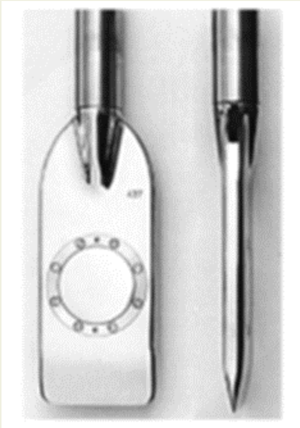
Clayton (1995) reported that the Standard Penetration test (SPT) is a widely used in-situ testing method in determining the geotechnical engineering properties of subsurface soils. It is a simple and inexpensive test to estimate the relative density of soils and approximate shear strength parameters.

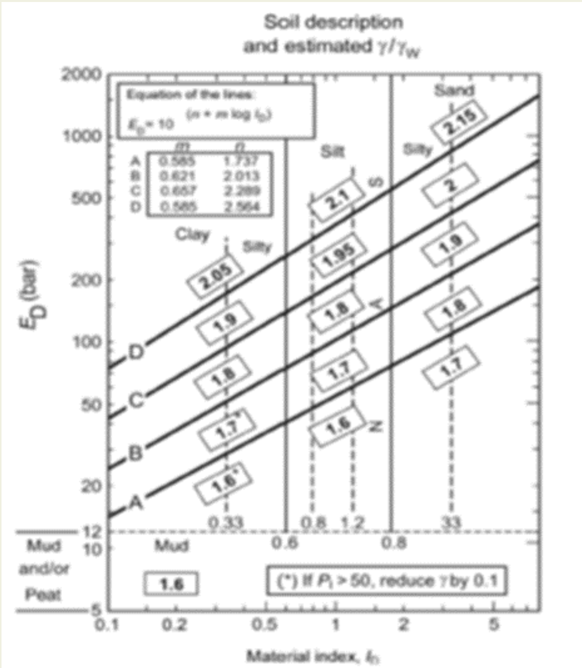
The test is extremely useful for determining the relative density and the angle of shearing resistance of cohesionless soils. It can also be used to determine the shear strength of cohesive and non-cohesive soils Clayton (1995).

In Hong Kong Practice, the SPT test in Saprolite is terminated where a maximum blow count of 200 is reached.

4.6 Flat Dilatometer Tests (DMT) (SPT 'N')

The DMT method is also commonly used for soil classification by the determination of soil stiffness with DMT. The equipment and method were developed in Italy by S. Marchetti in the 1990s (Marchetti, 1980). The front and side views of the dilatometer steel blade and pressure supply unit are shown below:





DMT results are presented in terms of 3 calculated parameters obtained from the test, namely material index, I_D; Horizontal Stress Index, K_D; and Dilatometer Modulus, E_D. Marchetti and Crapps (1980) proposed a chart for soil classification against the DMT parameters (Marchetti et al, 2001).

(Special thanks to Clayton Chan, SW Lee, Roger Lee and SL Chiu for preparation of this guideline)

4.7 Standpipe and Piezometers

Standpipe and Piezometer monitoring measure the ground water level and the piezometric pressure response at a certain depth of their installation. For the purposes of reclamation, there are three main functions of adopting groundwater monitoring results: 1. Measuring the tidal effects on existing land or newly reclaimed land, 2. assessing the performance of ground improvement works, for instances, PVD, deep cement mixing, etc., and the associated dissipation of excess porewater pressure in the soil under consolidation, and 3. evaluating the gain in the effective vertical stress of the soil with time.

A key factor to successful investigation is to correlate the groundwater monitoring with the geological profile, construction activities and boundary conditions, for instance, and proximity to the seawall. To suit the kinetic characteristics of reclamation works, necessary measures should be taken to protect the instrumentation from damage by construction activities and to facilitate instrumentation monitoring at different stages of lift in fill level. We recommend locating the piezometers at different levels throughout the Marine Deposit Clay, and the underlying foundation layers; and observation wells within the Fill layer.

4.8 Vane Shear Test

The vane shear test (VST) is an in-situ testing method used to determine the undrained shear strength of fully saturated clays with minimal disturbance. The test is common in geotechnical investigation as it is relatively simple and quick. It also provides a cost-effective way to estimate the soil shear strength. Moreover, the undisturbed and remoulded strength are useful for evaluating the sensitivity of soil.

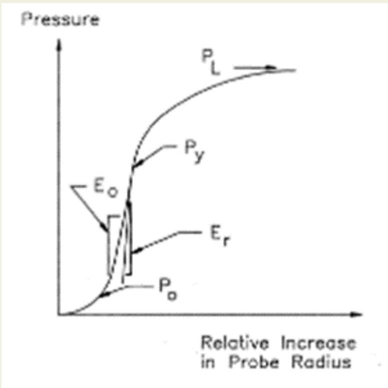
The test is done by rotating the vane in the soft soil at a designated rate and measuring the torque at regular time intervals until a maximum torque is reached. The vane will then rotate rapidly for several revolutions and the soil will fail in shear on a cylindrical surface around the vane.

The undrained shear strength of the saturated soil is proportional to the applied torque and the dimensions of the vane. The undrained shear strength, Su, is calculated by equating the torque to the moments corresponding to the total shear strength over the sides and the ends of the shear failure surface.

The Su value determined by VST should be corrected based on Bjerrum curves and based on the Clay Plasticity Index (Chandler, 1998). Furthermore, the Su should be reviewed in conjunction with related parameters such as cross check with laboratory Triaxial Compression Tests (Chandler, 1988), calibration with CPTs, and compared with those documented in the literature review (Meigh, 1987).

4.9 Pressuremeter Test

Pressuremeters are devices for carrying out in situ testing of soils and weak rocks for strength and stiffness parameters. With test conducted in a pre-bored hole (for instance, Menard pressuremeter (Mair & Wood, 1987), the test can be carried out in either stress control or strain control procedure. The initial cavity pressure would be equal to the in-situ total horizontal stress. The initial volume of the cylindrical cavity can be calculated from the initial cavity radius and the height of the pressuremeter cavity. In the initial part of loading, it is assumed that soil behaves elastically and obeys Hooke's law until the onset of yielding. Using a small strain theory in cylindrical coordinates, the change of volume can be determined. Typical data from a Menard pressuremeter test is shown below:



Where E_o is a first loading modulus, E_r a first reload modulus, P_o the horizontal at-rest pressure, P_y the yield pressure, and P_L the limit pressure.

With a push-in pressuremeter, for instance, Flat plate dilatometer (Marchetti, 1980), this testing method provides valuable in-situ Soft Clay strength and stiffness parameters which will facilitate the prediction of movement during the reclamation filling works.

4.10 Constant Head and Falling Head Test

Variable head or constant head permeability test conducted with casing in a drillhole during site investigation, or with using a piezometer in a borehole are the most widely used and economical method to evaluate in-situ soil permeability. The advantages of field test include that soil zone being tested are subjected to less disturbance and more representative of the mass property (as some soil types may be largely heterogeneous and anisotropic that laboratory test on a small sample would give biased result). It should be noted that where the test location is hydraulically connected with tidal or other watercourse, fluctuating water readings may occur. In such case, variable head method should be used with the calculation performed on the initial (straightest) portion of the H/H_o curve, which is unlikely to be affected significantly affected by

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head fluctuations (as there typically occur at a much slower rate). More information about types of field permeability test and their applications can be referred to Geoguide 2 - Guide to site investigation (GEO, 2017b).

5. LABORATORY TESTING

(Reclamation key points)

- **Determination of moisture content, atterberg limits, particle size distribution and void ratio by laboratory testing provides information to classify Marine Deposit or Alluvium.**
- **Direct shear test and triaxial compression tests can determine the stress-strain behaviour of Marine Deposit and Alluvial Clay. The results of direct shear test can facilitate reclamation stability assessment.**
- **Consolidation properties such as coefficient of volume compressibility, compression index, coefficient of consolidation, etc are useful to predict the consolidation settlement in reclamation design.**
- **A plot of void ratio against the logarithm of effective stress can determine whether the soil is over-consolidated or normally consolidated.**

5.1 Moisture Content

The moisture content (MC) of a soil is defined as the amount of water within the pore space between the soil particles that can be removed by oven drying at 105-110°C. The MC facilitates classification of Marine Deposit and Alluvium. Approximate range of Compression Ratio CR = $C_c/(1 + e_0)$, Coefficient of Secondary Compression (or Creep), C_α can also be correlated from the sample's MC (Fadum, 1941).

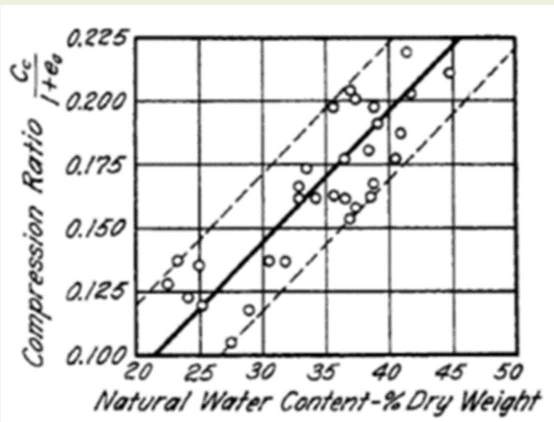
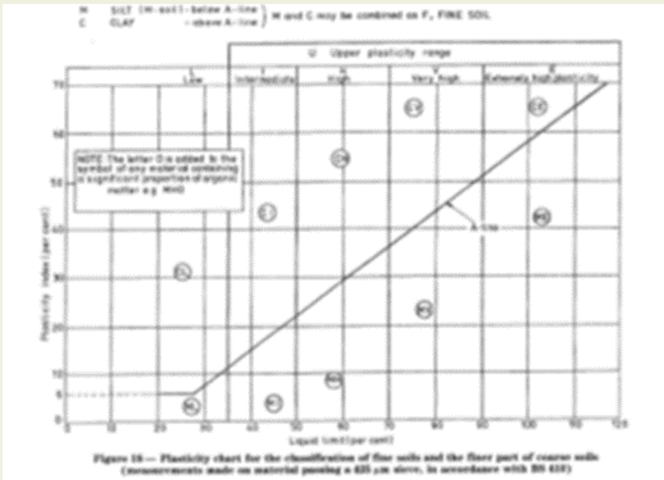


Table 16.1 Values of C_α/C_c for Geotechnical Materials

Material	C_α/C_c
Granular soils including rockfill	0.02 ± 0.01
Shale and mudstone	0.03 ± 0.01
Inorganic clays and silts	0.04 ± 0.01
Organic clays and silts	0.05 ± 0.01
Peat and muskeg	0.06 ± 0.01

5.2 Atterberg Limits and Indices

Moisture content by itself cannot define the associated engineering behaviour of a clay soil, it therefore requires reference indices (Atterberg Limits) to identify the effects of the moisture content. Atterberg limits include Shrinkage Limit (SL), Plastic Limit (PL) and Liquid Limit (LL). With the A-Line plot of Plasticity Index (PI) against LL on the Casagrande plasticity chart, fine-grained soils can be classified into main terms of silt or clay with levels of plasticity (BS 5930, 1999). In general, clay with high level of plasticity is more compressible and require a longer period of time for consolidation than clay with low level of plasticity.



5.3 Particle Size Distribution

In lieu of soil classification, it is common that the grading of fill material for marine works is controlled due to the variability of imported material. The particle size distribution of reclamation fill is typically controlled such that the material is not susceptible to volume change. The fill types for site preparation of the Hong Kong International airport built in the mid 1990s (Plant et al, 1998) are shown for example:

(Special thanks to Clayton Chan, SW Lee, Roger Lee and SL Chiu for preparation of this guideline)

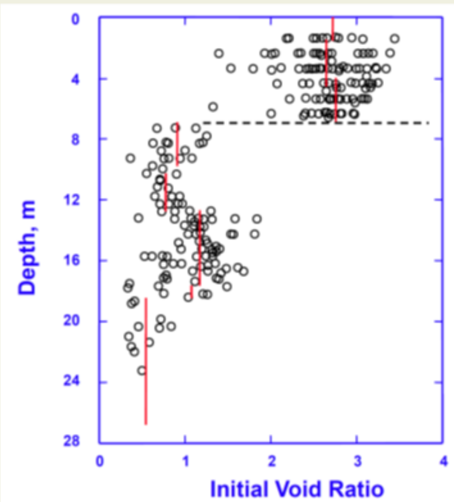
Type A	As-blasted rock with a maximum size of 2000 mm and a fines limit of 5%.
Type B	Excavated soil or rock with a maximum size of 300 mm. This material is described as "pileable" in that heavy piling can be driven through it.
Type A/B	A mixture of Type A and Type B fill which was not included in the original SPC specification. This material type evolved from a request by the contractor in order to avoid delays to the excavation components of the contract. Although predominantly Type A material, it was highly variable in nature.
Type C	Sandfill with a fines content of 20% or less, generally placed wet, and won from marine sources.
Type D	Rockfill for seawalls, not coarser than Type A nor finer than Type E, assumed to be quarry run material with 5% fines limit.
Type E	Rockfill as blasted, crushed, and/or screened, as necessary with a maximum size limit of 150 mm and intended for use in areas to be re-excavated or piled later.
Type F	Completely Decomposed Granite (CDG) with a maximum size limit of 200 mm.

The particle size distribution also provides some indication of the source of Fill, and will help plan proposed improvement methods.

5.4 Void Ratio

5.4.1 Ground Model and Soil Classifications

Void ratio is an important parameter for consolidation characteristics. The rate of change in void ratio governs the consolidation settlement and the surcharge period in the reclamation design. The void ratio also relates to the permeability of the soil (Koutsoftas et al, 1987). The initial void ratio (e_o) also provides indication of the soil type: Marine Deposit e_o=2-3 and Alluvium (Chek Lap Kok Formation) e_o = 1.5-2.5.



5.4.2 Consolidation Characteristics

The initial void ratio is one of the primary parameters for estimating consolidation settlement when soils are under loading and can be calculated with the following formulae, GEOSPEC 3 (GEO, 2017a):

$$e_0 = \frac{\rho_s}{\rho_{do}} - 1$$

Where p_s = particle density; p_{do} = initial dry density

The dry density, ρ_d, can be determined with the following relationship with the bulk density, ρ, and moisture content, w of the specimen:

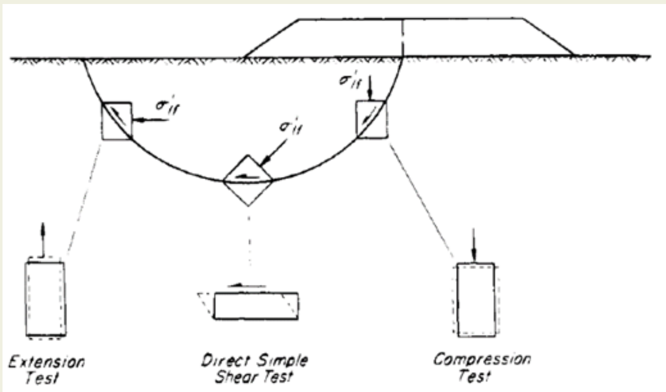
$$\rho_d = \frac{100\ \rho}{100 + w}$$

5.5 Triaxial Tests

Geospec 3 (GEO, 2017) provides model specification for soil testing that is commonly adopted in the local practice. Laboratory testing produces relatively consistent results as testing is carried out in a controlled environment adopting predetermined stress conditions. Triaxial Compression tests are well suited with homogeneous soils such as Marine Deposit Clay.

The testing data is highly sensitive to the effects of sample disturbance which may incorrectly classify the Clay as normally consolidated and underestimate the compression index.

The undrained shear strength depends on the mode of shear that occurs along the slip plane during the reclamation filling works. The undrained shear strength mobilized in different directions can be measured by laboratory shear tests that simulates distinct modes of shear as indicated in the figure below.



5.5.1 Unconsolidated Undrained Triaxial Compression Test

The triaxial compression test is carried out to measure the shear strength of a soil sample under compression. The unconsolidated undrained compression test (UU) is a total stress test to determine the undrained shear strength (s_u) of the clay. Confining pressure (σ_3) is applied on the soil sample without drainage of pore water known as the minor principal stress, followed by incremental axial stress(σ_1) until the specimen fails. As the dissipation of water is not allowed on the unconsolidated undrained triaxial compression test, the test can be done quickly. For reclamation design, testing of Marine Deposit Clay by UU is carried out as a

(Special thanks to Clayton Chan, SW Lee, Roger Lee and SL Chiu for preparation of this guideline)

necessity. The data obtained by UU can be assessed with field testing data from CPT and VST.

Noting the potential disturbance of the sample during drilling, sampling and storage, the UU remains a reliable method of testing to determine the S_u which is used to assess the slip failure stability in Marine Clay during reclamation filling works.

5.5.2 Consolidated Undrained Triaxial Compression Test

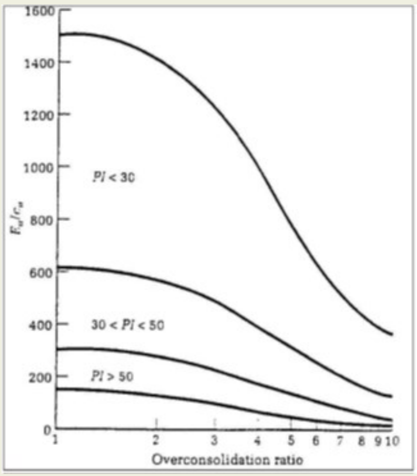
The purpose of the consolidated undrained triaxial compression test is to determine both the undrained and effective shear strength. The confining pressure is kept constant and additional axial stress (σ'1) is added slowly under undrained conditions with pore water pressure measurement. In the consolidation, the dissipation of water is allowed, thus the volumetric strain is measured; however, the shear stage is in undrained condition and excess pore water pressure is generated. Both the stress, strain and excess pore water pressure are measured to compute both the total stress path and effective stress path. As the dissipation of water takes time in the consolidation stage, the consolidated undrained triaxial compression test takes a longer time to complete. The long-term soil strength in Alluvium and Marine Deposit is adopted for assessing the stability of the proposed seawall in the permanent condition.

5.5.3 Triaxial Extension Test

The procedure of triaxial extension test is similar to that of triaxial compression test, except the decreasing axial stress but in need of special set up at the top cap of triaxial apparatus; therefore, triaxial extension test is less common than compression test in conventional practice of laboratory testing. Triaxial extension test tends to give a lower value of Cu but a higher value of Φ'cs under careful control. The ratio of Cu value obtained from extension test and compression test is about 0.7 to 0.85 for value of Φ'cs varying from 30 to 15 degrees according to the critical state theory of soils (Atkinson, 2007).

5.6 Direct Shear Test

The main purpose of the direct shear test is to determine the stress-strain behaviour of Marine Deposit and Alluvial Clay and determine the undrained shear strength. The direct shear test allows large strain and provides a stress-strain curve, and the peak which defines the mobilized strength. The results of the direct shear test can facility reclamation stability assessment. The normal load applied to the test sample should be prescribed and representative of site conditions. It is based on the in-situ stress or the anticipated stress in the permanent conditions.



5.7 Oedometer Test

5.7.1 Permeability

Where laboratory odeometer test is carried out for a fine -grained soil specimen, the coefficient of permeability in vertical direction (k_v) can be back calculated from the test results of coefficient of consolidation with vertical drainage (C_v) and coefficient of volume compressibility (M_v) theoretically. For soft clay of the Hang Hau Formation, where macro-fabric is not well pronounced and can largely be considered as homogeneous, the permeability in horizontal direction (k_h) may be reasonably assumed to be $1.5k_v$, as supported by data in some previous case studies, for instance, Yeung & So (2001).

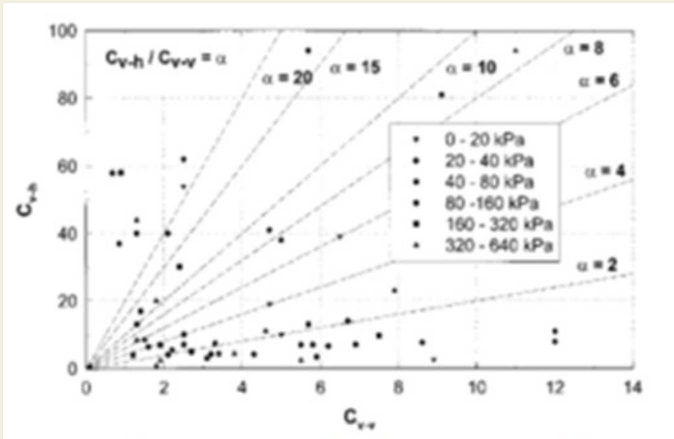


Figure 9. $C_{v\text{-}h}$ versus $C_{v\text{-}v}$ for Hong Kong marine clays

After Yeung & So (2001).

Rowe cell test with controlled radial drainage condition should also be carried out on some soil samples since the results enable k_h to be back calculated directly from the test results of coefficient of consolidation with horizontal drainage (C_h) and M_v.

(Special thanks to Clayton Chan, SW Lee, Roger Lee and SL Chiu for preparation of this guideline)

5.7.2 Consolidation Characteristics

Oedometer test is a common test for determining the one-dimensional compression and consolidation properties of soils (GEO, 2017a). Various parameters including the vertical coefficient of consolidation, the coefficient of volume compressibility, the coefficient of secondary compression, the compression index and pre-consolidation pressure can be determined with this test. A typical test comprises 4 to 6 loading stages and 2 to 3 unloading stage, with each applied stress being doubled or quartered that of the previous stage respectively. The initial pressure which shall be specified before the test shall also depend on the soil type (GEO, 2017). When carrying out the test on soft soils, high quality piston samples shall be used since the consolidation and compressibility properties of soils can be seriously affected by the disturbance of soft soils.

5.8 Pre-consolidation Pressure and Over-consolidation Ratio

Pre-consolidation pressure is defined as the maximum effective vertical stress that has acted on the soil in the past while the over-consolidation ratio (OCR) is defined as the ratio of the pre-consolidation pressure to the present effective vertical stress. When the OCR of soil is greater than 1, we say the soil is over-consolidated. Possible causes of over-consolidation include preloading and fluctuation of groundwater table. The pre-consolidation pressure can be determined based on the plot of void ratio versus the logarithm of effective vertical stress from the results of oedometer test (ASTM D 2435-04). For details of oedometer test, the previous paragraph shall be referred to.

5.9 Rowe Cell

Rowe Cell Test is similar to the Oedometer test which can be used to determine the consolidation and compressibility properties of soils and can accommodates larger soils samples, and is less sensitive to sample disturbance. Although it is not as common as the oedometer test in Hong Kong, it has several advantages over the traditional oedometer tests, including less vibration effects, allowing measurement of pore water pressure, allowing application of back pressure to simulate the in-situ condition etc. (Premchitt, Ho & Evans, 1996), and thus it may provide more representative results.

6. POST-RECLAMATION INVESTIGATION

(Reclamation key points)

- **Monitoring during the post reclamation stage may include pore water pressure, vertical settlement andlateral deformation are reviewed to assess the performance of the reclamation works and verify initial design assumptions.**

The site investigation and subsequent assumptions at the pre-reclamation stage is verified at the post-reclamation stage. Investigation is often carried out to (1) confirm the subsurface stratigraphy; (2) to evaluate change in consolidation characteristics including OCR, compressibility indices, and pre-consolidation pressure; And (3) to monitor ground response, performance of the design, and impacts to surrounding by the installation of marine and land instrumentation.

6.1 Subsurface Stratigraphy

Sampling drillhole logging is recommended to be done after the completion of reclamation. This serves to confirm the sub-layered soil is settled as per calculation with or without the installation of PVDs and/or DCM. The change in soft soil thickness could also be determined as to verify the reclamation design.

6.2 Consolidation Characteristics

The degree of consolidation is measured by determining its remaining depth after time t to its final depth ($U = S_{tt}/S_{tf}$). Other factors such as OCR, pre-consolidation pressure, and compressibility indices are found by carrying out oedometer test based on the soft soil samples collected from the drillhole logging (details could be referred to previous paragraph).

6.3 Marine and Land Instrumentation Monitoring

Marine and land instrumentation monitoring are required to monitor the serviceability performance. These data include change in pore water pressure, ground settlement, lateral displacement of structural elements, groundwater level, and functionality of installed components such as DCM's integrity. Continuous monitoring should be implemented to ensure the reclamation design performs as predicted during the construction works.

(Special thanks to Clayton Chan, SW Lee, Roger Lee and SL Chiu for preparation of this guideline)

7. SUMMARY

This technical note provides an outline of Site Investigation for Reclamation Works. Although this document provides an introductory base to suit reclamation design, its objective is primarily to provide awareness of industry standard site investigation methods in addition to providing an overview for the seasoned practitioner.

This document will be continuously fine-tuned and kept up-to-date. We at AGS(HK) welcome any suggestions on updates, amendments or additions.

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