Review of Corrugated Sheathing for Corrosion Protection of Steel Soil Nails

GEO Report No. 315

Halcrow China Limited

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
Special Administrative Region

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Review of Corrugated Sheathing for Corrosion Protection of Steel Soil Nails

GEO Report No. 315

Halcrow China Limited

This report was originally produced in April 2013 as Agreement No. CE 29/2009 (GE)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

First published, September 2015

Prepared by:

Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Preface

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

The Geotechnical Engineering Office also produces documents specifically for publication in print. These include guidance documents and results of comprehensive reviews. They can also be downloaded from the above website.

The publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

H.N. Wong
Head, Geotechnical Engineering Office
September 2015

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Foreword

Long-term performance of soil nails depend on their ability to withstand corrosive attack from the environment. Due to its durability and water tightness, corrugated sheathing is one of the measures commonly used in an aggressive soil condition to protect the steel bars in a soil-nail system from corrosion during the design life.

This report documents the findings of a review of both international and local standards related to material requirements when corrugated sheathing is used for corrosion protection. The working mechanism of corrugated sheathing in soil nails, together with the related material properties, is discussed. Key material properties and properties of corrugated pipes are reviewed and their corresponding testing criteria recommended for material selection. The study recommends thirteen parameters that should be tested for quality control, in which nine are material tests and four are tests on final product. Further laboratory trial tests are necessary to investigate the practicality of carrying out the recommended tests in Hong Kong.

The report was prepared by Halcrow China Limited as part of the Consultancy Agreement No. CE 29/2009 (GE) “Landslip Prevention and Mitigation Programme, 2009, Package C, Natural Terrain Hazard Mitigation Works, Lantau and Outlying Islands - Investigation, Design and Construction” for the Geotechnical Engineering Office, Civil Engineering and Development Department. C M Wong & Associates Ltd. was appointed as the sub-consultant for conducting this study.

H.W. Sun
Ag. Chief Geotechnical Engineer/Standards & Testing

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Contents

Page No.

Table of Contents
Table of Contents
Table of Contents

Page No.

Table of Contents
Table of Contents
Table of Contents

List of Tables

Table of Contents
Table of Contents
Table of Contents

Table of Contents

Table of Contents

Table of Contents

Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

List of Figures

1 Introduction

Halcrow China Limited has been commissioned by the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department to undertake Consultancy Agreement No. CE 29/2009 (GE) “Landslip Prevention and Mitigation Programme, 2009, Package C, Natural Terrain Hazard Mitigation Works, Lantau and Outlying Islands - Investigation, Design and Construction”. One of the services to be provided by the Consultant is to conduct a study on testing requirements of corrugated sheathing for corrosion protection of steel soil nails. C M Wong & Associates Ltd. was appointed as the sub-consultant for conducting this special task.

In this study, the following tasks have been carried out:

(a) a review of international and local standards and specifications has been made to study the material requirements that a corrugated sheathing, if used for corrosion protection, should meet;

(b) a recommended list of required material properties has been prepared and tabulated together with the acceptance criteria and test methods; and

(c) fabrication details and storage for corrugated sheathing have also been reviewed.

2 Objectives of the Assignment

2.1 Primary Objectives

As set out in Item (h) of Clause 6.2(vi) of the Brief, the Consultants shall carry out a study to develop new material/product specifications and compliance testing for corrugated sheathing used in corrosion protection of steel soil nail reinforcement.

2.2 Main Tasks of the Study

The major tasks of the study are set out in Items (i) to (vi) of Clause 6.2(vi)(h) of the Brief, as follows:

(i) review the latest international standards on material properties and testing methods of corrugated sheathing used in the corrosion protection of steel reinforcement for, including but not limited to, soil nails, ground anchors and bridge tendons;

Table of Contents
Table of Contents
Table of Contents
Table of Contents

(ii) review the current specification on corrugated sheathing for double corrosion protection of soil nails given in the Particular Specification and General Specification for Civil Engineering Works (GS), examine the rationale of each material property to be tested and benchmark the requirement with international standards, and propose a new material specification, including material properties to be tested, testing methods and acceptance criteria;

(iii) review the adequacy of the current arrangement of material compliance testing on site for corrugated sheathing and propose a new material compliance testing arrangement, including material properties to be tested, testing methods, frequency of testing and acceptance criteria;

(iv) review the adequacy of the current corrugated sheathing fabrication details in forming a continuous protection for soil nail steel bar and propose improvement and specification of the details;

(v) review the adequacy of the current material storage and handling practice of corrugated sheathing and propose improvement and specification on material handling and storage; and

(vi) plan, arrange and supervise site trials on soil-nailed slope with corrugated sheathing to demonstrate the practicality of the new specification and material compliance testing.

General Specification for Civil Engineering Works (CEDD, 2006) states that, for soil nails with double corrosion protection, "plastic sheathing and all associated components shall comply with the requirements as stipulated in Table 2 of the Model Specification for Prestressed Ground Anchors (GEOSPEC 1)". No clauses in the Particular Specification normally used for LPMit works are related to corrugated sheathing. Therefore, the review of the current specification used in Hong Kong is mainly based on Table 2 of Geospec 1 (GCO, 1989).

Items (i) to (v) above have been carried out under this study and the results are presented in this report. The site trials as stated in Item (vi) above have not been carried out under this study. The site trials would be carried out in-house by LPM Division 3's contractor. However, field test has been carried out under this study to facilitate the review of the criterion for the softening point of corrugated sheathing.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

3 Corrosion Protection of Soil Nail

Corrosion protection is of great importance for soil nails since their long-term performance depends on the ability to withstand corrosion attack from the surrounding soils. Corrosion protection of the steel reinforcement can be enhanced by:

(a) preventing the essential elements of corrosion (i.e. oxygen and water) from reaching the steel reinforcements; and

(b) limiting the diffusion of CO_2 and SO_2 to the grout within the corrugated sheathing, thus reducing the rate of corrosion.

The principles of corrosion protection are given in Appendix A.

A number of provisions are available to mitigate the effects of corrosion of soil nails. These include (Shiu & Cheung, 2003):

(a) cement grout;

(b) sacrificial thickness to the steel;

(c) sacrificial metallic coating on the steel;

(d) non-metallic coating on the steel; and

(e) corrugated sheathing.

Depending upon the site condition, one or more of the above provisions could be adopted. Normally, the first four methods are employed to offer low levels of corrosion protection. Their functions are given in Shiu & Cheung (2003). Corrugated sheathing is used in conjunction with cement grout when a high level of corrosion protection is required.

In Hong Kong practice, for soil nails installed in highly aggressive ground or aggressive ground with a design life up to 120 years, Class 1 corrosion protection scheme should be employed for protecting the steel bars against corrosion (GEO, 2008). The corrosion protection is provided by means of hot-dip galvanizing with a minimum zinc coating of 610 g/m^2 plus corrugated sheathing. The steel bar is grouted inside the corrugated sheathing. The annulus between the sheathing and the drillhole wall is also grouted with cement. The use of corrugated sheathing, as long as it is intact without cracks or voids on the surface, provides an additional barrier to prevent groundwater, air and chloride ions from reaching the steel reinforcement, thus enhancing the resistance against corrosion (FIP, 1986; fib, 2000; Shiu & Cheung, 2003; GEO, 2008).

The corrugated sheathing used shall (FIP, 1986; fib, 2000):

Table of Contents
Table of Contents
Table of Contents
Table of Contents

(a) have an effective life at least equal to that required for the soil nail;

(b) not adversely affect the environment or the efficiency of the soil nail;

(c) not fail under stress due to mobilization of forces in the soil nailed slope; and

(d) be tough enough to withstand handling during manufacture, transportation and installation.

To fulfil the requirements above, a corrugated sheathing used in a soil nail system for corrosion protection should have adequate durability, environmental compatibility, strength and good operability. Consequently, it is worthwhile to have a list of properties to be tested for quality assurance and control. To achieve this, a detailed review of relevant overseas and local standards and specifications has been made and the findings are presented in Section 4 of this report. Based on the review and additional analysis, Section 5 recommends the testing requirements and acceptance criteria of corrugated sheathing used for corrosion protection of soil nails.

4 International Review and Recommendations on Required Properties of Corrugated Sheathing

4.1 Review Summary and Discussions

A review of the available literatures indicates that several organizations have developed their own requirements of corrugated sheathing used for corrosion protection. In total, nine sets of local and overseas guidance documents/standards have been reviewed. Among them, three are related to plastic ducts used for corrosion protection in a soil nail system, four are for ground anchors and two are for other applications such as post-tensioning tendons. These guidance documents and standards are discussed in the following paragraphs.

Based on the guidance documents and standards reviewed, the materials commonly used to produce corrugated sheathing are Polyvinyl Chloride (PVC), High Density Polyethylene (HDPE), Polypropylene (PP) and Polyethylene (PE). Table 4.1 summarizes the specifications and the corresponding required testing properties for corrugated sheathing.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4.1 Local and International Material Requirements of Plastics to Be Used as Corrugated Sheathing for Corrosion Protection

	Application	Soil Nails				Ground Anchors					Post-tensioning Tendon		
	Literature	GEO (2008)	Clouterre (1991)	Lazarte et al (2003)		Sabatini et al (1999)		BS 8081:1989 (BSI, 1989) (1)	FIP (1986)	AASHTO (2010)	Corven & Moreton (2004)		fib (2000)
	Publisher	CEDD, HK	FHWA, USA	FHWA, USA		FHWA, USA		BSI, UK	FIP, Switzerland	AASHTO, USA	FHWA, USA		fib, Switzerland
	Specifications/references for Corrugated sheathing	CEDD (2006) & Table 2 of Geospec 1	French Recommendations on Ground Anchors - TA 86	- AASHTO M252-09 (2) (HDPE) - ASTM D1784 (PVC) (Class 13464-B)		- AASHTO M252-09 (2) (HDPE) - ASTM D1784 (PVC) (Class 13464-B)		CP312:1973 Part 1 (BSI, 1973) (3) & Table 2 of Geospec 1 (3)	Table 2 of Geospec 1 (4)	AASHTO M252 - 09 (HDPE)	- ASTM D3350 (PE) (344434C) - ASTM D4101 (PP) (PP0340B44544 to PP0340B65884)		- Table 3.1 of Report
	Material	PVC, PP & HDPE	PP & PE	HDPE	PVC	HDPE	PVC	PVC, PP & HDPE	PVC, PP & HDPE	HDPE	PE	PP	HDPE & PP
Criteria	Thickness	1 mm	-	1 mm	0.8 mm	1 mm	1 mm	0.8 - 1.5 mm	-	0.8 mm	-	-	-
	Density	✓	"French Recommandations on Ground Anchors" cannot been found					✓(3)	✓(4)		✓		✓
	Tensile Strength	✓			✓		✓	✓(3)	✓(4)		✓	✓	✓
	Vicat Softening Point	✓						✓(3)	✓(4)				✓
	Hardness	✓						✓(3)	✓(4)				✓
	Brittleness Temperature	✓						✓(3)	✓(4)				
	Environmental Stress Cracking Resistance	✓		✓		✓		✓(3)	✓(4)	✓	✓		✓
	Fungal Resistance	✓						✓(3)	✓(4)				
	Bacteria Resistance	✓						✓(3)	✓(4)				
	Water Absorption	✓						✓(3)	✓(4)				
	Hydrostatic Pressure Resistance	✓						✓(3)	✓(4)		✓		
	Pipe Stiffness			✓		✓				✓			
	Pipe Flattening			✓		✓				✓			
	Brittleness			✓		✓				✓			
	Elongation at Break												✓
	Izod Impact Resistance				✓		✓	✓(3)				✓	
	Elastic Modulus				✓		✓						✓
	Deflection Temperature under Load				✓		✓					✓	
	Flammability				✓		✓						
	Long Term Stress Rating							✓(3)					
	Thermal Conductivity							✓(3)					
	Volume Resistivity							✓(3)					
	Melt Mass-flow Rate/Melt Flow Index										✓	✓	✓
	Flexural Modulus										✓	✓	
	Indentation Test												✓
	Charpy Impact Strength of Notched Specimens												✓
	Tensile Impact Strength of Notched Specimens												✓
	Linear Expansion-coefficient							✓(3)					✓
	Carbon Black Content												✓
	Homogeneousness												✓
	Pitch and Amplitude of Corrugation							✓	✓				

Notes:
(1) Only those parts that deal with the construction (or 'execution') of ground anchors are superseded by BS EN 1537:2000 (BSI, 2000).
(2) The standard specification is designed for drainage pipe.
(3) BS 8081:1989 states that "CP312: Part 1 provides general guidance on choice of material" and adopts the requirements specified in GCO Publication No. 3/84 in its Appendix K.
(4) Table 2 of Geospec 1 is included in the literature "for information".

Remarks:

PVC - Polyvinyl Chloride
HDPE - High Density Polyethylene
PP - Polypropylene
PE - Polyethylene
Geospec 1 - GCO (1989)
AASHTO M252-09 - AASHTO (2009)
ASTM D1784 -08 - ASTM (2008a)
ASTM D3350-08 - ASTM (2008b)ASTM D4101-09 - ASTM (2009a)
AASHTO - American Association of State Highway and Transportation Officials
BSI - British Standard Institution
FHWA - Federal Highway Administrationfib - International Federation for Structural Concrete
FIP - International Federation for Prestressing
GCO Publication No. 3/84 - GCO (1984)

Table of Contents
Table of Contents
Table of Contents

Hong Kong

Table 2 of Geospec 1 (GCO, 1989) lists the requirements for selecting corrugated sheathing to be used for corrosion protection of ground anchors. In Hong Kong practice, this table is also used for soil nails. General Specification for Civil Engineering Works (CEDD, 2006) states that, for soil nails with double corrosion protection, “plastic sheathing and all associated components shall comply with the requirements as stipulated in Table 2 of the Model Specification for Prestressed Ground Anchors (GEOSPEC 1)”. The table covers ten properties for polyvinyl chloride (PVC), polypropylene (PP) and high density polyethylene (HDPE), namely density, tensile strength, Vicat softening point, hardness (Shore D), brittleness temperature, environmental stress cracking resistance (ESCR), fungal resistance, bacteria resistance, water absorption and hydrostatic pressure resistance.

United Kingdom (UK)

BS 8006:1995 (BSI, 1995) includes the principle of design for soil nails and it refers to BS 8081:1989 for using corrugated sheathing as corrosion protection.

BS 8081:1989 is a current standard for ground anchors. Although parts of the standard (those parts that deal with construction (or ‘execution’) of ground anchors) are superseded by BS EN 1537:2000, the design of ground anchors and corrosion protection still refer to BS 8081:1989. In BS 8081:1989, it is mentioned that “CP312: Part 1 provides general guidance on choice of material” and one of its appendices “contains the properties of plastics which have been specified by Geotechnical Control Office, Hong Kong”. The testing requirements for corrugated sheathing given in Table 2 of Geospec 1 (GCO, 1989) are adopted for design of ground anchors in UK.

CIRIA (2005) has been reviewed. Based on the report, corrugated sheathing should be proven as an effective impermeable barrier by testing. For long nails, where lengths of sheathing need to be joined, the test regime also needs to address the effectiveness of the jointing method. However, no discussion on the tests of corrugated sheathing has been included in the report.

United States of America (USA)

Generally, HDPE and PVC can be used for corrugated sheathing for soil nails and ground anchors. HDPE shall follow the requirements stated in AASHTO M252-09 (AASHTO, 2009), which is a standard specification for drainage pipe. The tests included in the specification are carried out on the final products of corrugated sheathing. For PVC, it shall follow the requirements stated in ASTM D1784-08 (ASTM, 2008a) which includes standard test methods for PVC compounds.

A manual about corrugated plastic duct used in post-tensioning tendon installation for concrete bridges has also been reviewed (Corven & Moreton, 2004). This manual indicates that PE or PP should be used and the material properties specifications in ASTM D3350 and ASTM D4101 should be followed.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Switzerland

FIP (1986) specifies the pitch and amplitude of corrugation for plastic corrugated duct for corrosion protection of prestressed ground anchors. It also includes the properties of plastics specified in Geospec 1 in its appendix for information.

fib (2000) provides guidance on corrugated plastic duct used in internal bonded post-tensioning tendons for highway overpasses, viaduct and bridges. It indicates that HDPE and PP are most commonly used and provides a set of required material properties.

Discussions on the Review Results

Based on the preceding review, the properties selected for testing can be classified into two categories, namely properties of raw materials and properties of corrugated products (Table 4.2). In order to control the quality of corrugated sheathing for corrosion protection, testing on relevant properties is required and final products (i.e. corrugated sheathing), rather than raw materials, should be used for testing where practicable. However, due to the limitations and requirements on sample preparation for testing, many of the tests as stipulated in Geospec 1 (GCO, 1989) or other international standards are on raw materials, instead of the final products.

The material properties used in the present standards as criteria for material selection can be further classified into three types, i.e. degradation property, mechanical property and basic resin property. A summary of tests for different properties is given in Table 4.2.

Sections 4.2 and 4.3 discuss the properties of raw materials and properties of corrugated products considered by different standards and/or specifications. Properties to be selected for testing are also recommended.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4.2 Summary of Tests for Different Properties

Categories		Tests	
Properties of Raw Material	Degradation Properties	Vicat softening point*	Brittleness temperature*
		Environmental stress cracking resistance*	Water absorption*
		Fungal resistance*	Bacteria resistance*
		Chemical resistance	
	Mechanical Properties	Hardness*	Tensile strength*
		Elongation at break	Charpy impact strength of notched specimens
		Tensile impact strength of notched specimens	Izod impact resistance
		Flexural modulus	Elastic modulus
		Deflection temperature under load	Flammability
		Long term stress rating	Thermal conductivity
		Volume resistivity	Indentation test
		Linear expansion-coefficient	Homogeneousness
	Basic Resin Properties	Density*	Melt-mass flow rate and melt flow index
		Carbon black content	
Properties of Corrugated Product		Hydrostatic pressure resistance*	Pipe stiffness
		Pipe flattening	Pipe geometry (thickness, pitch and amplitude of corrugation)
		Brittleness	

Note: (*) Properties to be tested as required in Geospec 1.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

4.2 Selected Testing Properties of Raw Materials

4.2.1 Degradation Property

4.2.1.1 Vicat Softening Point

PVC, HDPE and PP are thermoplastic as their mechanical properties change with temperature. They soften when heated and harden when cooled. The Vicat softening point of a material is defined as the temperature at which the material softens and above which the rigidity and other mechanical properties (e.g. tensile strength and Young's modulus) decrease sharply (Maier & Calafut, 1998; Vasile & Pascu, 2005; Sarventnick, 1977). The Vicat softening point may also be defined as the maximum operating temperature, or as the heat distortion temperature (Maier & Calafut, 1998).

Local and International Standards

Vicat softening point is one of the requirements in Geospec 1. Some international standards also require the testing of Vicat softening point.

Table 4.3 Local and International Standards Requiring the Testing of Vicat Softening Point

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Vicat softening point	Yes	None	BS 8081:1989 [1] FIP (1986) [2]	fib (2000)

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.

(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Suggestion

The Vicat softening point of thermoplastic is not constant and is considerably affected by the use of additives and modifiers (Maier & Calafut, 1998; Vasile & Pascu, 2005; Biron, 2007). For example, PVC can have a Vicat softening point ranging from 54 to 80 ℃, due to the use of different additives (Maier & Calafut, 1998; Biron, 2007). However, a corrugated sheathing has to sustain the ambient temperature during grout hydration, which could be significantly higher than the normal ground temperature. It is therefore necessary to examine the Vicat softening point of corrugated sheathing in order that it would work effectively in its environment without suffering softening.

- **Vicat softening point** is suggested to be **required** for material property testing.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

4.2.1.2 Brittleness Temperature

At low temperatures all plastics tend to become rigid and brittle, because the mobility of chains is greatly reduced (Vasile & Pascu, 2005). The brittleness temperature defines the lower boundary at which thermoplastic works safely. At such temperature, brittle fracture becomes the dominant failure mechanism and the mechanical properties, such as tensile strength, elongation at break, etc., reduce substantially (Vasile & Pascu, 2005).

Local and International Standards

Brittleness temperature is one of the requirements in Geospec 1. Some international standards also require the testing of brittleness temperature.

Table 4.4 Local and International Standards Requiring the Testing of Brittleness Temperature

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Brittleness temperature	Yes	None	BS 8081:1989 [(1)] FIP (1986) [(2)]	None

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Suggestion

Since the ambient temperature varies throughout the year and the brittleness temperature of plastics changes with their compositions, it is necessary to examine the brittleness temperature of corrugated sheathing in order that it would work effectively at different times of the year.

- **Brittleness temperature** is suggested to be **required** for material property testing.

4.2.1.3 Environmental Stress Cracking Resistance

Generally speaking, the term environmental stress cracking (ESC) is defined as the premature cracking of a material under stress in the presence of an active environment (Spenadel, 1972). A wide range of different media can cause environmental stress cracking. The most active ones are usually polar in nature. They may be hydrophilic (e.g. typical detergents) or hydrophobic (e.g. silicone oils). The corrosion mechanism basically

Table of Contents Table of Contents Table of Contents Table of Contents

appears to be a physical phenomenon involving adsorption rather than swelling or chemical attack. For example, alcohols which are non-solvents for polyethylene can accelerate stress cracking.

ESC is a leading cause of service failure in plastics parts, accounting for perhaps 15% of all observed cases. It is noteworthy that a plastic component need not be externally loaded or stressed to suffer from ESC. Manufacturing processes, particularly injection moulding, would result in locking of stresses at specified locations. Locked-in stresses can render the material vulnerable to failure through ESC (Maier & Calafut, 1998; Vasile & Pascu, 2005). Corrugated sheathing can be degraded through ESC due to the presence of certain fluids including groundwater.

Local and International Standards

ESC resistance is one of the requirements in Geospec 1. All reviewed international standards (for soil nails, ground anchors and post-tensioning tendons) also require the testing of ESC resistance.

Table 4.5 Local and International Standards Requiring the Testing of Environmental Stress Cracking Resistance

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Environmental stress cracking resistance	Yes	Lazarte et al (2003) (3)	Sabatini et al (1999) (3) BS 8081:1989 (1) FIP (1986) (2) AASHTO (2000) (3)	Corven & Moreton (2004) (3) fib (2000)

Notes:
(1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.
(3) Testing of ESC resistance is specified for HDPE and PE only, but not PVC or PP.

Suggestion

ESC resistance is an indicator of ageing properties. It is therefore necessary to examine the ESC resistance of corrugated sheathing for ensuring its durability.

Table of Contents Table of Contents Table of Contents Table of Contents

- **Environmental stress cracking resistance** is suggested to be **required** for material property testing.

4.2.1.4 Water Absorption

Besides ESC resistance, water absorption also needs to be checked for material selection due to the likely presence of groundwater. It is found that absorption of moisture may result in swelling, dissolving, leaching, plasticizing and/or hydrolyzing events which can cause discoloration, embrittlement, changes in mechanical and electrical properties, lowering of resistance to heat, weathering and stress cracking (Nass, 1992; Maier & Calafut, 1998; Vasile & Pascu, 2005; Biron, 2007).

Local and International Standards

Water absorption is one of the requirements in Geospec 1. Some international standards also require the testing of water absorption.

Table 4.6 Local and International Standards Requiring the Testing of Water Absorption

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Water absorption	Yes	None	BS 8081:1989 [1] FIP (1986) [2]	None

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Suggestion

Since the corrugated sheathing for soil nails has the possibility of being located below the groundwater level, it is necessary to examine its water absorption property in order to control its adverse effect on the mechanical and electrical properties of the sheathing.

- **Water absorption** is suggested to be **required** for material property testing.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

4.2.1.5 Fungal Resistance

Fungi in soils have been found to have the potential to allow materials (e.g. iron) around it to be corroded (Chaker & Palmer, 1989). The resistance of corrugated sheathing to fungi determines, to some extent, its life time and serviceability, which in turn affects the serviceability of the whole soil nail system.

Local and International Standards

Fungal resistance is one of the requirements in Geospec 1. Some international standards also require the testing of fungal resistance.

Table 4.7 Local and International Standards Requiring the Testing of Fungal Resistance

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Fungal resistance	Yes	None	BS 8081:1989 (1) FIP (1986) (2)	None

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Suggestion

It is necessary to examine the fungal resistance of corrugated sheathing in order to ensure its life time and serviceability.

- **Fungal resistance** is suggested to be **required** for material property testing.

4.2.1.6 Bacteria Resistance

No active standards were available for testing the bacteria resistance of plastics. ASTM G22-76 (1980) was the testing standard adopted in Geospec 1. However, this ASTM standard was superseded by ASTM G22-76 (1996) which has then been withdrawn with no replacement.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Local and International Standards

Bacteria resistance is one of the requirements in Geospec 1. Only those international standards referring to GCO Publication No. 3/84 (which has been superseded by Geospec 1) require the testing of bacteria resistance.

Table 4.8 Local and International Standards Requiring the Testing of Bacteria Resistance

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Bacteria resistance	Yes	None	BS 8081:1989 [(1)] FIP (1986) [(2)]	None

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Suggestion

Thermoplastic is generally not biodegradable and no active standards were available for testing the bacteria resistance of plastics. Therefore, the testing of bacteria resistance is not recommended.

- **Bacteria resistance** is suggested to be **not required** for material property testing.

4.2.1.7 Chemical Resistance

Resistance against chemical attack has been considered as grout is alkaline and fluid in grout cracks, if any, normally has a pH value of 12.5 or above (CEB, 1992; GEO, 2002). Furthermore, soils around soil nails may be contaminated and contain anions such as chloride (Cl^-), sulfate (SO_4^{2-}) and so on. In addition, due to the leaching effect of rainfall and the presence of acid rain, soils tend to be somewhat acidic with H^+ ions of various concentrations (Chaker & Palmer, 1989).

Local and International Standards

Testing of chemical resistance is not a requirement in Geospec 1. It is also not specified in any reviewed international standards.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4.9 Local and International Standards Requiring the Testing of Chemical Resistance

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Chemical resistance	No	None	None	None

Suggestion

Plastics are known to have high resistance against chemical attacks and the concentration of hydroxide and acid in the ground is expected to be low.

HDPE has little or no degradation with long term exposure to an environment with a pH value ranging from 1.5 to 14.0 (Bennett, year unknown). PVC is capable of handling water with a pH value ranging from 2 to 12[1]. PP can withstand a condition with a pH range of less than 2 to more than 13[2]. It is unlikely that soils in Hong Kong would have a pH value as low as 2[3].

Concrete has a pH value of 12 to 13 (Broomfield, 2007). Grout should have a similar pH value due to similar ingredients. The upper bound pH value that thermoplastics in a soil nail system should withstand is therefore comparable to the alkaline condition of grout. According to Erlin (1994), the principal chemicals in concrete (which should be the same as grout) that could conceivably attack plastics are calcium hydroxide, sodium hydroxide and potassium hydroxide which create a minimum pH of 12.4. However, in spite of the pH value, PE and PVC (rigid[4]) have excellent resistance to these alkalis while PP has excellent to good resistance to these alkalis. Therefore, PE, PVC and PP are normally not attacked by grout.

Besides, chemical resistance is not tested elsewhere for soil nails, ground anchors and post-tensioning tendons. Therefore, it is considered not necessary to examine the chemical resistance of corrugated sheathing.

- **Chemical resistance** is suggested to be **not required** for property testing.

[1] http://www.tarunpipes.com/pvc_threaded.html.
[2] http://opus.mcerf.org/pair.aspx?appID=4889427233656159922&materialID=-2616673719130194264.
[3] The pH value of lemon juice is about 2.
[4] According to http://www.copeplastics.com/pvc.html, rigid PVC is the most common type of PVC used in the manufacture of pipe, fittings, valves, machining shapes, sheet and duct. Rigid PVC offers advantages for piping and related applications due to its low cost, high strength to weight ratio, pressure bearing capability, corrosion and chemical resistance and low friction loss characteristics. Flexible (plasticized) PVC is vinyl which has been heavily plasticized and is used to produce liners, film, packaging, wire and cable insulation jackets and many other products which require flexibility and resistance to tear, puncture and abrasion.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

4.2.2 Mechanical Property

The second main issue related to the performance of corrugated sheathing is its mechanical properties.

4.2.2.1 Hardness

Hardness is defined as the resistance of a material to deformation, particularly permanent deformation, indentation, or scratching. However, hardness is not a fundamental material property. It is a relative term only. Rockwell and Durometer hardness tests are commonly adopted for measurement of material hardness (Vasile & Pascu, 2005).

Local and International Standards

Hardness is one of the requirements in Geospec 1. Some international standards also require the testing of hardness.

Table 4.10 Local and International Standards Requiring the Testing of Hardness

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Hardness	Yes	None	BS 8081:1989 [(1)] FIP (1986) [(2)]	fib (2000)

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Suggestion

There is a possibility that corrugated sheathing may be scratched by hard and sharp obstructions during installation, given that space is limited in the annulus between the corrugated sheathing and the drillhole. It is therefore considered necessary to test hardness.

- **Hardness** is suggested to be **required** for property testing.

4.2.2.2 Elongation at Break

Elongation at break indicates how a material fails in tension. A low elongation figure denotes a brittle rupture, while a high elongation figure shows that the material responds to the exerted force in a ductile manner (Maier & Calafut, 1998).

Local and International Standards

Elongation at break is not a requirement in Geospec 1. Only a literature for post-tensioning tendons specifies the need for testing elongation at break.

Table 4.11 Local and International Standards Requiring the Testing of Elongation at Break

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Elongation at break	No	None	None	fib (2000)

Suggestion

Corrugated sheathing may be stretched under any slope movements. In order to protect steel bars against corrosion, corrugated sheathing should be more ductile than the protected steel bars.

- **Elongation at break** is suggested to be **required** for material property testing.

4.2.2.3 Tensile Strength

The tensile strength of a material is the breaking point of a brittle material or the yield point of a ductile material (Nass, 1992; Biron, 2007).

Local and International Standards

Tensile strength is one of the requirements in Geospec 1. All reviewed international standards (for soil nails, ground anchors and post-tensioning tendons) also require the testing of tensile strength.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4.12 Local and International Standards Requiring the Testing of Tensile Strength

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Tensile strength	Yes	Lazarte et al (2003) (3)	Sabatini et al (1999) (3) BS 8081:1989 (1) FIP (1986) (2) AASHTO (2000) (3)	Corven & Moreton (2004) (3) fib (2000)

Notes:
(1) The standard adopts the requirements specified in GCO Publication No 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.
(3) Testing of tensile strength is specified for PVC and PP only, but not HDPE and PE.

Suggestion

The typical tensile strength of thermoplastics ranges from 400 to 4000 MPa (Nass, 1992; Maier & Calafut, 1998; Vasile & Pascu, 2005; Biron, 2007). It is much less than the tensile strength of grout (20 GPa) and steel bar (200 GPa) in a soil nail system. The cross section of corrugated sheathing is much less than that of a steel bar. As a result, the stiffness (i.e. elongation per unit tension, EA) of corrugated sheathing is much smaller than that of the steel bar and its surrounding grout. The transmission of forces along a soil nail with corrugated sheathing is largely provided by the cement shear keys formed above and below the corrugated sheathing. However, in order to ensure the compatibility of corrugated sheathing during installation and the transmission of forces, it is recommended to examine the tensile strength of corrugated sheathing. The set-up of a tensile strength test is similar to that for testing elongation at break.

- **Tensile strength** is suggested to be **required** for material property testing.

4.2.2.4 Charpy Impact Strength of Notched Specimens

The Charpy impact test, also known as the Charpy v-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material in the form of a beam with a fabricated notch during fracturing (Vasile & Pascu, 2005). This absorbed energy is a measure of a material's toughness and acts as a tool to study temperature-dependent brittle-ductile transition (see Figure 4.1). However, a major disadvantage is that all test results are only comparative (Vasile & Pascu, 2005). The notch geometry and the size of the sample both affect the results of the impact test (BSI, 1989; Biron, 2007).

Table of Contents
Table of Contents
Table of Contents
Table of Contents

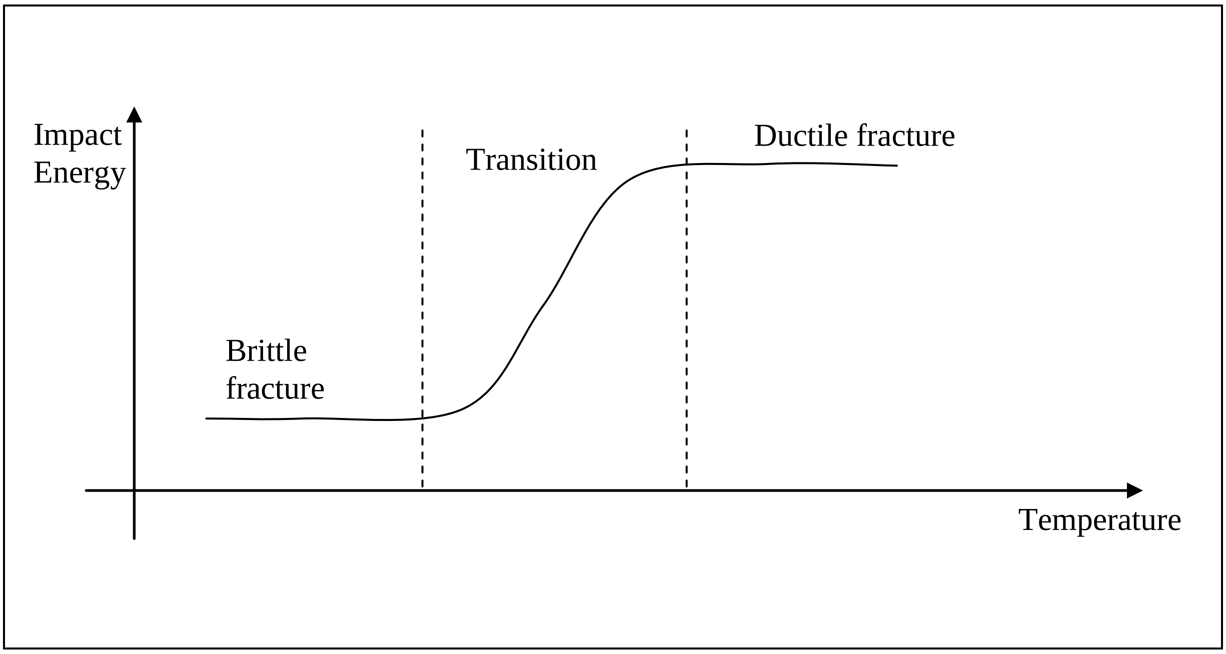


Figure 4.1 A Graph Showing the Temperature-dependent Brittle-ductile Transition

Local and International Standards

Charpy impact strength of notched specimens is not a requirement in Geospec 1. Only one literature specifying this test for post-tensioning tendons could be found.

Table 4.13 Local and International Standards Requiring the Testing of Charpy Impact Strength of Notched Specimens

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Charpy impact strength of notched specimens	No	None	None	fib (2000)

Suggestion

For thermal plastics, such as PVC, HDPE and PP, Vicat softening point and elongation at break are considered to be more appropriate for examining the ductility of a material than the test to determine Charpy impact strength of notched specimens (Maier & Calafut, 1998; Vasile & Pascu, 2005; Biron, 2007).

Table of Contents
Table of Contents
Table of Contents
Table of Contents

- **Charpy impact strength of notched specimens** is suggested to be **not required** for material property testing.

4.2.2.5 Tensile Impact Strength of Notched Specimens and Izod Impact Resistance

Besides the Charpy impact test, test methods for tensile impact strength of notched specimens and Izod impact resistance are also used to measure the impact resistance of plastics. These methods are used for assessing the behaviour of specimens under specified impact velocities, and for estimating the brittleness or the toughness of the specimens within the limitations inherent in the test conditions. The response of plastics to comparatively high rates of straining is useful to describe, for example, the behaviour of materials when subjected to weathering or thermal ageing, as well as to assess their properties under corresponding service conditions. However, these methods are not suitable for use as a source of data for design calculations on components (BSI, 1997).

Local and International Standards

Tensile impact strength of notched specimens is not a requirement in Geospec 1. Only one literature on the testing of tensile impact strength of notched specimens for post-tensioning tendons could be found.

Table 4.14 Local and International Standards Requiring the Testing of Tensile Impact Strength of Notched Specimens

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Tensile impact strength of notched specimens	No	None	None	fib (2000)

Izod impact resistance is also not a requirement in Geospec 1. However, some international literatures specify the need for testing Izod impact resistance.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4.15 Local and International Standards Requiring the Testing of Izod Impact Resistance

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Izod impact resistance	No	Lazarte et al (2003) [(2)]	Sabatini et al (1999) [(2)] BS 8084:1989 [(1)]	Corven & Moreton (2004) [(1)]

Notes: (1) The standard mentions that CP312: Part 1 provides general guidance on choice of material and CP312:1973 Part 1 specifies the property of Izod impact resistance.
(2) Testing of Izod impact resistance is specified for PVC and PP only, but not HDPE and PE.

Suggestion

These tests generally do not translate into explicit design parameters (ASTM, 2006a). The tensile impact strength of notched specimens and Izod impact resistance may be a concern only during installation and handling. However, other tests, such as pipe stiffness (Section 4.3.2), are considered to be more appropriate for checking the stiffness during installation and handling.

- **Tensile impact strength of notched specimens and Izod impact resistance** are suggested to be **not required** for material property testing.

4.2.2.6 Flexural Modulus

Flexural modulus is the ratio of stress to strain in flexural deformation. It is an indication of a material's stiffness when subject to bending.

Local and International Standards

Flexural modulus is not a requirement in Geospec 1. Only one literature on the testing of flexural modulus of post-tensioning tendons could be found.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4.16 Local and International Standards Requiring the Testing of Flexural Modulus

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Flexural modulus	No	None	None	Corven & Moreton (2004)

Suggestion

The lateral deflections of corrugated sheathing are limited by the use of centralizers. Flexural modulus, therefore, is considered unnecessary for material property testing.

- **Flexural modulus** is suggested to be **not required** for material property testing.

4.2.2.7 Elastic Modulus

The elastic modulus of an object is defined as the slope of its stress-strain curve in the elastic deformation region. It is generally used to determine the stiffness of an object.

Local and International Standards

Elastic modulus is not a requirement in Geospec 1. However, some literatures specify the need for testing elastic modulus.

Table 4.17 Local and International Standards Requiring the Testing of Elastic Modulus

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Elastic modulus	No	Lazarte et al (2003) [1]	Sabatini et al (1999) [1]	fib (2000)

Note: [1] Testing of elastic modulus is specified for PVC and PP only, but not HDPE and PE.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Suggestion

The stiffness of corrugated sheathing is a concern mainly during installation and handling. Although elastic modulus is an indicator of pipe stiffness, it is not the only factor affecting pipe stiffness. As such, testing the pipe stiffness directly (Section 4.3.2) is considered more appropriate than testing the elastic modulus of the raw material.

- **Elastic modulus** is suggested to be **not required** for material property testing.

4.2.2.8 Other Properties

Deflection temperature under load, flammability, long-term stress rating, thermal conductivity, volume resistivity, indentation test, linear expansion-coefficient and homogeneity are generally material properties not related to the corrosion protection of soil nails. Therefore, these properties are suggested to be **not required** for material property testing.

4.2.3 Basic Resin Property

4.2.3.1 Density

Density is a basic characteristic of thermoplastics. It helps to determine physical or chemical changes during production and use (fib, 2000). Also, it helps to indicate the type of plastic (e.g. PVC, HDPE or PP) of the specimen.

Local and International Standards

Density is one of the requirements in Geospec 1. It is also specified in some other literatures.

Table 4.18 Local and International Standards Requiring the Testing of Density

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Density	Yes	None	BS 8081:1989 (1) FIP (1986) (2)	Corven & Moreton (2004)

Notes:
(1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Table of Contents Table of Contents Table of Contents Table of Contents

Suggestion

Density alone cannot determine the properties of a thermoplastic since density can be greatly altered by adding different additives or fillers (Biron, 2007). However, density tests can be carried out on both raw materials and corrugated products. Any large variations between the densities of the thermoplastics given in testing certificates and that of corrugated products delivered to sites may indicate potential of non-compliance of the products. Therefore, it is necessary to test the density of corrugated products for quality control.

- **Density** is suggested to be **required** for material property testing.

4.2.3.2 Melt-mass Flow Rate and Melt Flow Index

Thermoplastics are formed into articles almost exclusively by melt processes that rely on the flow of the melted material at elevated temperatures. Injection moulding, blow moulding, extrusion and thermoforming are all examples of melt processing (Maier & Calafut, 1998). Melt mass flow rate, MFR and melt flow index, MFI, are measures of viscosity or flow resistance of plastic melt during processing. They serve for quality control during production to assure a proper manufacturing process (fib, 2000).

Local and International Standards

MFR and MFI are not required in Geospec 1. Some literatures on the testing of MFR and MFI for post-tensioning tendons could be found.

Table 4.19 Local and International Standards Requiring the Testing of Melt-mass Flow Rate and Melt Flow Index

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Melt-mass flow rate and melt flow index	No	None	None	Corven & Moreton (2004) fib (2000)

Suggestion

Both MFR and MFI can be taken as indicators of average molecular weight. However, these tests are used for quality control of resin rather than end products.

- **MFR and MFI** are suggested to be **not required** for material property testing.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

4.2.3.3 Carbon Black Content

The excellent capability of carbon black to absorb light of all wavelengths makes it a good choice for UV (ultraviolet radiation) protection measures for the thermoplastics (Sarventnick, 1977; Maier & Calafut, 1998; Vasile & Pascu, 2005; Biron, 2007).

Local and International Standards

Testing of carbon black content is not a requirement in Geospec 1. Only one literature specifying the need for carbon black content for post-tensioning tendons could be found.

Table 4.20 Local and International Standards Specifying the Carbon Black Content

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Carbon black content	No	None	None	fib (2000) [(1)]

Note: (1) fib (2000) specifies that carbon black content should not be less than 2%. However, carbon black content in corrugated sheathing is not checked by testing. It is attested by factory production control or guaranteed by the manufacturer.

On the other hand, testing of carbon black content for polymeric reinforcing element is stipulated in Geoguide 6: Guide to Reinforced Fill Structure and Slope Design. However, corrugated sheathing is for corrosion protection. The testing requirements for carbon black content of reinforced fill elements are not necessarily applicable to corrugated sheathing of soil nails.

Suggestion

ASTM D1603-06 (ASTM, 2006b) provides a test method for determination of carbon black content in PE and PP, but not PVC. However, this test method is not applicable to compositions that contain non-volatile pigments or fillers other than carbon black. Since it is hard to confirm that corrugated sheathing contains no non-volatile pigments or fillers other than carbon black, it is not appropriate to test the carbon black content of corrugated sheathing.

Moreover, corrugated sheathing is embedded in grout after installation. It may be at most exposed to sunlight during storage only.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

It is considered more pragmatic to protect corrugated sheathing from sunlight by providing proper and adequate measures during storage rather than conducting test to check on its carbon black content. Also, some suggested tests in Section 4.3 could be used to check the quality of corrugated sheathing delivered to sites.

- Testing of **carbon black content** is suggested to be **not required** for material property testing.

4.3 Properties of Corrugated Sheathing

In order to ensure that corrugated sheathing performs well to protect soil nails from corrosion, product properties of corrugated plastic pipe should also be tested where practicable. Available tests on the product properties of corrugated sheathing are considered in this Section.

4.3.1 Hydrostatic Pressure Resistance

Hydrostatic pressure resistance is mainly used as a design factor for pressurised pipes containing water or air. Existence of a huge pressure (several to tens MPa) inside a pipe could introduce crack or rupture in the pipe wall, which is normally surrounded or constrained by nothing (Watkins & Anderson, 2000).

Local and International Standards

Hydrostatic pressure resistance is one of the requirements in Geospec 1. It is also specified in some other literatures.

Table 4.21 Local and International Standards Requiring the Testing of Hydrostatic Pressure Resistance

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Hydrostatic pressure resistance	Yes	None	BS 8081:1989 [(1)] FIP (1986) [(2)]	Corven & Moreton (2004)

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Suggestion

Since the corrugated sheathing in a soil nail system may have to withstand internal hydrostatic pressure during grouting, hydrostatic pressure resistance should therefore be a criterion for product quality.

- **Hydrostatic pressure resistance** is suggested to be **required** for product property testing.

4.3.2 Pipe Stiffness

Corrugated sheathing should have enough stiffness to withstand possible loads on it during its whole life time which covers transportation, installation and service. There are two types of stiffness affecting the performance of a sheathing: longitudinal and pipe stiffness (Watkins & Anderson, 2000). The former is not crucial since the longitudinal deflection or bending would be minimized by the use of centralizer during installation. The latter, however, to some extent determines the operability of the sheathing. The sheathing would become oval in shape during handling due to surrounding pressures if it is not sufficiently stiff. Pipe stiffness can be measured by a parallel plate test. To perform the test, a length of pipe, usually longer than one diameter, on a flat surface is loaded as shown in Figure 4.2. As load per unit length of pipe (F) is applied in increments, corresponding deflections, Δ, are measured. The ratio F/Δ is called pipe stiffness (Watkins & Anderson, 2000).

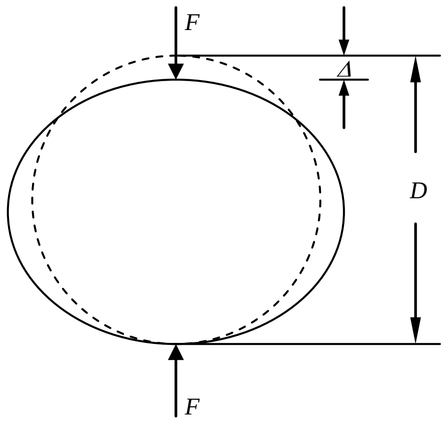


Figure 4.2 The Parallel Plate Test and Pipe Stiffness of Corrugated Sheathing (Watkins & Anderson, 2000)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Local and International Standards

Pipe stiffness is not a requirement in Geospec 1. However, literatures of USA for soil nails and ground anchors specify the need for testing pipe stiffness.

Table 4.22 Local and International Standards Requiring the Testing of Pipe Stiffness

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Pipe stiffness	No	Lazarte et al (2003) [1]	Sabatini et al (1999) [1] AASHTO (2010) [1]	None

Note: [1] The literatures refer to AASHTO Standard M252-09 which is designed for drainage pipe and the testing of pipe stiffness is specified for HDPE only, and not for PVC.

Suggestion

It is necessary to examine pipe stiffness in order to ensure the workability of the corrugated sheathing during installation.

- **Pipe stiffness** is suggested to be **required** for product property testing.

4.3.3 Pipe Flattening

Pipe flattening is a test to ensure the ductility of corrugated sheathing. In the test, the pipe specimen is loaded between two rigid parallel flat plates at a controlled rate until the inside diameter is reduced by 20%. The specimen is considered to have failed if buckling or cracking is observed.

Local and International Standards

Pipe flattening is not a requirement in Geospec 1. However, literatures of USA for soil nails and ground anchors specify the need for testing pipe flattening.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4.23 Local and International Standards Requiring the Testing of Pipe Flattening

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Pipe flattening	No	Lazarte et al (2003) [(1)]	Sabatini et al (1999) [(1)] AASHTO (2010) [(1)]	None

Note: [(1)] The literatures refer to AASHTO Standard M252-09 which is designed for drainage pipe and the testing of pipe flattening is specified for HDPE only, and not for PVC.

Suggestion

Ductility is important for corrugated sheathing to protect the steel reinforcement of a soil nail when the nail is mobilized and reinforcement is elongated. However, no direct test on the elongation of corrugated sheathing can be found. The elongation at break discussed in Section 5.2.7 can only be tested on specimen made from raw materials. It is therefore necessary to include the test on pipe flattening, which is an indirect test on the ductility of corrugated sheathing.

- **Pipe flattening** is suggested to be **required** for product property testing.

4.3.4 Pipe Geometry

Pipe geometry mainly refers to wall thickness, pitch and amplitude of corrugation.

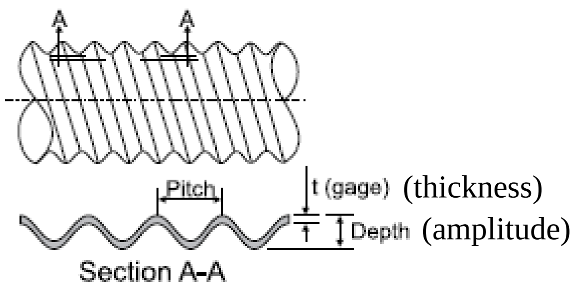


Figure 4.3 The Geometrical Properties of Corrugated Sheathing (Watkins & Anderson, 2000)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Corrugated sheathing together with the steel reinforcement inside should not be pulled out during mobilization of a soil nail. Adequate bond strength between the grout and the corrugated sheathing is therefore required.

Local and International Standards

Geospec 1 and some literatures specify a minimum wall thickness for corrugated sheathing.

Table 4.24 Local and International Standards Requiring the Measurement of Wall Thickness

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Wall thickness	Yes	Lazarte et al (2003)	BS 8081:1989	AASHTO (2010)

Pitch and amplitude of corrugation are not requirements in Geospec 1. However, some literatures for ground anchors specify the need for testing pitch and amplitude of corrugation.

Table 4.25 Local and International Standards Requiring the Testing of Pitch and Amplitude of Corrugation

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Pitch and amplitude of corrugation	No	None	BS 8081:1989 FIP (1986)	fib (2000)

Suggestion

Wall thickness is considered as a basic parameter for pipe geometry. Measuring the pitch and amplitude of corrugation is a simple way to ensure adequate bonding between the grout and corrugated sheathing.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

- Measurement of **wall thickness, pitch and amplitude of corrugation** is suggested to be **required** for product property testing.

4.3.5 Brittleness

Brittleness is a test to ensure that there would be no cracking on the corrugated sheathing when it is hit by a falling test plate.

Local and International Standards

Brittleness is not a requirement in Geospec 1. However, literatures of USA for soil nails and ground anchors specify the need for testing brittleness.

Table 4.26 Local and International Standards Requiring the Testing of Brittleness

Property	Required in Geospec 1?	International Standards Requiring Testing of the Property		
		Soil Nail	Ground Anchor	Post-tensioning Tendon
Brittleness	No	Lazarte et al (2003) [1]	Sabatini et al (1999) [1] AASHTO (2010) [1]	None

Note: (1) The literatures refer to AASHTO Standard M252-09 which is designed for drainage pipe and the testing of brittleness is specified for HDPE only, and not for PVC.

Suggestion

Testing of brittleness is necessary for drainage pipes, as they need to withstand the soil loads and surcharges from pedestrians and vehicles above. However, for soil nails, corrugated sheathing is filled with grout and is protected against breaking due to external loads. It is considered not necessary to examine the brittleness of corrugated sheathing in a soil nail system.

- **Brittleness** is suggested to be **not required** for product property testing.

4.4 Summary

Properties of corrugated sheathing reviewed above are summarized in Table 4.27. Thirteen properties of corrugated sheathing are suggested to be required for testing. Properties required by Geospec 1 are also listed for comparison.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4.27 Identification of Properties of Corrugated Sheathing (Sheet 1 of 2)

Categories		Properties	Requirement in Geospec 1	Suggestions in this Study
Material Properties	Degradation Properties	Vicat softening point	√	√
		Brittleness temperature	√	√
		Environmental stress cracking resistance	√	√
		Water absorption	√	√
		Fungal resistance	√	√
		Bacteria resistance	√	
		Chemical resistance		
	Mechanical Properties	Hardness	√	√
		Elongation at break		√
		Tensile strength	√	√
		Charpy impact strength of notched specimens		
		Tensile impact strength of notched specimens		
		Izod impact resistance		
		Flexural modulus		
		Elastic modulus		
		Deflection temperature under load		
		Flammability		
		Long term stress rating		
		Thermal conductivity		
		Volume resistivity		
		Indentation test		
		Linear expansion-coefficient		
		Homogeneity		
	Basic Resin Properties	Density	√	√
		Melt-mass flow rate and melt flow index		
		Carbon back content		

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 4.27 Identification of Properties of Corrugated Sheathing (Sheet 2 of 2)

Categories	Properties	Requirement in Geospec 1	Suggestions in this Study
Properties of Corrugated Pipe	Hydrostatic pressure resistance	√	√
	Pipe stiffness		√
	Pipe flattening		√
	Pipe geometry		√
	Brittleness		

Note: √ means that the property is required to be tested.

5 Acceptance Criteria and Test Methods for Selected Properties

5.1 General

The properties selected for testing have been identified in Sections 4.2 and 4.3. This section aims to determine the acceptance criteria for the tests.

As mentioned in Section 4.1, the materials commonly used to produce corrugated sheathing are PVC, PP and HDPE. Based on the literature review, it is found that these materials have a wide range of density, Vicat softening point, brittleness temperature and elongation at break. This is due to the diversity of additives (Maier & Calafut, 1998; Vasile & Pascu, 2005; Biron, 2007). The water absorption, tensile strength and hardness, however, fall into a relatively narrow range. All PVC, HDPE and PP materials have sound resistance to fungal attack. Details of the testing method and the acceptance criteria of each selected property are discussed below.

5.2 Properties of Material

5.2.1 Vicat Softening Point

Test Method and Test Specimen

BS EN ISO 306-04 (BSI, 2004a) is the current test method for determining Vicat softening point of plastics. A flat-ended needle loaded with a specified mass is placed in direct contact with a test specimen. The specimen and the needle are heated at either of two permissible rates: 50 ± 5°C/h or 120 ± 10°C/h. The temperature at which the needle has penetrated to a depth of 1 ± 0.01 mm is recorded as the Vicat softening temperature.

According to BS EN ISO 306-04, the test specimens shall be between 3 mm and 6.5 mm thick and at least 10 mm square or of 10 mm diameter. Their surfaces shall be flat and free from flash.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Typical Ranges and Local and International Standards

The typical ranges of Vicat softening points of PVC, HDPE and PP are tabulated in Table 5.1.

Table 5.1 Typical Ranges of Vicat Softening Point of PVC, HDPE and PP

Property	Unit	Typical Range		
		PVC	HDPE	PP
Vicat softening point	℃	54 to 83 (BSI, 1973; Maier & Calfut, 1998; Biron, 2007)	112 to 132 (Vasile & Pascu, 2005)	90 to 170 (Maier & Calfut, 1998; Tasdemir, 2003; Gregorová et al, 2005; Zhiping et al, 2010)

The acceptance criteria stipulated in the local and international standards are summarized in Table 5.2.

Table 5.2 Acceptance Criteria in Local and International Standards for Vicat Softening Point

Property	Unit	Acceptance Criteria				
		Geospec 1, BS 8081:1989 [(1)] FIP (1986) [(2)]			fib (2000) [(3)]	
		PVC	HDPE	PP	HDPE	PP
		(raw material)			(raw material)	
Vicat softening point	℃	≥ 75	≥ 110	≥ 150	70	70

Notes:
(1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.
(3) fib (2000) discusses about corrugated plastic ducts for internal bonded post-tensioning tendons.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

In Geospec 1, the acceptance criteria of Vicat softening point for corrugated sheathing made of different materials (PVC, HDPE and PP) are different and the specified values are comparable to the typical ranges of the corresponding materials. It is likely that the acceptance criteria of Vicat softening point in Geospec 1 are based on the typical values of PVC, HDPE and PP.

Discussion

The highest temperature that corrugated sheathing in a soil nail system would experience is the temperature during hydration of the cement in the grout. It is reported that the heat of hydration of Portland cement may be in the order of 300 kJ/kg at 7 days when cured at 20℃ (Domone & Jefferis, 1994). For cement grout of 0.40 water/cement ratio, hydration under adiabatic conditions such as a heat release could lead to a temperature rise of 120℃. Littlejohn & Hughes (1988) recorded a peak temperature of about 110℃ at 40 mm from the external surface of a fabric formwork. This peak temperature was achieved at about 5 hours after grouting and did not begin to decay for a further 3 hours.

No report about the hydration temperature of the grout in a soil nail system was available. In current practice, the water/cement ratio for the grout in a soil nail does not exceed 0.45. Although the water/cement ratio used for the grout in a soil nail is similar to that of the cement grout discussed in Domone & Jefferis (1994), the volume of grout used in a soil nail is usually much less. Therefore, it is considered that the grout in a soil nail would introduce a temperature rise much less than that discussed in Domone & Jefferis (1994) and recorded in Littlejohn & Hughes (1988) due to the nonadiabatic environment and relatively small volume of grout in the soil nail.

Field Test

Tests with simple set-up were conducted on 23 November 2010 and 13 December 2010 by C M Wong & Associates Ltd. A total of six soil nails were tested. Thermocouples with data loggers and wires (see Figure 5.1) were used to measure the temperature of grout during hydration.

The tested soil nails were 10 m long with corrugated sheathing. The diameter of the drillholes and steel bars were 150 mm and 40 mm respectively. Two wires were fixed on the steel bar at each soil nail. One was used to measure the grout temperature at the middle of the soil nail while the other was used to measure the grout temperature at the end of the soil nail. The temperature was recorded at every 1 to 5 minutes.

As shown in Figure 5.2, the measured highest temperature in grout was about 65.3℃ at around 6 hours after grouting with an ambient temperature of 25℃.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

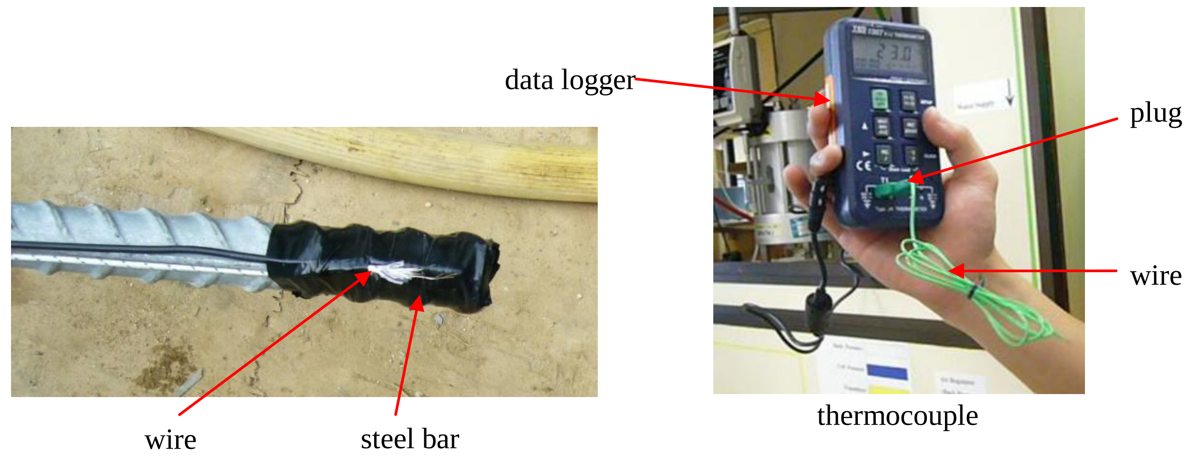


Figure 5.1 The Set-up for Testing Hydration Temperature in Soil Nail

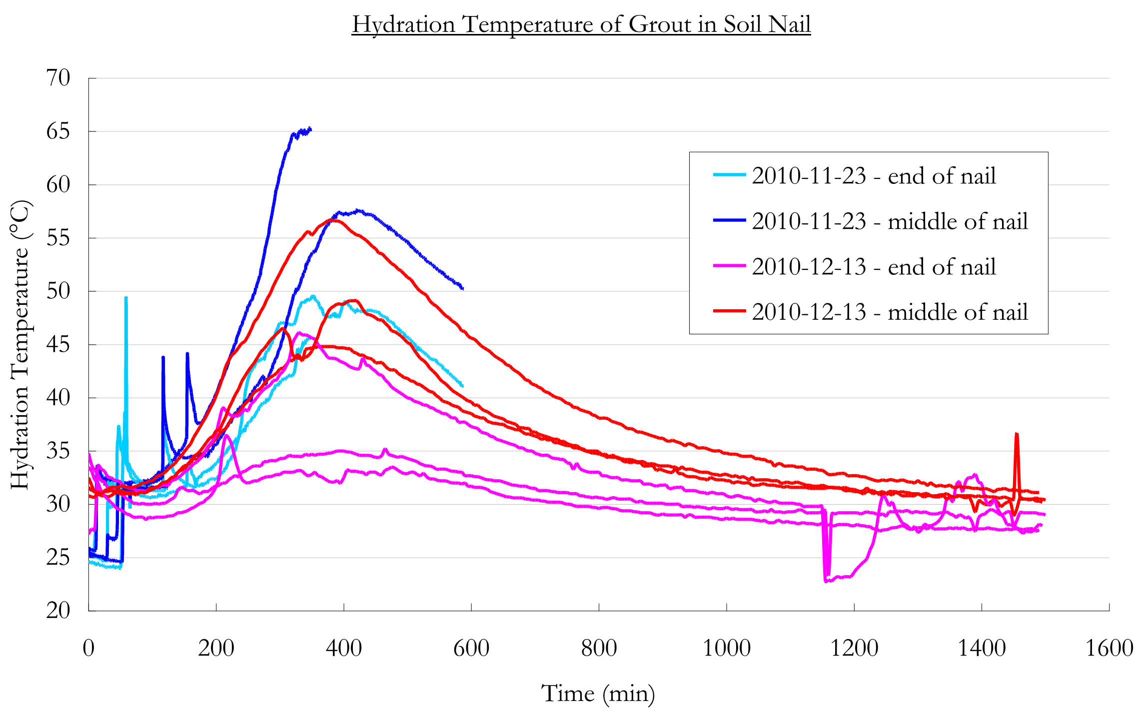


Figure 5.2 The Recorded Hydration Temperature vs Elapsed Time

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Suggestion

The measured highest temperature in the field test was about 65℃. Therefore, the existing criterion of the minimum Vicat softening point of 75℃ is considered appropriate for corrugated sheathing.

- **Vicat softening point** is suggested to be **≥ 75℃**.

5.2.2 Brittleness Temperature

Test Method and Test Specimen

ASTM D746-07 (ASTM, 2007a) is the current test method for determining brittleness temperature. Specimens are secured to a specimen holder with a torque wrench. The specimen holder is immersed in a bath containing a heat-transfer medium that is cooled. The specimens are struck at a specified linear speed and then examined. The brittleness temperature is defined as the temperature at which 50% of the specimens fail.

According to ASTM D746-07, the test specimens shall be a narrow strip rectangular in shape or T-shaped depending on the apparatus used. The specimens shall be 2.50 - 6.36 mm wide by 20.00 - 31.75 mm long and 1.60 - 1.91 mm thick.

Typical Ranges and Local and International Standards

The typical ranges of brittleness temperature of PVC, HDPE and PP are tabulated in Table 5.3.

Table 5.3 Typical Ranges of Brittleness Temperature of PVC, HDPE and PP

Property	Unit	Typical Range		
		PVC	HDPE	PP
Brittleness temperature	℃	0 to -70 (Nass, 1992; Maier & Calfut, 1998)	-70 to -156 (Vasile & Pascu, 2005)	15 to -40 (Maier & Calfut, 1998)

The acceptance criteria stipulated in the local and international standards are summarized in Table 5.4.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 5.4 Acceptance Criteria in Local and International Standards for Brittleness Temperature

Property	Unit	Acceptance Criteria	
		Geospec 1	BS 8081:1989 (1) FIP (1986) (2)
		PVC, HDPE & PP (raw material)	PVC, HDPE & PP (raw material)
Brittleness temperature	℃	≤ 5 (3)	≤ - 5 (3)

Notes:
(1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.
(3) Geospec 1, BS 8081:1989 and FIP (1986) both make reference to GCO Publication No. 3/84, which specifies the recommended criterion of brittleness temperature to be ≤ - 5℃. It seems that there is an inconsistency between Geospec 1 and GCO Publication No. 3/84 on the recommended criterion of brittleness temperature.

Discussion

During service, the lowest temperature a corrugated sheathing would encounter is the extremely low soil temperature in winter.

Tables 5.5 to 5.7 summarize the air temperatures and soil temperatures recorded by the Hong Kong Observatory.

Table 5.5 Extreme Values of Air Temperature between 1884 and 1939 and between 1947 and 2006

Temperature	November	December	January	February	March
Absolute minimum	6.5℃	4.3℃	0.0℃	2.4℃	4.8℃

Table 5.6 Monthly Air Temperature Recorded at the Observatory between 1961 and 1990

Temperature	November	December	January	February	March
Mean	21.4℃	17.6℃	15.8℃	15.9℃	18.5℃

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 5.7 Monthly Mean of Soil Temperature Recorded at the Observatory between 1971 and 2000

Measured Depth	Measured Time	November	December	January	February	March
0.5 m	0700 hours	24.4°C	20.5°C	18.8°C	18.9°C	20.6°C
	1900 hours	24.3°C	20.5°C	18.8°C	18.9°C	20.7°C
1.0 m	0700 hours	25.6°C	22.4°C	20.3°C	19.8°C	20.8°C
	1900 hours	25.5°C	22.4°C	20.4°C	19.9°C	20.8°C
1.5 m	0700 hours	26.3°C	23.6°C	21.6°C	20.8°C	21.1°C
	1900 hours	26.3°C	23.6°C	21.6°C	20.8°C	21.1°C

According to the records from the Hong Kong Observatory, the lowest recorded air temperature in Hong Kong is 0°C in January 1893.

The soil temperature is always higher than the air temperature in cold weather and lower than the air temperature in hot weather. Based on the records from the Hong Kong Observatory, in winter, the soil temperature at 0.5 m depth is generally 2.1°C - 3°C higher than the air temperature while the soil temperature at 1.5 m depth is generally 2.6°C - 6.0°C higher than the air temperature.

Suggestion

To be conservative, it is recommended that the brittleness temperature for corrugated sheathing should be lower than - 5°C.

- **Brittleness temperature** is suggested to be **≤ - 5°C**.

5.2.3 Environmental Stress Cracking Resistance (ESCR)

Test Method and Test Specimen

ASTM D1693-08 (ASTM, 2008c) is the current test method for determination of ESC resistance of plastics. Sheet specimen molded in accordance with ASTM D4703 or cut from smooth sheet shall be used. During the test, bent specimens of the plastics, each having a controlled imperfection on one surface, are exposed to the action of a surface-active agent. The proportion of the total number of specimens that crack in a given time is observed.

A testing method on corrugated plastic pipe is found in AASHTO M252-09. The testing method is generally the same as that in ASTM D1693-08 except for some modifications with regard to specimen preparation. A 90-degree arc length of pipe cut from corrugated sheathing is used as the specimen. Since specimens cut from the final product of

Table of Contents
Table of Contents
Table of Contents
Table of Contents

corrugated sheathing can be used, AASHTO M252-09 is proposed instead of ASTM D1693-08.

Although nonylphenoxy poly (ethyleneoxy) ethanol is recommended as the reagent in AASHTO M252-09, AASTM D1693-08 states that other surface-active agents, soaps, or any liquid organic substance that is not absorbed appreciably by the polymer can also be used. In the current local practice, soap water (10% by volume) at 50℃ is usually used. The use of nonylphenoxy poly (ethyleneoxy) ethanol or soap water (10% by volume) at 50℃ as the reagent in the test shall be further reviewed after some trials using the new testing method have been conducted.

Typical Ranges and Local and International Standards

The typical ranges of ESC resistance of PVC, HDPE and PP are not available.

The acceptance criteria stipulated in the local and international standards are summarized in Table 5.8.

Table 5.8 Acceptance Criteria in Local and International Standards for ESC Resistance

Property	Unit	Acceptance Criteria			
		Geospec 1, BS 8081:1989 (1) FIP (1986) (2)	Lazarte et al (2003) (3) Sabatini et al (1999) (3) AASHTO (2000) (3)	Corven & Moreton (2004)	fib (2000)
		PVC, HDPE, PP (raw material)	HDPE (corrugated sheathing)	PE (raw material)	HDPE, PP (raw material)
ESC resistance	hrs	200 (No cracking)	24 (No cracking)	192 (max 20% failure)	192 (No cracking)

Notes:
(1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.
(3) The literatures refer to AASHTO Standard M252-09 which is designed for drainage pipe and the testing of environmental stress cracking resistance is specified for HDPE only, but not PVC or PP.

Discussion

Environmental stress cracking is the surface-initiated brittle fracture of a polymer

Table of Contents
Table of Contents
Table of Contents
Table of Contents

under stress when in contact with a medium in the absence of which fracture does not occur under the same conditions of stress (Vasile & Pascu, 2005). Accelerated test methods are generally employed to maintain or optimize material quality. Increasing the test temperature is frequently used but this must be below 50℃ where morphological changes are induced (Vasile & Pascu, 2005). Increasing the applied stress is not an option because it induces ductile failure.

Suggestion

No literature discussing the acceptable limits of ESC resistance can be found. Among the local and international literatures, the duration specified in Geospec 1 is the longest. Taking into consideration the uncertainties involved, it is recommended to adopt the acceptance criteria of ESC resistance given in Geospec 1.

- **Environmental stress cracking resistance** is suggested to be "**200 hours, no cracking**".

5.2.4 Water Absorption

Test Method and Test Specimen

Water absorption should be examined according to ASTM D570-98 (R2010) (ASTM, 1998a). It refers to the increase in weight (%) after being immersed in distilled water. In the test, the test specimen shall be in the form of a disk of 50.8 mm in diameter and 3.2 mm in thickness.

Typical Ranges and Local and International Standards

The typical ranges of water absorption of PVC, HDPE and PP is tabulated in Table 5.9.

Table 5.9 Typical Ranges of Water Absorption of PVC, HDPE and PP

Property	Unit	Typical Range		
		PVC	HDPE	PP
Water absorption	%	0.04 to 0.4 (Nass, 1992; Maier & Calfut, 1998; Biron, 2007)	0.005 to 0.01 (Vasile & Pascu, 2005)	0.01 to 0.02 (Maier & Calfut, 1998; Tasdemir, 2003; Gregorová et al, 2005; Zhiping et al, 2010)

The acceptance criteria of the local and international standards are summarized in Table 5.10.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 5.10 Acceptance Criteria in Local and International Standards for Water Absorption

Property	Unit	Acceptance Criteria in Geospec 1, BS 8081:1989 (1), FIP (1986) (2)		
		PVC (raw material)	HDPE (raw material)	PP (raw material)
Water absorption	%	≤ 0.5		

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1)in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Discussion

As shown in Table 5.9, PVC, HDPE and PP materials are virtually impermeable to water (Vasile & Pascu, 2005). The maximum water absorption of PVC, HDPE and PP are 0.4%, 0.01% and 0.04% respectively. The small values are due to the non-polar nature of the materials and they make water absorption not a dominant factor influencing degradation of materials (Patrick, 2005). Previous researches indicate that water absorption is largely unaffected by fillers and additives, although a marginal increase does occur with the use of calcium carbonate fillers (Maier & Calafut, 1998). Changes in relative humidity have no effect on water absorption of the materials and only very slight water uptake can be determined even when the specimen is moved to a hot and damp atmosphere (Vasile & Pascu, 2005).

Suggestion

No literature discussing the acceptance value of water absorption can be found. Except Geospec 1, no literature specifies criteria for water absorption. It is therefore recommended to adopt the acceptance criterion of water absorption specified in Geospec 1.

- **Water absorption** is suggested be **≤ 0.5%**.

5.2.5 Fungal Resistance

Test Method and Test Specimen

ASTM G21-09 (ASTM, 2009b) is the current test method for determining fungal resistance of thermoplastics in the form of moulded and fabricated articles, tubes, rods, sheets, and film materials. The test methods consist of selection of suitable specimens for determination of pertinent properties, inoculation of the selected specimens with suitable organisms, exposure of inoculated specimens under conditions favourable to growth, examination and rating for visual growth, and removal of the specimens from the favourable

Table of Contents
Table of Contents
Table of Contents
Table of Contents

conditions and observations for testing, either before cleaning or after cleaning and reconditioning.

The test specimen may be a 50 mm by 50 mm piece, a 40 mm diameter piece, or a piece (rod or tubing) at least 76 mm long cut from the material to be tested (ASTM, 2009b). Although a piece of tubing can be used as the test specimen, the standard does not provide any guidelines on measurement of the coverage of fungi growth for samples with corrugations. Therefore, the use of specimens cut from corrugated sheathing may not be appropriate for determining the rating of the observed growth of fungi on the specimens.

Typical Ranges and Local and International Standards

The typical ranges of fungal resistance of PVC, HDPE and PP are tabulated in Table 5.11.

Table 5.11 Typical Ranges of Fungal Resistance of PVC, HDPE and PP

Property	Unit	Typical Range		
		PVC	HDPE	PP
Fungal resistance	-	Should be free of attack of fungi		

The acceptance criteria stipulated in the local and international standards are summarized in Table 5.12.

Table 5.12 Acceptance Criteria in Local and International Standards for Fungal Resistance

Property	Unit	Acceptance Criteria in Geospec 1, BS 8081:1989 [(1)], FIP (1986) [(2)]		
		PVC (raw material)	HDPE (raw material)	PP (raw material)
Fungal resistance	-	Rating 1 or less (Traces of growth less than 10% of the surface area)		

Notes: [(1)] The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
[(2)] The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Table of Contents Table of Contents Table of Contents Table of Contents

Discussion

The synthetic polymer portion of PVC, HDPE and PP materials is usually fungus-resistant in that it does not serve as a carbon source for the growth of fungi (Maier & Calafut, 1998; Vasile & Pascu, 2005; Biron, 2007). It is generally the other components, such as plasticizers, cellulosics, lubricants, stabilizers, and colorants, that are responsible for fungus attack on plastic materials (ASTM, 2009b).

Suggestion

No literature discussing the acceptance value of fungal resistance can be found. Except Geospec 1, no literature specifies criteria for fungal resistance. Since PVC, HDPE and PP generally are free of attack of fungi, the best rating is recommended for the fungal resistance.

- **Fungal resistance** is suggested to be **rating 1 or less (traces of growth less than 10% of the surface area)**.

5.2.6 Hardness

Test Method and Test Specimen

BS EN ISO 868:2003 (BSI, 2003) and ASTM D2240-05 (R2010) (ASTM, 2005) are the current test methods for determining indentation hardness (also known as durometer hardness or shore hardness). As Geospec 1 uses BS test method for hardness, the test method in BS EN ISO 868:2003 is recommended.

Type A and Type D are the two most commonly used types of durometer. Type D durometer is used for harder materials and is recommended in this report for testing PVC, HDPE and PP. This test is based on the penetration of a specific type of indentor when forced into the material under specified conditions. The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behaviour of the material (ASTM, 2005).

According to the standard, the test specimen shall be at least 4 mm thick. The dimensions shall be sufficient to permit measurements at least 9 mm away from any edges. The surface of the test specimen shall be flat over an area sufficient to permit the presser foot to be in contact with the test specimen over an area having a radius of at least 6 mm from the indenter point. Satisfactory durometer hardness determinations cannot be made on rounded, uneven or rough surfaces (BSI, 2003).

Typical Ranges and Local and International Standards

The typical ranges of hardness (Shore D) (shore hardness determined by Type D durometer) of PVC, HDPE and PP are tabulated in the Table 5.13.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 5.13 Typical Ranges of Hardness (Shore D) of PVC, HDPE and PP

Property	Unit	Typical Range		
		PVC	HDPE	PP
Hardness (Shore D)	-	15 to 90 (Biron, 2007)	65 to 90 (Vasile & Pascu, 2005)	85.2 to 98.1 (Maier & Calfut, 1998)

The acceptance criteria stipulated in the local and international standards are summarized in Table 5.14.

Table 5.14 Acceptance Criteria in Local and International Standards for Hardness (Shore D)

Property	Unit	Acceptance Criteria				
		Geospec 1, BS 8081:1989 (1) FIP (1986) (2)			fib (2000)	
		PVC	HDPE	PP	HDPE	PP
		(raw material)			(raw material)	
Hardness (Shore D)	-	≥ 65			Not the same testing method (3)	

Notes:
(1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.
(3) fib (2000) discusses corrugated plastic ducts for internal bonded post-tensioning. The hardness is tested in according to ISO 2039-1 (ISO, 2001) using a different indenter and different equation for calculating the value of hardness as compared to BS EN ISO 868:2003 or ASTM D2240-05 (R2010).

Discussion

The testing of hardness (Shore D) is an empirical method intended primarily for control purposes. No simple relationship exists between indentation hardness determined by this method and any fundamental property of the material tested (BSI, 2003; ASTM, 2005).

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Suggestion

Except Geospec 1, no other literature specifics criteria for hardness (Shore D). It is therefore recommended to adopt the acceptance criterion of hardness (Shore D) specified in Geospec 1.

- **Hardness (Shore D)** is suggested be **≥ 65**.

5.2.7 Elongation at Break

Test Method and Test Specimen

ASTM D638-10 (ASTM, 2010a) is the current testing standard for elongation at break. BS 2782-3:Methods 320A to 320F:1976 (BSI, 1976b) was withdrawn on 1 January 2012. there is currently no replacement standard for this test. The ASTM standard for testing tensile properties, ASTM D638-10 (ASTM, 2010a), is therefore recommended.

According to the standard, the specimen shall be 4 mm to 14 mm thick. It shall be 63.5 mm to 165 mm long and 19 mm to 29 mm wide depending on the thickness of the specimen. The specimen shall conform to the shape shown in Figure 5.3.

During the test, the specimen is stressed and extended under a specified condition and speed. The elongation at break is recorded and the percentage (elongation/initial length) calculated.

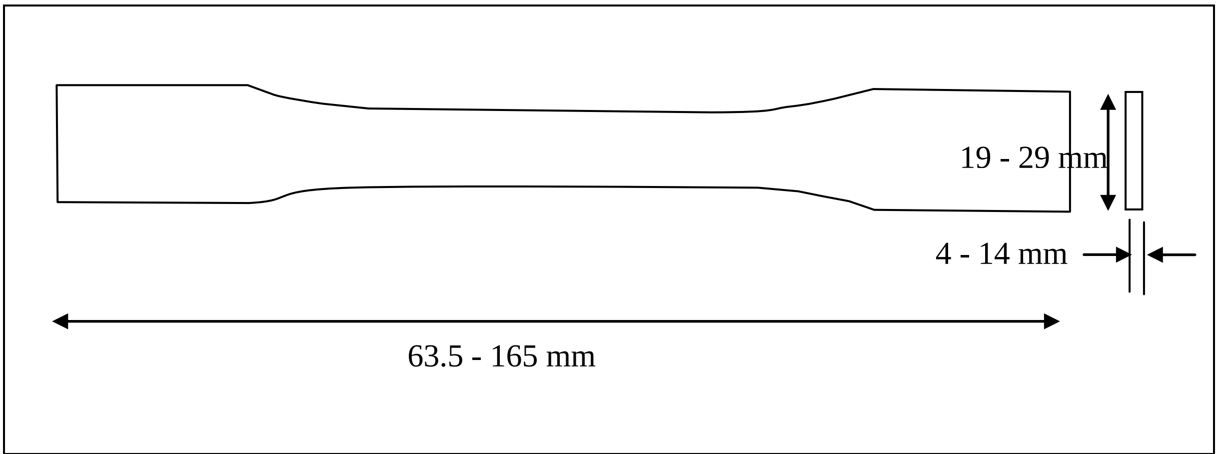


Figure 5.3 Shape of Specimen for Testing Tensile Strength

Typical Ranges and Local and International Standards

The typical ranges of elongation at break of PVC, HDPE and PP are tabulated in Table 5.15.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 5.15 Typical Ranges of Elongation at Break of PVC, HDPE and PP

Property	Unit	Typical Range		
		PVC	HDPE	PP
Elongation at break	%	6 to 144 (Nass, 1992)	10 to 150 (Vasile & Pascu, 2005)	8 to 350 (Maier & Calfut, 1998)

The criteria of the local and international standards are summarized in Table 5.16.

Table 5.16 Acceptance Criteria in Local and International Standards for Elongation at Break

Property	Unit	Acceptance Criteria		
		Geospec 1	fib (2000)	
		PVC, HDPE, PP	HDPE (raw material)	PP (raw material)
Elongation at break	%	NA	≥ 7	≥ 10

Discussion

The stability of a soil-nailed slope is maintained through the mobilisation of tensile forces in the passive zone of the soil nails. When the soil nails are in action, the corrugated sheathing should be more ductile than the protected steel bar.

Suggestion

According to CS 2:2012 (HKG, 2012), the elongation at break of the steel bars used in a soil nail system is 12%. In order to ensure the corrugated sheathing will not break during the service life of the soil nails, the elongation at break for the corrugated sheathing should not be lower than that of the steel bars. Therefore, 12% is recommended.

- **Elongation at break** is suggested to be **≥ 12%**.

5.2.8 Tensile Strength

Test Method and Test Specimen

ASTM D638-10 (ASTM, 2010a) is the current testing standard for tensile strength.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

The ASTM standard for testing tensile properties, ASTM D638-10 (ASTM, 2010a), is recommended.

The testing method and testing specimens are the same as those for testing elongation at break. However, the load, instead of the extension, at the yield point is recorded in the test.

Typical Ranges and Local and International Standards

The typical ranges of tensile strength of PVC, HDPE and PP are tabulated in Table 5.17.

Table 5.17 Typical Ranges of Tensile Strength of PVC, HDPE and PP

Property	Unit	Typical Range		
		PVC	HDPE	PP
Tensile strength	MPa	10 to 60 (Biron, 2007)	20 to 35 (Vasile & Pascu, 2005)	16 to 90 (Maier & Calfut, 1998)

The criteria of the local and international standards are summarized in Table 5.18.

Table 5.18 Acceptance Criteria in Local and International Standards for Tensile Strength

Property	Unit	Acceptance Criteria							
		Geospec 1, BS 8081:1989 [(1)] FIP (1986) [(2)]			Lazarte et al (2003), Sabatini et al (1999)	Corven & Moreton (2004)		fib (2000)	
		PVC	HDPE	PP	PVC	PE	PP	HDPE	PP
		(raw material)			(raw material)	(raw material)		(raw material)	
Tensile strength	MPa	≥ 45	≥ 29	≥ 30	≥ 48.3	21-24	≥ 20 & < 35	≥ 22	≥ 24

Notes:
(1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Discussion

Different criteria were adopted for different materials in Geospec 1. It is likely that the criteria were proposed for quality control of the forming materials, but not for the functioning of ground anchors.

Suggestion

As discussed in Section 4.2.2.3, the tensile stress taken by the corrugated sheathing is minimal. Besides, there is no literature about the tensile stress to be sustained by corrugated sheathing. The criteria adopted in Geospec 1, which can serve the purpose of quality control, are therefore recommended.

- **Tensile strength of PVC** is suggested to be **≥ 45** kPa.
- **Tensile strength of HDPE** is suggested to be **≥ 29** kPa.
- **Tensile strength of PP** is suggested to be **≥ 30** kPa.

5.2.9 Density

Test Method and Test Specimen

BS EN ISO 1183-1:2004 (BSI, 2004b) Method A is the current test method for determination of the density of plastics. The density of specimen is determined by weighing the specimen in the immersion liquid. The specimen may be in any void-free form except for powder.

Typical Ranges and Local and International Standards

The typical ranges of density of PVC, HDPE and PP are tabulated in Table 5.19.

Table 5.19 Typical Ranges of Density of PVC, HDPE and PP

Property	Unit	Typical Range		
		PVC	HDPE	PP
Density	kg/m^3	1150 to 1500 (BSI, 1973; Biron, 2007)	935 to 965 (BSI, 1973; Gabriel, unknown)	900-910 (BSI, 1973)

The acceptance criteria stipulated in the local and international standards are summarized in Table 5.20.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 5.20 Acceptance Criteria in Local and International Standards for Density

Property	Unit	Acceptance Criteria			
		Geospec 1, BS 8081:1989 (1) FIP (1986) (2)			Corven & Moreton (2004) (3)
		PVC	HDPE	PP	PE
		(raw material/corrugated sheathing)			(raw material/corrugated sheathing)
Density	kg/m^3	1350 - 1400	940 - 950	900 - 910	940 - 947

Notes:
(1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.
(3) fib (2000) discusses about corrugated plastic ducts for internal bonded post-tensioning.

Discussion

In Geospec 1, the criteria for density of different materials (PVC, HDPE and PP) are different and the values are comparable to the typical ranges of the materials. It is likely that the criteria for density in Geospec 1 are the typical values for PVC, HDPE and PP and are not related to their use in soil nails or ground anchors.

The density alone cannot determine the properties of a thermoplastic since the density can be altered a lot by adding different additives or fillers (Biron, 2007). For example, a mineral filler-reinforced PP may have a density 1.2 times the neat PP, while the tensile strength may be reduced to 70% of the neat PP. With a very similar density, a polyamide with a nanofiller of natural layered silicate has significantly better thermomechanical properties than the neat polyamide (Biron, 2007).

Suggestion

As discussed, the density of PVC, HDPE and PP varies due to the present of additives. It is recommended to adopt wider ranges as acceptance criteria.

- **Density of PVC** is suggested to be **1150 - 1500** kg/m^3.
- **Density of HDPE** is suggested to be **935 - 965** kg/m^3.
- **Density of PP** is suggested to be **900 - 910** kg/m^3.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

5.3 Properties of Corrugated Plastic Pipe

5.3.1 Hydrostatic Pressure Resistance

Test Method and Test Specimen

BS EN 13244-2:2002 (BSI, 2002) is the present standard for determining hydrostatic pressure resistance. Details of the testing procedure and the preparation of testing specimens shall refer to BS EN 1167-1:2006 (BSI, 2006a) and BS EN 1167-2:2006 (BSI, 2006b) respectively. ASTM D2837-08 (ASTM, 2008d) provides similar testing standard. However, as Geospec 1 uses BS test method for hydrostatic pressure resistance, the testing standard in BS EN 1344-2:2002 is recommended.

During the test, the specimen is filled with water. Pressure is then applied progressively and smoothly until the test pressure is achieved. The test is terminated either when the specified duration is reached, or when a failure or leak occurs in the test piece (BSI, 2006a).

Unlike drainage pipes, the internal pressure of corrugated sheathing used in soil nails is small and is restrained by the grout around. Therefore, the criteria for the lowest grade in BS EN 13244-2:2002, i.e. PE 63, is recommended. The testing parameters for grade PE 63 are as follows:

Table 5.21 Recommended Testing Parameters for Hydrostatic Pressure Resistance

Condition	Test Temperature	Test Period	Circumferential (Hoop) Stress
1	20°C	100 hours	8.0 MPa
2	80°C	165 hours	3.5 MPa
3	80°C	1000 hours	3.2 MPa
Note:	The specimens should be tested under all three test conditions above.		

The test specimen shall be a pipe of about 140 mm to 250 mm long, depending on the type of moulding (BSI, 2006b).

Typical Ranges and Local and International Standards

The typical ranges of hydrostatic pressure resistance of PVC, HDPE and PP are not available.

The acceptance criteria stipulated in the international standards are summarized in Table 5.22.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 5.22 Acceptance Criteria in Local and International Standards for Hydrostatic Pressure Resistance

Property	Unit	Acceptance Criteria	
		Geospec 1, BS 8081:1989 (1) FIP (1986) (2)	Corven & Moreton (2004)
		PVC, HDPE & PP (Corrugated sheathing)	PE (Corrugated sheathing)
Hydrostatic pressure resistance	-	No localised swelling, leaking or weeping	No bursting, cracking, splitting, or weeping

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Discussion

Although corrugated sheathing may have to withstand internal hydrostatic pressure during grouting, the internal pressure would not be large as the grout is filled by gravity only.

Suggestion

The acceptance criterion for hydrostatic pressure resistance stipulated in Geospec 1 is recommended.

- The criterion for **Hydrostatic pressure resistance** is suggested to be **no localised swelling, leaking or weeping**.

5.3.2 Pipe Stiffness

Test Method and Test Specimen

AASHTO M252-09 (AASHTO, 2009) is the present test method for determining pipe stiffness. The method is similar to ASTM D 2412 (ASTM, 2002) with some specific modifications for corrugated pipe. In the test, a 300 mm length of pipe (cut to include full corrugations) is loaded between two rigid parallel flat plates at a controlled rate of approach to one another. Load per unit length of pipe (F) and diametral deflection of the pipe (Δ) are obtained to get the pipe stiffness (F/Δ), while % deflection is given by (Δ/pipe diameter).

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Typical Ranges and Local and International Standards

The typical ranges of pipe stiffness of PVC, HDPE and PP are not available.

The acceptance criteria stipulated in the international standards are summarized in Table 5.23.

Table 5.23 Acceptance Criteria in Local and International Standards for Pipe Stiffness

Property	Unit	Acceptance Criteria in Lazarte et al (2003) [(1)], Sabatini et al (1999) [(1)], AASHTO (2010) [(1)]
		HDPE (Corrugated sheathing)
Pipe stiffness	kPa	≥ 240 at 5% deflection

Note: [(1)] Lazarte et al (2003), Sabatini et al (1999), AASHTO (2010) are literatures for soil nails and ground anchors. The requirement for pipe stiffness in all these literatures refers to AASHTO Standard M252-09 which is designed for drainage pipe.

Discussion

As discussed before, pipe stiffness plays an important role in the performance of corrugated sheathing. Pipe stiffness can be obtained by means of parallel plate test and it is equal to applied force divided by the corresponding deflection. AASHTO M252-09 requires a minimum pipe stiffness of 240 kPa at 5% deflection.

Suggestion

The acceptance criterion for pipe stiffness stipulated in the reviewed literatures are recommended.

- **Pipe stiffness** is suggested to be **≥ 240 kPa at 5% deflection**.

Taking into account the different loading conditions between drainage pipes and corrugated sheathing, the acceptance criteria for pipe stiffness of corrugated sheathing should be further reviewed after some trials using the new testing method have been conducted.

5.3.3 Pipe Flattening

Test Method and Test Specimen

AASHTO M252-09 (AASHTO, 2009) is the present test method for determining pipe

Table of Contents
Table of Contents
Table of Contents
Table of Contents

flattening. The method is the same as that for pipe stiffness except that the specimen is loaded until the vertical inside diameter is reduced by 20% instead of 5%. Besides, the value of loading is no longer the acceptance criterion. Instead, the specimen shall be free of buckling, cracking, splitting and delaminating.

The test specimen shall be the same as that for pipe stiffness, i.e. 300 mm long, cut to include full corrugations.

Typical Ranges and Local and International Standards

The typical ranges of pipe flattening of PVC, HDPE and PP are not available.

The acceptance criteria stipulated in the international standards are summarized in Table 5.24.

Table 5.24 Acceptance Criteria in Local and International Standards for Pipe Flattening

Property	Unit	Acceptance Criteria in Lazarte et al (2003) [1], Sabatini et al (1999) [1], AASHTO (2010) [1]
		HDPE (Corrugated sheathing)
Pipe flattening	-	No cracking at 20% deflection

Note: [1] Lazarte et al (2003), Sabatini et al (1999), AASHTO (2010) are literatures for soil nails and ground anchors. The requirement for pipe flattening in all these literatures refers to AASHTO Standard M252-09 which is designed for drainage pipe.

Discussion

As discussed before, pipe flattening indicates indirectly the ductility of the corrugated sheathing. AASHTO M252-09 requires no cracking at 20% deflection during the test of pipe flattening.

Suggestion

The acceptance criterion for pipe flattening stipulated in the reviewed literatures are recommended.

- **Pipe flattening** is suggested to be **no cracking at 20% deflection**.

Table of Contents Table of Contents Table of Contents Table of Contents

5.3.4 Pipe Geometry

Test Method and Test Specimen

ASTM D2122-98 (R2010) (ASTM, 1998b) is the current test method for determining dimensions of plastic pipes. This test method covers the determination of diameter, wall thickness, and length dimensions of thermoplastic pipes.

No standard method for measuring pitch and amplitude of corrugation has been found. However, the pitch of corrugation can be determined by cutting a corrugated sheathing at the peak or trough at both ends and measuring the length of the cut pipe according to ASTM D2122-98 (R2010). The pitch can then be calculated as follows:

$$\text{pitch} = \frac{\text{length of pipe}}{\text{no. of corrugation}} \quad \text{.. (5.1)}$$

The amplitude can be determined by measuring the outside diameter at the peak and the inside diameter at the trough according to ASTM D2122-98 (R2010). The amplitude can be calculated as follows:

$$\text{amplitude} = \frac{\text{(outside diameter at peak - inside diameter at trough)}}{2} \quad \text{......... (5.2)}$$

Typical Ranges and Local and International Standards

The typical ranges of thickness of pipe, pitch and amplitude of corrugation of PVC, HDPE and PP are not known.

Geospec 1 requires a minimum thickness of 1 mm for corrugated sheathing. However, no requirements on the pitch and amplitude of corrugation are included. For international practice, most of the literatures include requirements on minimum thickness. However, only two of them include requirements on pitch and amplitude of corrugation. The acceptance criteria in local and international standards are summarized in Tables 5.25 and 5.26.

Table 5.25 Acceptance Criteria in Local and International Standards for Thickness

Property	Unit	Acceptance Criteria						
		Geospec 1	Lazarte et al (2003) [1]		Sabatini et al (1999) [1]	BS 8081:1989	AASHTO (2010) [1]	CIRIA (2005)
		PVC, HDPE & PP	HDPE	PVC	HDPE & PVC	PVC, HDPE & PP	PVC & HDPE	PVC & HDPE
Thickness	mm	1	1	0.8	1	0.8 - 1.5	0.8	0.5 - 1.0

Note: [1] Lazarte et al (2003), Sabatini et al (1999), AASHTO (2010) are literatures for soil nails and ground anchors.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 5.26 Acceptance Criteria in Local and International Standards for Pitch and Amplitude of Corrugation

Property	Unit	Acceptance Criteria in BS 8081:1989 [(1)], FIP (1986) [(2)] for PVC, HDPE & PP
Pitch of corrugation	-	6 to 12 times the wall thickness
Amplitude of corrugation	-	≥ 3 times the wall thickness

Notes: (1) The standard adopts the requirements specified in GCO Publication No. 3/84 (which has been superseded by Geospec 1) in its Appendix K.
(2) The standard adopts the properties specified by GCO Publication No. 3/84 or Geospec 1 in its Appendix 3 for information.

Discussion

The bond strength between grout and corrugated sheathing depends on the geometry of the sheathing which includes wall thickness, pitch and amplitude/depth of corrugation (FIP, 1986; BSI, 1989).

In order to provide the corrugated sheathing with sufficient stiffness for handling as well as to ensure effective bond strength between sheathing and grout, the wall thickness should be at least 1 mm, the pitch should be 6 to 12 times the wall thickness and the amplitude of corrugation should be ≥ 3 times the wall thickness (FIP, 1986; BSI, 1989).

Suggestion

- **Pipe geometry** is suggested to satisfy:

  (a) wall thickness $t \geq 1$ mm;
  (b) $12t \geq$ pitch $\geq 6t$; and
  (c) amplitude of corrugation $\geq 3t$.

5.4 Summary

A summary of the above discussions is given in Table 5.27, which tabulates the recommended properties, acceptance criteria and test method for material selection. In addition, the requirements in Table 2 of Geospec 1 are also listed in Table 5.27 for comparison. Based on the present study, nine properties, namely density, Vicat softening point, brittleness temperature, environmental stress cracking resistance, water absorption, fungal resistance, hardness (Shore D), tensile strength and hydrostatic pressure resistance are recommended to be tested for selection of corrugated sheathing. One property (bacteria resistance), which is employed in Geospec 1 for material selection, is not recommended.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 5.27 Properties and Criteria for Material Selection Compared with the Requirements in Table 2 of Geospec 1

Property	Geospec 1						Recommended					
	Test Method	Specimen Cut from Corrugated sheathing	Unit	Acceptance Criterion			Test Method	Specimen Cut from Corrugated sheathing	Unit	Acceptance Criterion		
				PVC	HDPE	PP				PVC	HDPE	PP
Density	BS 2782: Part 6: 1980, Method 620A	√ [(1)]	kg/m^3	1350-1400	950-940	900-910	BS EN ISO 1183-1:2004 Method A	√ [(1)]	kg/m^3	1150 - 1500	935 - 965	900 - 910
Vicat softening point	BS 2782: Part 1: 1976, Method 120A		℃	≥ 75	≥ 110	≥ 150	BS EN ISO 306 -04		℃	≥ 75		
Brittleness temperature	ASTM D746 -79		℃	≤ 5			ASTM D746 -07		℃	≤ - 5		
Environmental stress cracking resistance	ASTM D1693-70 (1980)		hours	200 (No cracking)			AASHTO M 252-09	√	hours	200 (No cracking)		
Water absorption	ASTM D570 - 81 (Long term immersion)		%	≤ 0.5			ASTM D570 - 98 (R2010) (Long term immersion)		%	≤ 0.5		
Fungal resistance	ASTM G21 - 70 (1980)		-	Rating 1 or less (Traces of growth less than 10% of the surface area)			ASTM G21 - 09		-	Rating 1 or less (Traces of growth less than 10% of the surface area)		
Hardness (Shore D)	BS 2782: Part 3: 1981, Method 365B		-	≥ 65			BS EN ISO 868:2003		-	≥ 65		
Tensile strength	BS 2782: Part 3: 1976, Method 320C		MPa	≥ 45	≥ 29	≥ 30	ASTM D638 - 10		MPa	≥ 45	≥ 29	≥ 30
Hydrostatic pressure resistance	BS 6437:1984	√	-	No localised swelling leaking or weeping			BS EN 13244-2:2002 (grade PE 63)	√	-	No localised swelling, leaking or weeping		
Bacteria resistance	ASTM G22 - 76 (1980) procedure B		-	No bacteria growth on surface of specimen			Not Recommended					

Notes: √ denotes the specimen is cut from corrugated sheathing.
(1) The specimens may be in any void-free form except for powder.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Based on the above discussions, apart from the nine properties recommended in Table 5.27, another four properties listed in Table 5.28 are also recommended as criteria for material selection although they are not included in Table 2 of Geospec 1.

Table 5.28 Additional Properties Suggested to Be Criteria for Material Selection

Property	Test Method	Specimen Cut from Corrugated sheathing	Unit	Criteria
Elongation at break	ASTM D638 - 10		%	≥ 12
Pipe stiffness and pipe flattening	AASHTO M 252-09	√	-	≥ 240 kPa at 5% deflection, no cracking at 20% deflection
Pipe geometry	ASTM D2122-98 (R2010)	√	-	Wall thickness: ≥ 1 mm Pitch: 6 to 12 times the wall thickness Amplitude of corrugation: ≥ 3 times the wall thickness

Note: √ denotes the specimen is cut from corrugated sheathing.

Although Geospec 1 and some of the literatures reviewed are based on ground anchors, the recommendations in Tables 5.27 and 5.28 are considered suitable for soil nail application only. The requirements for ground anchors may be similar, but not necessarily the same as those for soil nails.

5.5 Proposed Trial Laboratory Tests

Currently, the density of corrugated plastic pipe is usually carried out on specimens made from raw materials. Trial tests on density using specimens from both raw materials and final products is proposed to review the possible changes of properties during manufacturing.

For ESC resistance, a new testing method in ASSHTO M252-09 using final products of corrugated sheathing is recommended (see Section 5.2.3). Therefore, trial laboratory test is recommended to review the practicality of the new testing method.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Testing on elongation at break, pipe wall geometry, pipe stiffness and pipe flattening are new requirements. In order to review the practicality of these requirements (both testing methods and acceptance criteria), trial laboratory tests for these requirements are recommended.

6 Fabrication Details

6.1 End Cap

Generally, two types of end caps for corrugated sheathing are used in Hong Kong. The first type is an end cap with threaded connection. It is connected to the corrugated sheathing by screwing. A grout tube can be connected to this type of end cap as shown in Figure 6.1 for grouting the inner annular space between the wall of sheathing and soil-nail reinforcement. However, some contractors have indicated that this grout tube can be easily jammed due to bending of the grout tube. They would therefore seal the hole at the end cap and insert a grout tube inside the corrugated sheathing for grouting (see Figure 6.2).

The second type is a "snap end cap" as shown in Figure 6.3. The inner annular space between the wall of sheathing and soil-nail reinforcement is grouted by inserting a grout tube inside the sheathing.

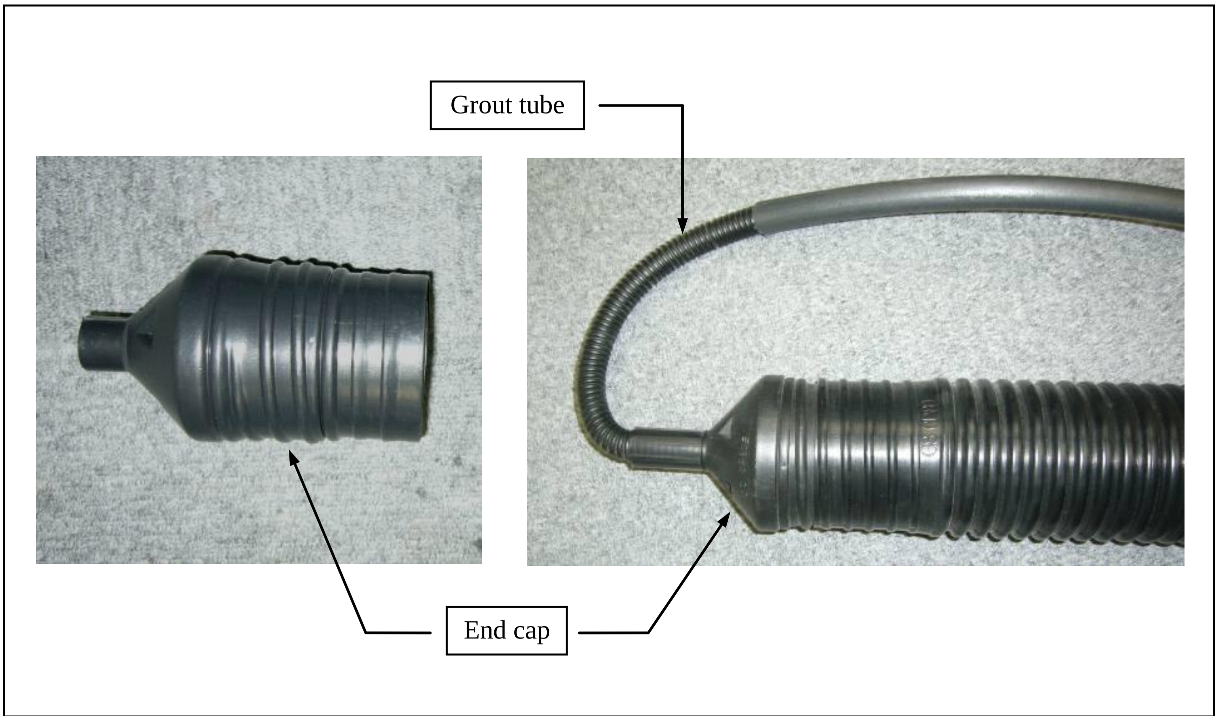


Figure 6.1 End Cap with Threaded Connection

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Figure 6.2 Sealed End Cap

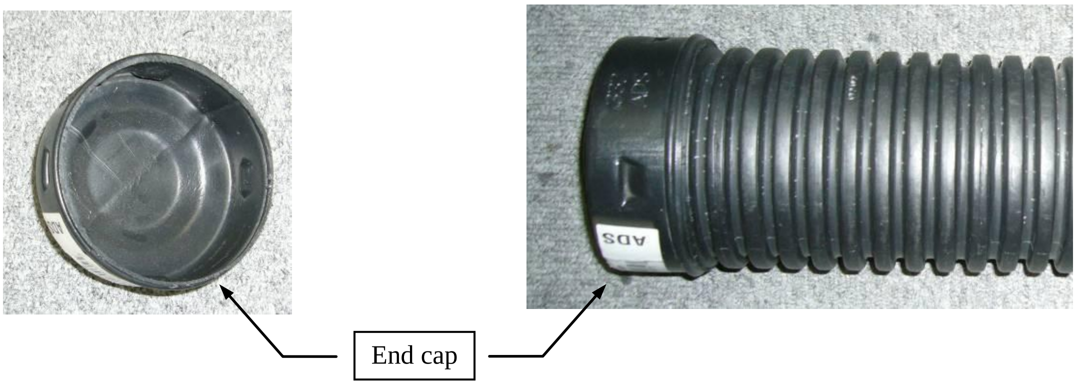


Figure 6.3 Snap End Cap

6.2 Sheathing Connection Used in Hong Kong

There are two types of connections commonly used in Hong Kong for connecting two individual pieces of corrugated sheathing to increase the total length. The first type consists of a threaded connection as shown in Figure 6.4, in which the pieces of corrugated sheathing are connected by screwing. The second type makes use of a joint casing with one-way snaps on both ends as shown in Figure 6.5. It is found that both types of connection are efficient in engineering practice.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Figure 6.4 The Screw Type Connection of Corrugated Sheathing

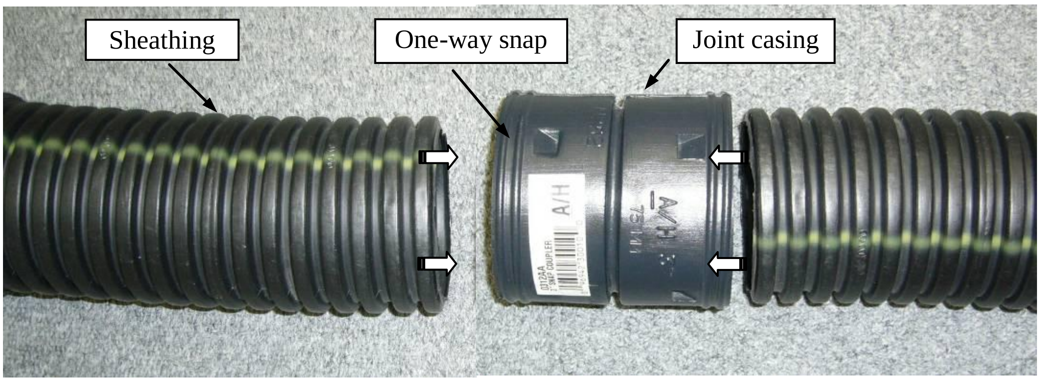
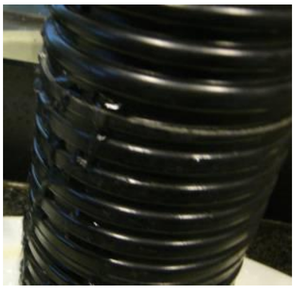


Figure 6.5 The Joint Casing Connection of Corrugated Sheathing

Both types of end caps and connections are however not watertight (Figure 6.6). Contractors should therefore either design a watertight connection or adopt heat shrink sleeve, if practicable, to improve watertightness.

If heat shrink sleeve is used to improve watertightness at the joints, the shrinkage temperature of the sleeve should be lower than the Vicat softening point of the corrugated sheathing.

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Screw type connection

Joint casing

Screw type end cap

Figure 6.6 Water Leakage at the Connection and End Cap

6.3 Sheathing Connection Used Overseas

6.3.1 Coupler

Corrugated plastic pipes are commonly used as drain pipes. Couplers for connecting corrugated drain pipes are available in the market, which may be suitable for use in corrugated sheathing in a soil-nail system, provided that these couplers will remain intact and the joints will maintain watertightness after installation of the soil nails.

6.3.2 Bell-and-spigot Joint

Bell-and-spigot joint, another type of connection for corrugated pipe, may also be adopted. It is a watertight joint for corrugated polyethylene drainage pipe.

6.3.3 Elastomeric Seal

Elastomeric seal, in accordance with ASTM F477 (ASTM, 2010b), is also used for connection of corrugated plastic pipe[5].

6.4 Specification for Connection

According to General Specification for Civil Engineering Works (CEDD, 2006), gravity sewage and storm water pipes (uPVC pipes) and fittings below ground with diameter between 110 and 160 mm shall comply with BS 4660, in which test methods for tightness against leaking of elastomeric sealing ring type joints are specified. ASTM D 3212-07 (ASTM, 2007b) also provides the requirements and testing methods for flexible elastomeric seals.

[5] An example could be found in this link: http://www.baughmantile.com/dw15print.pdf.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

According to General Specification for Civil Engineering Works, water test or air test and infiltration test shall be carried out to test the completed pipeline. ASTM F1417-11a (ASTM, 2011) also specifies the water-tight field test requirements. However, these testing methods may not be suitable for testing the connections of corrugated sheathing in a soil-nail system as the completed form is different.

6.5 Way Forward

Site trial and further study shall be carried out to investigate the availability and practicability of other forms of sheathing connection and the suitable testing methods for testing the connections of corrugated sheathing in soil nails.

7 Storage

7.1 Factors Causing Deterioration of the Corrugated Sheathing

During storage, environmental factors including sunlight can cause deterioration of the corrugated sheathing. When thermoplastic is exposed to relatively high temperatures below its maximum operating temperature, gradual deterioration takes place (Maier & Calafut, 1998). The effect is known as thermal aging. It is an oxidation process and so is related to weathering (Maier & Calafut, 1998). The key factors at work in the process are:

(a) solar radiation;

(b) moisture in the form of humidity, condensation or rain;

(c) temperature; and

(d) pollutants including ozone, acid rain and so on.

The principal problem is solar radiation and more specifically, ultraviolet radiation. Some 6% of solar radiation consists of wavelengths below 400 nm, which is the upper limit of the ultraviolet region. The midrange UV-B radiation with a wavelength in the range 290 nm to 315 nm is by far the most damaging (Maier & Calafut, 1998; Vasile & Pascu, 2005).

Thermoplastic is highly susceptible to damage by exposure to the UV radiation in sunlight. The surface deteriorates by crazing to a chalky friable material of very low strength. The mechanism of UV thermoplastic failure is akin to oxidation as crystalline regions are more impervious to oxygen than amorphous regions.

Although pigments that are opaque to UV radiation can give a measure of protection, the fact remains that thermoplastic is intrinsically unsuited to sunlight exposure unless it is specially stabilized to resist photo-oxidation through the use of UV stabilizer additives (Maier & Calafut, 1998; Vasile & Pascu, 2005). Even then, there is likely to be some minor deterioration of the surface. The effect can often be noticed on garden furniture and stadium seating.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

As an example, it was found on a site that the corrugated sheathing delivered to site was less stiff than the product samples. As shown in Figure 7.1, the sheathing became oval in shape when squeezed by hand on site, and it is possible that the material properties of the corrugated sheathing could have been deteriorated during transportation and storage.

Figure 7.1 Oval Shape of Corrugated Sheathing Resulting from Squeezing by Hand

7.2 Counter Measures

During storage and before installation, corrugated sheathing is liable to be degraded by UV radiation. Therefore, the corrugated sheathing should be stored in a cool, dry, shaded location, on a raised platform, protected from weather and contamination (Clouterre, 1991).

However, it is not practical for site supervising personnel to check if there are suitable protective measures before the corrugated sheathing is delivered to site. The quality of the products delivered can be gauged by carrying out tests on their pipe stiffness and pipe flattening using samples collected on site.

8 Discussion

8.1 Current Practice and Problems

As discussed in Section 7, it had been found that some of the corrugated sheathing delivered to site was less stiff than normally expected (based on product samples) and that the sheathing could become oval in shape when squeezed by hand. A review of the current practice and standard of corrugated sheathing have therefore been undertaken to look for areas that deserve improvement.

Based on the review, the deficiencies are highlighted below:

Table of Contents
Table of Contents
Table of Contents
Table of Contents

(a) In Hong Kong, the corrugated sheathing used should comply with the requirements as stipulated in Table 2 of Geospec 1 according to the General Specification for Civil Engineering Works (CEDD, 2006). In accordance with the above General Specification, the Contractor is required to submit testing certificates indicating the suitability of the products. However, except for hydrostatic pressure resistance, all the tests stipulated in Table 2 of Geospec 1 are conducted on laminated specimens made from raw material (see Table 5.27). There is uncertainty that these specimens may not have the same properties as the final products, especially regarding structural and mechanical properties. No guidance to address the uncertainty can be found.

(b) Besides the uncertainty in respect of the quality of the products, the corrugated sheathing may be damaged during storage or handling. As discussed in Section 7, the corrugated sheathing can be degraded under adverse environmental conditions (e.g. high temperature, UV radiation, etc).

(c) Currently, there is no requirement for compliance tests to assure the quality of the products actually delivered to site.

8.2 Possible Areas for Improvement

As discussed in Section 4.2.3.3, there are technical difficulties in testing the carbon black content of plastics if the plastics contain non-volatile pigments or fillers other than carbon black and it is not suggested to include carbon black content for material selection of corrugated sheathing. The quality of the products should be maintained by good housekeeping practice and can be gauged by conducting relevant tests on the products delivered to site.

Some tests, including tests for density and ESC resistance (see Table 5.27), can be amended to be conducted on the final products. New tests including tests on pipe stiffness, pipe flattening and pipe geometry (See Table 5.28), which are conducted on final products, are recommended. These tests would directly reflect the properties of the corrugated sheathing.

A proposed specification is enclosed in Appendix B. The sampling frequency and number of additional samples in the event of non-compliances are adopted from those for drainage pipes in the General Specification for Civil Engineering Works (CEDD, 2006). Trial use of the proposed specification for corrugated sheathing in soil nails should be conducted before the proposed specification is implemented. The practicality of the test methods, the acceptance criteria proposed and the sampling frequency should also be reviewed.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

9 Conclusions and Recommendations

Long-term performance of soil nails depend on their ability to withstand corrosive attack from the environment. Due to its durability and water tightness, corrugated sheathing is one of the measures commonly used in an aggressive soil condition to protect the steel bars in a soil-nail system from corrosion during the design life. This report has reviewed both international and local standards related to material requirements when corrugated sheathing is used for corrosion protection. The working mechanism of corrugated sheathing in soil nails, together with the related material properties, has been discussed. Key material properties and properties of corrugated pipes have been reviewed and their corresponding testing criteria recommended for material selection (see Tables 5.27 and 5.28). Key recommendations are as follows:

(a) density, Vicat softening point, brittleness temperature, fungal resistance, ESC resistance, water absorption, hardness (Shore D), tensile strength, elongation at break, hydrostatic pressure resistance, pipe stiffness and pipe flattening, and pipe geometry are suitable parameters that should be tested for material selection;

(b) the practicality of carrying out the recommended testing (viz. density, ESC, elongation at break, pipe stiffness and pipe flattening, and pipe wall geometry) in Hong Kong should be further investigated by means of laboratory trials;

(c) the proposed acceptance criteria for the various properties of corrugated sheathing should be reviewed after further trial laboratory trials have been conducted;

(d) a watertight connection between the corrugated sheathing and the end caps should be used;

(e) a cool, dry and shaded area away from direct sunlight should be provided for storage of corrugated sheathing on site; and

(f) tests on density, ESC resistance, hydrostatic pressure resistance, pipe stiffness and pipe flattening may be carried out on corrugated sheathing delivered to site for quality control of the final products.

10 References

AASHTO (2009). *Standard Specification for Corrugated Polyethylene Drainage Pipe (AASHTO M252-09)*. American Association of State Highway and Transportation Officials, Washington, 9 p.

Table of Contents

Table of Contents

Table of Contents

Table of Contents

AASHTO (2010). *AASHTO LRFD Bridge Construction Specifications (3rd Edition).* American Association of State Highway and Transportation Officials, Washington.

American Water Works Association (2002). *PVC Pipe: Design and Installation (2nd Edition).* American Water Works Association, Denver, CO, 167 p.

ASTM International (1970a). *Standard Test Method for Environmental Stress-cracking of Ethylene Plastics (ASTM D1693-70 (1980)).* ASTM International, United States, 11 p.

ASTM International (1970b). *Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi (ASTM G21-70 (1980)).* ASTM International, United States, 4 p.

ASTM International (1976). *Standard Practice for Determining Resistance of Plastics to Bacteria (ASTM G22-76 (1980)).* ASTM International, United States, 3 p.

ASTM International (1979). *Standard Test Methods for Brittleness Temperature of Plastics and Elastomers by Impact (ASTM D746-79).* ASTM International, United States, 8 p.

ASTM International (1981). *Standard Test Methods for Water Absorption of Plastics (ASTM D570-81).* ASTM International, United States, 4 p.

ASTM International (1998a). *Standard Test Methods for Water Absorption of Plastics (ASTM D570-98 (Reapproved 2010)).* ASTM International, United States, 4 p.

ASTM International (1998b). *Standard Test Methods for Determining Dimensions of Thermoplastic Pipe and Fittings (ASTM D2122-98 (Reapproved 2010)).* ASTM International, United States, 5 p.

ASTM International (2002). *Standard Test Methods for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading (ASTM D2412-02 (Reapproved 2008)).* ASTM International, United States, 6 p.

ASTM International (2005). *Standard Test Methods for Rubber Property - Durometer Hardness (ASTM D2240-05 (Reapproved 2010)).* ASTM International, United States, 13 p.

ASTM International (2006a). *Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics (ASTM D256-06a).* ASTM International, United States, 20 p.

ASTM International (2006b). *Standard Test Method for Carbon Black Content in Olefin Plastics (ASTM D1603-06).* ASTM International, United States, 4 p.

ASTM International (2007a). *Standard Test Methods for Brittleness Temperature of Plastics and Elastomers by Impact (ASTM D746-07).* ASTM International, United States, 9 p.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

ASTM International (2007b). *Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals1 (ASTM D3212-07).* ASTM International, United States, 3 p.

ASTM International (2008a). *Standard Test Methods for Rigid Poly (Vinyl Chloride) (PVC) Compounds and Chlorinated Poly (Vinyl Chloride) (CPVC) Compounds (ASTM D1784-08).* ASTM International, United States, 4 p.

ASTM International (2008b). *Standard Specification for Polyethylene Plastics Pipe and Fittings Materials (ASTM D3350-08).* ASTM International, United States, 7 p.

ASTM International (2008c). *Standard Test Methods for Environmental Stress-Cracking of Ethylene Plastics (ASTM D1693-08).* ASTM International, United States, 11 p.

ASTM International (2008d). *Standard Test Methods for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products (ASTM D2837-08).* ASTM International, United States, 15 p.

ASTM International (2009a). *Standard Specification for Polypropylene Injection and Extrusion Materials (ASTM D4101-09).* ASTM International, United States, 17 p.

ASTM International (2009b). *Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi (ASTM G21-09).* ASTM International, United States, 5 p.

ASTM International (2010a). *Standard Testing Method for Tensile Properties of Plastics (ASTM D638-10).* ASTM International, United States, 16 p.

ASTM International (2010b). *Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe (ASTM F477-10).* ASTM International, United States, 4 p.

ASTM International (2011). *Standard Practice for Installation Acceptance of Plastic Non-pressure Sewer Lines Using Low-Pressure Air1 (ASTM F1417-11a).* ASTM International, United States, 6 p.

Bennett O. (year unknown). *Use of Corrugated HDPE Products (Chapter 3).* Plastic Pipe Institute, 10 p.

Biron, M. (2007). *Thermoplastics and Thermoplastic Composites: Technical Information for Plastics Users*, Elsevier, 874 p.

Böhni, H. (2005). *Corrosion in Reinforced Concrete Structures*. Woodhead Publishing Limited, Cambridge England, 248 p.

Broomfield, J.P. (2007). *Corrosion of Steel in Concrete, Understanding, Investigation and Repair (2nd Edition).* Taylor & Francis, London and New York, 277 p.

BSI (1973). *British Standard Code of Practice for Plastics Pipework (Thermoplastics Material) - Part 1: General Principles and Choice of Material (CP 312-1:1973).* British Standards Institution, London, 46 p.

BSI (1976a). *Methods of Testing Plastics. Thermal Properties. Determination of the Vicat Softening Temperature of Thermoplastics (BS 2782-1 Methods 120A to 120E:1976).* British Standards Institution, London.

BSI (1976b). *Methods of Testing Plastics - Part 3: Mechanical Properties - Methods 320A to 320F: Tensile Strength, Elongation and Elastic Modulus (BS 2782-3:Methods 320A to 320F:1976).* British Standards Institution, London, 12 p.

BSI (1980). *Methods of Testing Plastics. Dimensional Properties. Determination of Density of Solid Plastics Excluding Cellular Plastics (Immersion Method). Determination of Density of Solid Plastics Excluding Cellular Plastics (Pyknometer Method). Determination of Density of Solid Plastics Excluding Cellular Plastics (Sink-float Method). Determination of Density of Solid Plastics Excluding Cellular Plastics (Density Gradient Column Method) (BS 2782-6: Methods 620A to 620D:1980).* British Standards Institution, London.

BSI (1981). *Methods of Testing Plastics. Mechanical Properties. Determination of Indentation Hardness by Means of a Durometer (Shore Hardness) (BS 2782-3 Method 365B:1981).* British Standards Institution, London.

BSI (1984). *Specification for Polyethylene Pipes (Type 50) in Metric Diameters for General Purposes (BS 6437:1984).* British Standards Institution, London, 12 p.

BSI (1989). *British Standard Code of Practice for Ground Anchorages (BS 8081:1989).* British Standards Institution, London, 178 p.

BSI (1995). *Code of Practice for Strengthened/Reinforced Soils and Other Fills (BS 8006:1995).* British Standards Institution, London, 197 p.

BSI (1997). *Plastics - Determination of Tensile-impact Strength (BS EN ISO 8256:1997).* British Standards Institution, London, 18 p.

BSI (2000). *British Standard Execution of Special Geotechnical Work - Ground Anchors (BS EN 1537:2000).* British Standards Institution, London, 61 p.

BSI (2002). *Plastics Piping Systems for Buried and Above-ground Pressure Systems for Water for General Purposes, Drainage and Sewerage - Polyethylene (PE) - Part 2: Pipes (BS EN 13244-2:2002).* British Standards Institution, London, 21 p.

BSI (2003). *Plastics and Ebonite - Determination of Indentation Hardness (Shore D) by Means of a Durometer (Shore Hardness (Shore D)) (BS EN ISO 868:2003).* British Standards Institution, London, 6 p.

BSI (2004a). *Plastics - Thermoplastic Materials - Determination of Vicat Softening Temperature (VST) (BS EN ISO 306:2004).* British Standards Institution, London, 10 p.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

BSI (2004b). *Plastics - Methods for Determining the Density of Non-cellular Plastics - Part 1: Immersion Method, Liquid Pyknometer Method and Titration Method. (BS EN ISO 1183-1:2004).* British Standards Institution, London, 9 p.

BSI (2006a). *Thermoplastics Pipes, Fittings and Assemblies for the Conveyance of Fluids - Determination of the Resistance to Internal Pressure - Part 1: General Method (BS EN 1167-1:2006).* British Standards Institution, London, 8 p.

BSI (2006b). *Thermoplastics Pipes, Fittings and Assemblies for the Conveyance of Fluids - Determination of the Resistance to Internal Pressure - Part 2: Preparation of Pipe Test Pieces (BS EN 1167-2:2006).* British Standards Institution, London, 4 p.

CEB (1992). *Durable Concrete Structures: Design Guide*. Comité euro-international du béton (Euro-International Concrete Committee), Thomas Telford, Switzerland, 112 p.

Chaker, V. & Palmer, J.D. (1989). *Effects of Soil Characteristics on Corrosion*. American Society for Testing and Materials, Philadelphia, 172 p.

CIRIA (2005). *Soil Nailing - Best Practice Guidance*. Construction Industry Research & Information Association, London, UK, Report No. C637, 286 p.

Clouterre (1991). *French National Research Project Clouterre - Recommendations Clouterre 1991: Soil Nailing Recommendations for Designing, Calculation, Constructing and Inspecting Earth Support System Using Soil Nailing (English Translation 1993) (Report No. FHWA-SA-93-026).* Federal Highway Administration, Washington, D.C., USA, 321 p.

Corven, J. & Moreton, A. (2004). *Post-tensioning Tendon Installation and Grouting Manual.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 172 p.

Dew, P.A., Ozsoy, B., Wharmby, N.J., Judge, J. & Barley, A.D. (2005). *Soil Nailing - Best Practice Guidance (CIRIA C637).* CIRA, London, 286 p.

Dieter, G.E. (1986). *Mechanical Metallurgy (3rd Edition).* McGraw-Hill, New York, 751 p.

Domone, P.L.J. & Jefferis, S.A. (1994). *Structural Grouts*. Chapman & Hall, 222 p.

Elias, V. (2000). *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes (Report No. FHWA-NHI-00-044)*. National Highway Institute, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 94 p.

Erlin, B. (1994). Embedded metals and materials other than reinforcing steel. *Significance of Tests and Properties of Concrete and Concrete-making Materials*, STP 169C, ASTM, West Conshohocken, Pa., 1994, pp 174 -183.

fib (2000). *Corrugated Plastic Ducts for Internal Bonded Post-tensioning*. Fédération internationale du béton (International Federation for Structural Concrete), Lausanne, 46 p.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

FIP (1986). *Corrosion and Corrosion Protection of Prestressed Ground Anchorages*. Fédération Internationale de la Précontrainte (International Federation for Prestressing), Telford, London, 28 p.

Gabriel, L.H. (unknown). *History and Physical Chemistry of HDPE (Chapter 1)*. Plastic Pipe Institute, 18 p.

GCO (1984). *Model Specification for Prestressed Ground Anchors (GCO Publication No. 3/84) (Superseded by Geospec 1)*. Geotechnical Control Office, Hong Kong.

GCO (1989). *Model Specification for Prestressed Ground Anchors (Geospec 1)*. Geotechnical Control Office, Hong Kong, 168 p.

GEO (1993). *Guide to Retaining Wall Design (Geoguide 1). (Second edition)*. Geotechnical Engineering Office, Hong Kong, 258 p.

GEO (2002). *Guide to Reinforced Fill Structure and Slope Design (Geoguide 6)*. Geotechnical Engineering Office, Hong Kong, 236 p.

GEO (2008). *Guide to Soil Nail Design and Construction (Geoguide 7)*. Geotechnical Engineering Office, Hong Kong, 97 p.

Gregorová, A., Cibulková, Z., Košíková, B. & Šimon, P. (2005). Stabilization effect of lignin in polypropylene and recycled polypropylene. *Polymer Degradation and Stability*, vol. 89, no. 3, pp 553-558.

Highways Agency (2009). *Design Manual for Roads and Bridges*. Highways Agency, Department of Transport, UK.

HKG (1995). *Construction Standard - Carbon Steel Bars for the Reinforcement of Concrete (CS2:1995)*. Hong Kong Government, 35 p.

HKSARG (2006). *General Specification for Civil Engineering Works*. The Government of the Hong Kong Special Administrative Region, Hong Kong.

International Organization for Standardization (2001). *Plastics - Determination of hardness - Part 1: Ball indentation method (ISO 2039-1)*. International Organization for Standardization, 6 p.

Lazarte, C.A., Elias, V., Espinoza, R.D. & Sabatini, P.J. (2003). *Soil Nail Walls (Geotechnical Engineering Circular No. 7)*. Federal Highway Administration, USA, 182 p.

Littlejohn, G.S. & Hughes, D.C. (1988). *Thermal Behaviour of Grouted Supports for Pipelines, in Grouts and Grouting for Construction and Repair of Off-shore Structures (Department of Energy Offshore Technology Report No. OTH-88-289)*. HMSO, London, pp 111-120.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Maier, C. & Calafut, T. (1998). *Polypropylene - The Definitive User's Guide and Databook.* Plastics Design Library, NY, 413 p.

Nass, L.I. & Heiberger, C.A. (1992). *Encyclopedia of PVC (2^{nd} Edition).* M Dekker, New York, 586 p.

Patrick, S.G. (2005). *Practical Guide to Polyvinyl Chloride*. Rapra Technology Limited, UK,165 p.

Roberge, P.R. (2000). *Handbook of Corrosion Engineering*. McGraw - Hill, New York, 1139 p.

Sabatini, P.J., Pass, D.G. & Bachus, R.C. (1999). *Ground Anchors and Anchored Systems (Geotechnical Engineering Circular No. 4).* Federal Highway Administration, USA, 308 p.

Sarventnick, H.A. (1977). *Polyvnyl Chloride*. R. E. Krieger Pub. Co., 255 p.

Shiu, Y.K. & Cheung, W.M. (2003). *Long-term Durability of Steel Soil Nails (GEO Report No. 135).* Geotechnical Engineering Office, Hong Kong, 65 p.

Spenadel, L. (1972). Effect of rubber on the environmental stress-crack resistance of polyethylene. *Journal of Applied Polymer Science*, vol. 16, pp 2375-2386.

Tasdemir, M. (2003). Mechanical, thermal, and microstructural properties of polypropylene/polyamide-6/styrene-ethylene-butadiene-styrene polymer alloys. *Journal of Applied Polymer Science*, vol. 89, no. 13, pp 3485-3491.

Vasile, C. & Pascu, M. (2005). *Practical Guide to Polyethylene.* Rapra Technology Limited, UK, 180 p.

Watkins, R.K. & Anderson, L.R. (2000). *Structural Mechanics of Buried Pipes*. CRC Press, 444 p.

Zhiping, L.V., Kunjun, W., Zhihua, Q. & Wenjie, W. (2010). The influence of modified zeolites as nucleating agents on crystallization behavior and mechanical properties of polypropylene. *Materials and Design*, vol. 31, no. 8, pp 3804-3809.

Table of Contents
Table of Contents
Table of Contents

Table of Contents

Table of Contents

Appendix A

Principles of Corrosion Protection

Table of Contents

Table of Contents

Contents

Table of Contents
Table of Contents
Table of Contents

Generally, steel corrodes when there are oxygen and water. When it corrodes, the strength capacity will be reduced due to the reduction in cross-sectional area of the steel material. Besides, rust which has two to four times the volume of the original steel material is being formed in the process of corrosion. The expansion of the rusting steel will induce cracks in the grout which will lead to increased exposure to the surrounding corroding agents and then further and accelerated corrosion. Therefore, corrosion protection is of great importance for soil nails and the long-term performance of soil nails depends on their ability to withstand corrosion attack from the surrounding soils.

A.1 Corrosion of Steel

Generally speaking, corrosion of steel comprises several main electrochemical reactions, which can be illustrated by Figure A1 and the following equations (Shiu & Cheung, 2003; Broomfield, 2007):

- The anodic reaction, by which the iron element in the steel dissolves in the water and gives up electrons:

  $Fe \rightarrow Fe^{2+} + 2e^{-}$

- The cathodic reaction, by which the electrons created in the anodic reaction are consumed to form hydroxide anion:

  $2e^{-} + H_2O + 1/2O_2 \rightarrow 2OH^{-}$

- The "rust" formation, in which ferrous hydroxide becomes ferric hydroxide and then hydrated ferric oxide or rust:

  $Fe^{2+} + 2OH^{-} \rightarrow Fe(OH)_2$
  Ferrous hydroxide

  $4Fe(OH)_2 + O^2 + 2\ H_2O \rightarrow 4Fe(OH)_3$
  Ferric hydroxide

  $2Fe(OH)_3 \rightarrow Fe_2O_3{\cdot}H_2O + 2H_2O$
  Hydrated ferric oxide (rust)

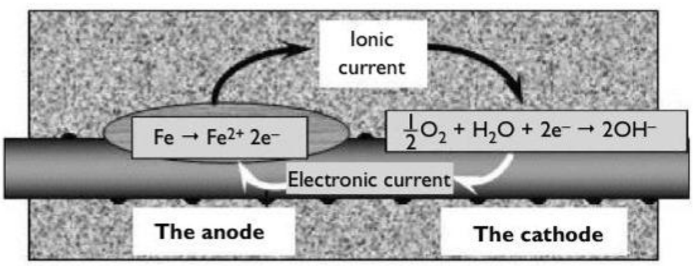


Figure A1 The Anodic, Cathodic, Oxidation and Hydration Reactions (Broomfield, 2007)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Unhydrated ferric oxide Fe_2O_3 has a volume of about twice that of the original steel material before rusting, as shown in Figure A2. When it becomes hydrated it swells even more and becomes porous. This leads to a loss of bond between the steel and the grout, thus reducing the integrity and performance of a structure as a result of delamination and spalling (Broomfield, 2007).

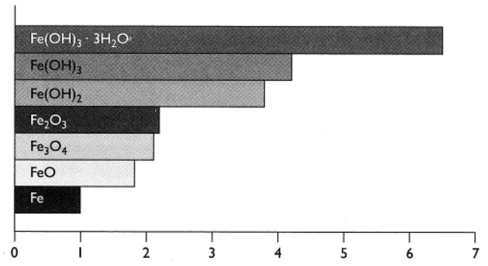


Figure A2 Relative Volume of Iron and Its Oxides (Broomfield, 2007)

A.2 Corrosion of Steel in Concrete/Grout

Cement grout or concrete cover provides chemical as well as physical protection to the steel. Hydrated cement in grout makes the pore water highly alkaline (with pH value over 12.5), which acts as a protective layer on the steel and inhibits corrosion (Böhni, 2005; Broomfield, 2007). Two processes, however, may destroy this protective layer - carbonation of grout and chloride attack (Böhni, 2005; Broomfield, 2007). The acidic gases (e.g., CO_2, SO_2) in the atmosphere may react with cement grout to form carbonates and sulphates, causing a reduction in its pH value. If the carbonated front travels sufficiently into the grout and reaches the reinforcement, the passive protective layer will be lost. If both oxygen and moisture are available, the corrosion process will commence (Broomfield, 2007). This process is called carbonation:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Gas Water Carbonic acid

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O$$

Carbonic acid Pore solution

The passivity provided by the alkaline conditions can also be destroyed by the presence of chloride ions (normally originating from sea water or de-icing salt) (CEB, 1992). Some soil may be contaminated and may have some free chloride ions in it. As shown in Figure A3, the chloride ion can promote active metal dissolution by locally depassivating the metal and activating the anodic reaction with the aid of the following reaction (Shiu & Cheung, 2003; Böhni, 2005; Broomfield, 2007):

Table of Contents
Table of Contents
Table of Contents
Table of Contents

$$Fe + 2HCl \rightarrow FeCl_2 + H_2$$

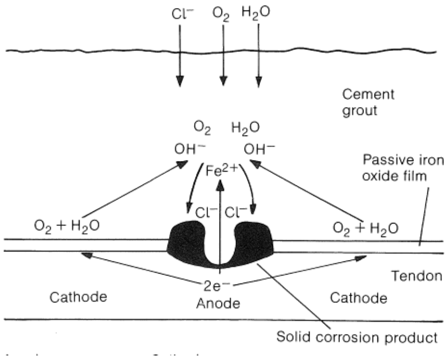


Figure A3 Corrosion Mechanism of Steel in Concrete/Grout and Destruction of Passive Layer (FIP, 1986)

A.3 Corrosion of Steel in Soil Nail System

In the case of soil nail, the steel bar is protected by a layer of grout, which in turn is surrounded by soil. The grout may be permeable due to its porosity and the presence of fissures or cracks formed as a result of tensile loading, shrinkage or other factors. The permeability of grout allows the ingress of acidic gases in the atmosphere (CO_2 and SO_2) and aggressive anions (chloride) to reach the steel bar (Elias, 2000; Broomfield, 2007). It also allows the groundwater to circulate and reach the steel bar, thus accelerating the corrosion (Elias, 2000; Broomfield, 2007).

A.4 Corrosion Protection

Considering the mechanisms of corrosion discussed above, corrosion protection of the steel reinforcement in soil nails can be enhanced by:

(a) avoiding the essential elements of corrosion, i.e. oxygen and water, from reaching the steel reinforcement; and

(b) obstructing the diffusion of air (which contains CO_2 and SO_2) to the grout within the corrugated sheathing and thus avoiding carbonation of grout and active metal dissolution by chloride attack.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents

Table of Contents

Appendix B

Proposed Specification

Table of Contents

Table of Contents

SECTION 7

PART 3: SLOPE TREATMENT WORKS

MATERIALS

Soil nails with double-corrosion protection 7.95S1 Replace GS Clause 7.95(2) with the following:

(2) Corrugated sheathing for the double corrosion protection shall be a proprietary type approved by the Engineer and shall be made of high density thermoplastic materials which shall be homogeneous, thermally stable, chemically inert and resistant to fungal attack. Corrugated sheathing and all associated components shall comply with the following requirements:

Property	**Test Method**	**Unit**	**Acceptance Criterion**		
			PVC	**HDPE**	**PP**
Density	BS EN ISO 1183-1:2004 Method A	kg/m^3	1150 - 1500	935 - 965	900 - 910
Vicat softening point	BS EN ISO 306-04	^{o}C	≥ 75		
Brittleness	ASTM D746-07	^{o}C	≤ -5		
Environmental stress cracking resistance	AASHTO M 252-09	hours	200 (No cracking)		
Water absorption	ASTM D570-98 (R2010) (Long Term immersion)	%	≤ 0.5		
Fungal resistance	ASTM G21-09	-	Rating 1 or less (Traces of growth less than 10% of the surface area)		
Hardness (Shore D)	BS EN ISO 868:2003	-	≥ 65		
Tensile strength	ASTM D638-10	MPa	≥ 45	≥ 29	≥ 30
Hydrostatic pressure resistance	BS EN 13244-2:2002 (grade PE 63)	-	No localized swelling, leaking or weeping		
Elongation at break	ASTM D638-10	%	≥ 12		
Pipe stiffness and pipe flattening	AASHTO M 252-09	-	≥ 240 kPa at 5% deflection, no cracking at 20% deflection		
Pipe geometry	ASTM D2122-98 (R2010)	-	Wall thickness: ≥ 1 mm Pitch(1): 6 to 12 times the wall thickness Amplitude of corrugation(2): ≥ 3 times the wall thickness		

Note 1: pitch = length of pipe/no. of corrugations

Note 2: amplitude = (outside diameter at peak - inside diameter at trough) /2

Remark: The criteria for hydrostatic pressure resistance, pipe stiffness, pipe flattening and pipe geometry are required for corrugated sheathing only, but not the associated components.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Add the following Clause after GS Clause 7.270:

Batch corrugated sheathing 7.271A1 A batch of corrugated sheathing is any quantity of corrugated sheathing of the same type, manufactured by the same manufacturer, covered by the same certificates and delivered to the Site at any one time.

Samples: corrugated sheathing 7.272A1 Unless otherwise required by the Engineer, one sample of corrugated sheathing shall be provided from each 50 numbers of corrugated sheathing or part thereof in a batch.

Testing: corrugated sheathing 7.273A1 (1) Each sample of corrugated sheathing shall be tested to determine the density, environmental stress cracking resistance, hydrostatic pressure resistance, pipe stiffness and pipe flattening, and pipe geometry.

(2) The method of testing shall be in accordance with the following:

Density	: BS EN ISO 1183-1:2004 Method A
Environmental stress cracking resistance	: AASHTO M 252-09
Hydrostatic pressure resistance	: BS EN 13244-2:2002 (grade PE 63)
Pipe stiffness and pipe flattening	: AASHTO M 252-09
Pipe geometry	: ASTM D2122-98 (R2010)

Compliance criteria: corrugated sheathing 7.274A1 The results of tests for density, environmental stress cracking resistance, hydrostatic pressure resistance, pipe stiffness and pipe flattening, and pipe geometry shall comply with the following requirements:

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Property	Unit	Criteria		
		PVC	HDPE	PP
Density	kg/m^3	1150 - 1500	935 - 965	900 - 910
Environmental stress cracking resistance	hours	200 (No cracking)		
Hydrostatic pressure resistance	-	No localized swelling, leaking or weeping		
Pipe stiffness and pipe flattening	-	≥ 240 kPa at 5% deflection, no cracking at 20% deflection		
Pipe geometry	-	Wall thickness: ≥ 1 mm Pitch: 6 to 12 times the wall thickness Amplitude of corrugation: ≥ 3 times the wall thickness		

Non-compliance: corrugated sheathing

7.275A1 (1) If the result of any test for density, environmental stress cracking resistance, hydrostatic pressure resistance, pipe stiffness and pipe flattening, and pipe geometry does not comply with the specified requirements for the property, one additional sample shall be provided from the same batch and additional tests for the property shall be carried out.

(2) The batch shall be considered as not complying with the specified requirements for the property if the result of any additional test does not comply with the specified requirements for the property.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Appendix C

Response to Comments

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table C1 Response to Comments on Final Report Submitted in August 2011 (Sheet 1 of 9)

Member	Comment	Response to Comment
LPM1 Division on 31 August 2011	Section 5.2.5 Fungal Resistance: It is stated that for determining the rating of the observed growth of fungi on specimens, the use of specimens cut from corrugated sheathing may not be appropriate. Please elaborate on the reasons why the test cannot be performed on specimens cut from corrugated sheathing.	ASTM G21-09 stated that a piece of tubing can be used as the test specimen and the rating depends on the coverage of fungi growth. However, the standard does not provide any guidelines for measurement of the coverage of fungi growth for sample with corrugations, the test may not be appropriate for specimens cut from corrugated sheathing.
	Section 5.2.6 Hardness: Please review the unit for Hardness (Shore D) given in Table 5.10.	Table 5.13 (Table 5.10 previously) has been amended.
Planning Division on 5 September 2011	The report recommends the suppliers to design a water-tight joint or use heat shrink sleeve if that is practical. In this connection, you may wish to consider employing silicone sealant as an alternative waterproofing method.	Noted. The long-term performance of silicone sealant under alkaline condition should be further studied to determine its applicability.
ME Division on 5 September 2011	a. With reference to Table 4.2.7, it is suggested to develop specifications for those properties to be identified/tests to be carried out, if the relevant details are not found in Geospec 1/GS etc.	The specification has been included.
	b. It is suggested to run some pilot projects to review the performance based on the recommendation of the study.	Site trial will be carried out in-house by LPM Division3's contractor.

Table of Contents
Table of Contents
Table of Contents

Table C1 Response to Comments on Final Report Submitted in August 2011 (Sheet 2 of 9)

MW Division on 8 September 2011	**A General Comments**	
	A1. What is the objective for this review study? Are there problems in getting corrugated sheaths that conform with the requirements specified in Table 2 of Geospec 1?	The study aims to develop the new specification and material compliance test for corrugated sheath used in corrosion protection of steel soil nail reinforcement. The problems encountered are discussed in Section 8.1.
	A2. A quick check shows that the definitions of "flexural modulus" and "elastic modulus" in Sections 4.2.2.6 and 4.2.2.7 respectively are copied from Wikipedia but no reference to this source is provided in the report. Please ask the consultants to provide all the sources of information in the report, and preferably re-write the definitions using authors' own words. A detailed check should be made to the rest of the report to ensure that information is not quoted without any reference.	Sections 4.2.1.3, 4.2.2.1, 4.2.2.5, 4.2.2.6, 4.2.2.7 and 4.2.3.2 have been amended.
	B Specific Comments	
	B1. Section 1, para 2. Items (iv) and (v) are out of place as they are not the works that have been carried out in this study. They look more like conclusions/recommendations.	Section 1, para. 2 has been amended.

Table of Contents
Table of Contents
Table of Contents

Table C1 Response to Comments on Final Report Submitted in August 2011 (Sheet 3 of 9)

MW Division on 8 September 2011 (cont'd)	B2. It is stated repeatedly in different parts of the report that corrugated sheathing is not a structural element or structural component of a soil nail (e.g. Sections 1 (iv), 3 and 4.2.2). Some of the recommendations given in the report are based on this view. It should be noted that this view is contrary to the advices given in various national or international standards. Some examples are given below: (a) FIP (1986) advises that the sheath "has to transmit stresses from the filler to the external grout without displacement or distress", and that sheaths are corrugated to ensure effective load transfer between filler and grout; (b) BS 8081:1989 also provides the same advice as that given in FIP (1986), please see (a) above; and (c) Geotechnical Engineering Circular No. 7: Soil Nail Walls (Lazarte et al, 2003) states that "the sheathing is corrugated to transfer the effect of anchorage to the surrounding grout". Other national standards such as Ground Anchors and Anchored Systems (Sabatini et al, 1999) and CIRIA C637: Soil nailing-Best Practice Guidance also stress the importance of corrugated sheath in the transfer of loads. It is clear that corrugated sheath is an important structural component in a soil nail.	Agreed. The statement "corrugated sheathing is not a structural element" has been deleted. Tensile strength is now suggested to be required for material selection.

Table of Contents
Table of Contents
Table of Contents

Table C1 Response to Comments on Final Report Submitted in August 2011 (Sheet 4 of 9)

MW Division on 8 September 2011 (cont'd)	B3. Page 13, 2nd para., line 3. "Shui & Cheung" should read "Shiu & Cheung".	Amended.
	B4. Table 4.1 and the subsequent discussions in Sections 4 and 5 of the report give an impression that various local and international material requirements are compared. Both FIP (1986) and BS 8081:1989 just quote and use the properties requirements given in an outdated GCO publication (Publication 3/84). As the GCO publication has long been superseded by Geospec 1, there is not much use to compare the latest property requirements in Geospec 1 with the outdated requirements in FIP (1986) and BS 8081:1989.	Noted. FIP (1986) and BS 8081:1989 are quoted to illustrate the overseas practice in connection with the use of corrugated sheaths.
	B5. Section 4.2.1.6. The meaning of the statements "No active standards were found for testing bacteria resistance for plastic. Therefore the testing of bacteria resistance is not recommended" is not clear. In any case, this recommendation is not supported. Some bacteria (such as sulpho bacteria, ferro bacteria and sulphate reducing bacteria) can give rise conditions that are conducive to corrosion. Hence, the requirement for 'bacteria resistance' as given in Table 2 of Geospec 1 should be retained.	Section 4.2.1.6 has been amended. ASTM G22-76 (1980) was the testing standard adopted in Geospec 1. However, this ASTM standard was superseded by ASTM G22-76 (1996) which has then been withdrawn with no replacement.

Table of Contents
Table of Contents
Table of Contents

Table C1 Response to Comments on Final Report Submitted in August 2011 (Sheet 5 of 9)

MW Division on 8 September 2011 (cont'd)	B6. Section 4.2.2. As discussed in B2 above, corrugated sheath is an important structural element in a soil nail. The recommendation of deleting "tensile strength" from the property requirements is not supported.	The report has been amended to include the testing for tensile strength.
	B7. Section 4.3.1. It is not agreed that 'hydrostatic pressure resistance' is to be removed from the property requirements. Although the corrugated sheath is not used for drainage purpose, it is still necessary to ensure that it can withstand internal grouting pressures developed during grouting. What is specified in Table 2 of Geospec 1 (i.e. no localized, swelling, leaking or weeping) is reasonable for soil nail application where the grouting pressures are usually not high. This property requirement should be retained.	The report has been amended to include the testing for hydrostatic pressure resistance.
	B8. Unlike Geospec 1 which has been developed specifically for ground anchors, the US literatures for soil nails (Lazarte et al, 2003) and ground anchors (Sabatini et al, 1999) just make reference to other American standards (AASHTO M252 and ASTM D1784) which are not specifically developed for ground anchors or soil nails. AASHTO M252 is a specification for corrugated polyethylene drainage pipe whereas ASTM D1784 provides standard test methods for rigid PVC and CPVC compounds. Many of the test specifications/requirements (e.g. "pipe stiffness" and "pipe flattening") specified in these standards are applicable to drainage pipe but they may not be relevant to soil nail. Please also see B9 below.	See responses for B9.

Table of Contents
Table of Contents
Table of Contents

Table C1 Response to Comments on Final Report Submitted in August 2011 (Sheet 6 of 9)

MW Division on 8 September 2011 (cont'd)	B9. Sections 4.3.2 and 4.3.3. The report recommends that "pipe stiffness" and "pipe flattening" should be required for material selection. Pipe stiffness is usually used for determining allowable burial depth of underground drain pipes. Pipe flattening is a measure of how much deflection that a flexible pipe can take without damage. Pipe stiffness and pipe flattening have applicability in buried drain pipes or buried utility pipes. However, it has little use in soil nailing application as corrugated sheath in a soil nail does not need to take overburden stresses. Loads on the sheath during transportation and installation are small. The need for pipe stiffness and pipe flattening tests should be further reviewed.	According to the General Specification, during grouting, the annular space between the wall of drillhole and corrugated sheathing shall be grouted first in a continuous operation. The annular space between corrugated sheathing and steel bars shall be grouted immediately afterwards in a continuous operation. Therefore, the corrugated sheathing s have to withstand the outside pressure for a short period of time. Please see Section 7.2 for problems encountered during site operation.
	B10. In Tables 5.4, 5.5, 5.7, 5.9, 5.11 and 5.15, "BS 808:1989" should be changed to "BS 8081:1989".	Tables 5.4, 5.5, 5.10, 5.12, 5.14 and 5.18 (Table 5.7, 5.9, 5.11 and 5.15 previously) have been amended.
	C Other Comment	
	C1. There is an error in Table 2 of Geospec 1. The Brittleness Temperature should be "≦ -5°C" instead of "≦ 5°C". Please check.	Section 5.2.2 has been amended. The acceptance criteria for brittleness temperature has been amended from ≦ 5°C to ≦ -5°C.

Table of Contents
Table of Contents
Table of Contents

Table C1 Response to Comments on Final Report Submitted in August 2011 (Sheet 7 of 9)

LPM2 Division on 8 September 2011	Apparently, the focus of the entire study was shifted to the update of laboratory testing for corrugated sheathing specifically for soil nails. That's good. But recall the original purpose of the study is that there was a concern from LPM Branch a few years ago about the difference between the approved materials and materials delivered on site. And according to the study report, it is not desirable to introduce compliance tests for corrugated sheathing because it is not a structural element for soil nails. I don't think the argument could stand; although it is not a structural element, it will affect directly the performance of the nail structure (i.e. durability is one of the key design requirements that we have to meet). Perhaps the Consultants should address the LPM Branch's concern specifically and propose certain measures that can be demonstrated in the subsequent site trial.	Except hydrostatic pressure resistance, all the tests currently conducted under Geospec 1 are on laminated specimens made from raw material, instead of corrugated sheath. Since the proposed tests on density, environmental stress cracking resistance, pipe stiffness and pipe flattening could be conducted on corrugated sheath, carrying out these tests on the final products will help to control the quality of the products. A proposed specification is enclosed in Appendix B.

Table of Contents
Table of Contents
Table of Contents

Table C1 Response to Comments on Final Report Submitted in August 2011 (Sheet 8 of 9)

LPM3 Division on 14 September 2011	Table 4.2 - A typo mistake. Hydrostatic pressure resistance is one of the properties that need to be tested in accordance with Geospec 1, and hence, the symbol of asterisk (*) is missing for this item.	Table 4.2 has been amended.
	Table 5.10 - A typo mistake. There should be no unit for the property of hardness	Table 5.13 (Table 5.10 previously) has been amended.
	Sections 5.3.1 and 5.3.2 - It is noted that the suggested acceptance criteria for pipe stiffness and pipe flattening (which are new tests and not required by Geospec 1) are obtained from overseas standards which are applicable for HDPE only. What are the typical range of these properties for PVC and PP? Please review whether the acceptance criteria should be the same or different for the three different materials (i.e. PVC, HDPE and PP).	Trial laboratory tests are proposed for some products available in the market (including HDPE and PVC sheaths). The test results of the these properties will be reviewed.
	Section 6.3 - Using heat-shrinkable sleeve at the end cap and connections for watertightness may not be practicable at the site as it is difficult to control the temperature of the heat source under site conditions to ensure that it is below the Vicat softening point of the plastic sheath. The site trial recommended in Section 9.2 should cover this issue.	Noted. Other methods, such as watertight coupler, bell-and-spigot joint and elastomeric seal have also been included in the report for consideration. However, the availability and practicability of these methods should further be reviewed.
	It is suggested that the consultants also review the grouting method mentioned in GS 7.137(11).	Questionnaire has been sent to government departments, LPM consultants and LPM contractors on the grouting method mentioned in General Specification. No adverse comments were received.
	Please note that there are no laboratories accredited by HOKLAS for all the tests mentioned in the draft report.	Noted.

Table of Contents
Table of Contents
Table of Contents

Table C1 Response to Comments on Final Report Submitted in August 2011 (Sheet 9 of 9)

GP Division on 12 September 2011	Nil return	Noted
SS Division on 20 September 2011	Nil return	Noted.
Island Division on 20 September 2011	Nil return	Noted.
Mines Division on 21 September 2011	I have no comments on the recommendations of the consultant summarized by Thomas Hui below.	Noted.
CGE/SM, LandsD	No reply received	-

Table of Contents
Table of Contents
Table of Contents

Table C2 Response to Comments on Revised Final Report Submitted in January 2013 (Sheet 1 of 2)

Member	Comment	Response to Comment
LPM2 Division on 27 February 2013	1. Please consider including in the literature review those technical documents from nearby region/country where ground anchors are common (e.g. Japan and Mainland China).	The literature review has already included the most relevant international standards and guidance documents and is considered adequate for the scope of the current study.
	2. It is shown in Table 4.1 that the recommendations in respect of "French Recommendations on Ground Anchors - TA 86" cannot been found. It is noted, however, from the TRID website (http://trid.trb.org/view.aspx?id=385673) that the publication "Retaining structures: proceedings of the conference retaining structures" has referred to this TA 86. The consultants may wish to see if further information could be obtained from this publication.	The publication was reviewed and no further information relevant to this study could be obtained.
	3. It is noted that Wikipedia is quoted as the source of information on p. 24 & 44 of the report. As Wikipedia is a publicly editable information source which may not be reliable and professionally recognised, it may not be appropriate to treat it as a reliable source of information and be quoted in the study report.	Agreed. The additional information from Wikipedia is deleted.
	4. As noted from Appendix B, the compliance tests are intended to be mandatory instead of "if there are concerns" as mentioned in Table B1 in Appendix C.	Text amended accordingly.

Table of Contents
Table of Contents
Table of Contents

Table C2 Response to Comments on Revised Final Report Submitted in January 2013 (Sheet 2 of 2)

LPM2 Division on 27 February 2013 (cont'd)	5. The sampling unit in Clause 7.155A of the suggested PS "Unless otherwise required by the Engineer, one sample of corrugated sheathing shall be provided from each 50 corrugated sheathing or part thereof in a batch" is unclear. Do you mean a sample should be taken from each 50 m long sheathing?	The intention should be "one sample from each 50 numbers of corrugated sheathing or part thereof in a batch". The text is amended accordingly. (PS Clause 7.155A has been renamed as 7.272A)
	6. Apparently, there is no testing requirements/ specifications on the end-caps/connectors, it is advisable to include such details in the suggested PS. Such details would facilitate the RSS's supervision of works for example.	The material testing requirements of corrugated sheathing and all associated components are given in the proposed GS Clause 7.95S1. Product testing requirements for end caps/connectors would be examined in future studies, if found necessary (see Section 6.5)
LPM1 Division on 6 February 2013	Nil return	Noted.
LPM3 Division on 7 March 2013	Nil return	Noted.
Planning Division on 27 February 2013	Nil return	Noted.
ME Division on 27 February 2013	Nil return	Noted.
MW Division on 28 February 2013	Nil return	Noted.

Table of Contents
Table of Contents
Table of Contents

GEO PUBLICATIONS AND ORDERING INFORMATION
土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

Copies of GEO publications (except geological maps and other publications which are free of charge) can be purchased either by:

Writing to
Publications Sales Unit,
Information Services Department,
Room 626, 6th Floor,
North Point Government Offices,
333 Java Road, North Point, Hong Kong.

or

- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http:// www.bookstore.gov.hk
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submitting the order online or by fax to (852) 2523 7195
- Placing order with ISD by e-mail at puborder@isd.gov.hk

讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外):

書面訂購
香港北角渣華道333號
北角政府合署6樓626室
政府新聞處
刊物銷售組

或

- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址為 http://www.bookstore.gov.hk
- 透過政府新聞處的網站 (http://www.isd.gov.hk) 於網上遞交訂購表格，或將表格傳真至刊物銷售小組 (傳真：(852) 2523 7195)
- 以電郵方式訂購 (電郵地址：puborder@isd.gov.hk)

1:100 000, 1:20 000 and 1:5 000 geological maps can be purchased from:

Map Publications Centre/HK,
Survey & Mapping Office, Lands Department,
23th Floor, North Point Government Offices,
333 Java Road, North Point, Hong Kong.
Tel: (852) 2231 3187
Fax: (852) 2116 0774

讀者可於下列地點購買1:100 000、1:20 000及1:5 000地質圖：

香港北角渣華道333號
北角政府合署23樓
地政總署測繪處
電話: (852) 2231 3187
傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports and other publications which are free of charge should be directed to:

For Geological Survey Sheet Reports which are free of charge:
Chief Geotechnical Engineer/Planning,
(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5380
Fax: (852) 2714 0247
E-mail: jsewell@cedd.gov.hk

For other publications which are free of charge:
Chief Geotechnical Engineer/Standards and Testing,
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5346
Fax: (852) 2714 0275
E-mail: florenceko@cedd.gov.hk

如欲索取地質調查報告及其他免費刊物，請致函：

免費地質調查報告:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
規劃部總土力工程師
(請交:香港地質調查組)
電話: (852) 2762 5380
傳真: (852) 2714 0247
電子郵件: jsewell@cedd.gov.hk

其他免費刊物:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
標準及測試部總土力工程師
電話: (852) 2762 5346
傳真: (852) 2714 0275
電子郵件: florenceko@cedd.gov.hk

MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.
GEO Publication No. 1/2009	Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p.
GEO Publication No. 1/2011	Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

Table of Contents
Table of Contents
Table of Contents
Table of Contents