Guidance on the structural use of plastic sheet piling in highway applications

Prepared for Safety, Standards and Research, Civil Engineering Division, Highways Agency

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Executive Summary

Plastic sheet piling manufactured from either polyvinyl chloride or fibre reinforced polymer has been extensively used for soil retention in North America and Europe particularly for waterway and marine applications. Recent innovations in the UK plastics industry have included the production of sheet piling from recycled polyvinyl chloride. This product appears to have potential for use in highways related applications in offering a cost effective and environmentally friendly solution to the provision of low height retaining walls.

There are however some concerns about the use of plastic piling in highway applications, particularly structural performance in terms of driveability, a lower bending moment resistance than steel products of similar cross-section, and creep under sustained load. Another potentially serious problem may be that of weathering and durability in the long term, particularly in view of the deleterious effects of ultra violet light on the physical properties and hence useful life of some plastic products.

This report gives a short review of the manufacturing process and the potential applications of plastic piling. Findings are reported from tests to evaluate the effect of artificial weathering on the mechanical properties of recycled uPVC piles and also the effects of creep upon their bending moment resistance under the lateral loading expected in a retaining wall situation.

Plastic piling has many apparent advantages over conventional steel piling. These include ease of handling and transportation of the lightweight piles, improved corrosion resistance to both fresh and salt water, better resistance to chemicals, the opportunity to use recycled materials in manufacture, a competitive price and an improved appearance.

Accelerated weathering tests simulating about 40 years demonstrated that the tensile and flexural strengths of the pile material were virtually unaffected. Impact tests showed no deterioration in strength after 25 years of weathering with all samples being basically ductile. However, after 40 years, the samples although still quite tough were brittle and showed a reduction in impact strength.

The creep deformation under a loading equivalent to 1m of granular backfill was small and the pile remained serviceable although the situation became more marginal when the retained height was increased to 1.6m. Significant creep deformation was recorded when loads equivalent to 2.5m of cohesive backfill were applied with the pile becoming unserviceable.

1 Introduction

Recent innovations in the UK plastics industry have included the production of plastic sheet piling. The product has already been extensively used for soil retention in North America and Europe particularly for waterway and marine applications. The physical properties of piles from six manufacturers (one from the UK, one from Holland, and four from the US) are compared. Five of these manufacturers supply piles extruded from polyvinyl chloride (PVC) whilst the other uses fibre reinforced polymer.

Plastic piling has many apparent advantages over conventional steel piling. The advantages claimed for the product include ease of handling and transportation of the lightweight piles, improved corrosion resistance to both fresh and salt water, better resistance to chemicals, the opportunity to use recycled materials in manufacture, and an improved appearance. Plastic piling is also competitively priced and can potentially be extruded and moulded to meet design requirements.

There are however some concerns about the use of plastic piling in highways related applications. The most obvious concerns are those of structural performance in terms of driveability, a lower bending moment resistance than steel products of similar cross-section, and creep under sustained load. Another potentially serious problem may be that of weathering and durability in the long term, particularly in view of the deleterious effects of ultra violet light on the physical properties and hence useful life of some plastic products. For this reason tests have been undertaken to determine the mechanical properties of plastic piles before and after accelerated weathering in a cyclic ultra-violet radiation cabinet.

The effect of creep has also been investigated as, under the applied ground and water pressures, it may lead to unacceptable deformation of the structure and loss of serviceability. Results are reported from tests simulating the effect of sustained lateral loading on plastic sheet piling from different heights of retained ground.

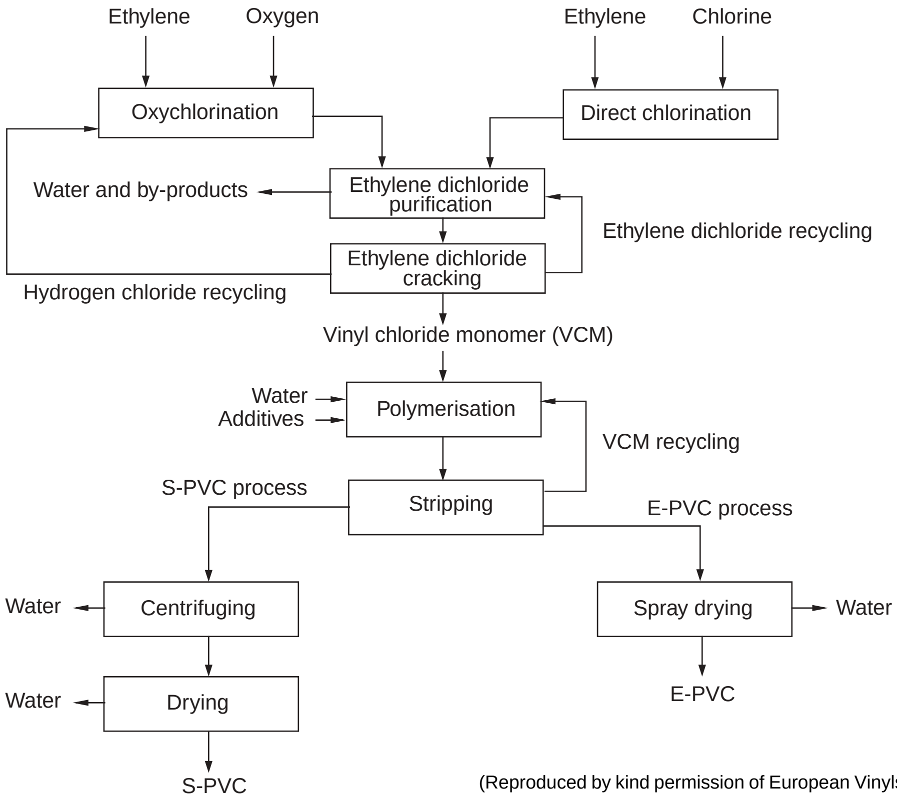
The implications of the findings upon possible uses on the highway network are discussed. Particular applications of the technique in highways schemes are expected to include those of deep trenching, construction of road/rail interchanges where grade separations are required, improving slope stability, noise barriers, and the retention of land for the construction of footpaths and cycle-ways.

2 Manufacturing processes

2.1 Polyvinyl chloride

Polyvinyl chloride (PVC) is manufactured from oil to provide the hydrocarbon and salt to provide the chlorine. According to the European Vinyls Corporation '… 57% of PVC is derived from salt which has inexhaustible reserves'.

The processes involved in the manufacture of PVC are shown in simplified form in Figure 1. The two types of PVC produced namely Suspension PVC (S-PVC) and Emulsion PVC (E-PVC) are used for different manufacturing processes. For example virtually all extruded products are made from S-PVC whilst E-PVC is used for coatings, spreadings, etc.



(Reproduced by kind permission of European Vinyls Corporation)

Figure 1 Schematic showing the processes involved in manufacturing PVC

The PVC is then further modified with additives in the processes employed to manufacture individual products. Additives such as plasticisers, lubricants, stabilisers and impact modifiers can be employed to give the properties desired for the individual application.

Recycled plastic (unplasticised PVC) piling currently manufactured in the UK uses window grade material (95% rigid and 5% flexible) that has failed to meet the manufacturer's quality control standard for dimensional requirements and would otherwise be scrapped. The material for recycling is granulated and re-extruded without the addition of further additives. The plastic in this instance is from a single source and of known composition and has relatively consistent properties unlike recycled 'mixed' plastic whose properties are extremely variable. Because the material used to make plastic piles in the UK was originally manufactured for a purpose other than the manufacture of piling it would seem possible that its formulation is not the optimal composition for the production of plastic piles.

2.2 Fibre reinforced polymers

Fibre reinforced polymer (FRP) is manufactured by a pultrusion process. In this process the reinforcement is continuously drawn through a liquid thermosetting resin bath. Changes in strength, colour, and other characteristics can be designed into the profile by changes in the resin mixture and reinforcement materials. The process is illustrated very simply in Figure 2.

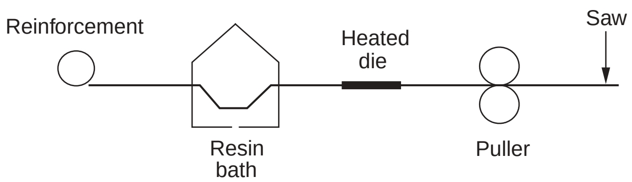


Figure 2 Illustration of the pultrusion process

The design of a composite for a particular application involves specialised consideration before it is manufactured. The product design, in this case a sheet pile, should also be considered carefully as a straight copy of the dimensions and shape of a steel pile may not be give the best product.

Designers can choose from a wide range of fibrous reinforcements and resins to develop a laminate suitable for their requirements. Several plies of reinforcement can be used in a laminate depending on the desired properties of the finished product. In essence the fibre reinforcement provides the mechanical properties such as tensile and impact strength, stiffness, etc whilst the resin contributes such properties as resistance to weather, ultra violet and corrosive chemicals. Fibres that can be used include fibreglass, aramid or even carbon fibre. The layout and form of fibres also affects the properties of the finished product. Resins used include polyester, vinyl, and epoxy types. Other additives such as fillers and many other chemicals further increase the range of properties available to a designer.

Many manufacturing processes are available which include injection moulding and pultrusion: it is the latter process that is used for the manufacture of sheet piles.

Pultrusion is a fully automated process capable of producing many shapes such as bars, channels, tubing and sheets. The process involves a reciprocating puller continuously drawing the resin and fibre through shaped bushings to squeeze out excess resin and thence through a heated die. The heated die serves both to shape and cure the fibre/resin combination. The resulting material is then sawn to the required length.

3 Technical data on available products

Product data were obtained from six manufacturers: of these four were from the USA, one from Holland and one from the UK. Five produce piles from forms of vinyl, the remaining one manufactures its products from fibre reinforced polymer. A summary of the pile dimensions and mechanical properties obtained from the manufacturers is given in Table 1. Requests for technical information from a fifth company in the USA were not forthcoming and that company has not been included in the table.

In Table 1 the tensile strength of the vinyl sheet piles is in the range 40 to 46MN/m^2, this can be compared with a minimum tensile strength of 410MN/m^2 for steel sheet piles of grade S270GP supplied to EN10248 (British Standards Institution, 1996). Other mechanical properties for plastic piles such as tensile modulus, flexural strength and modulus (Table 1) are also significantly below those expected when using steel. For these reasons, the allowable bending moments specified by the manufacturers of plastic piling are significantly lower than those of an equivalent steel section. The magnitude of the allowable moment has been increased in some cases by the addition of ribs to the plastic piles during their manufacture. The option of including steel reinforcement ribs within the sheet piles may also be worthy of consideration although the product cost will increase.

Because of the limitation on allowable moment, the safe retained height of a cantilever wall constructed using plastic piles will be less than for an equivalent steel section. This reduced ability to resist bending forces can in part be overcome by the use of a suitable anchoring or tieback system that will reduce the wall bending moments. Such anchoring systems have already been used successfully in the US to tie back plastic sheet pile walls for marine and waterway applications. A variety of tie back types have been employed including concrete anchor slabs, timber anchor piles, helical tiebacks, injection boring, and pre-stressed anchors. Clearly there is a cost implication in providing additional support in this way but, as plastic piles are cheaper than steel piles of the same dimensions, an economical design can still be achieved.

As with all types of sheet pile, both steel and plastic, when interlock of the piles is at the neutral axis of the wall

Table 1 Summary of the pile dimensions and mechanical properties of commercially available products

Product name	*Z-Ribbed*	*Box-Ribbed*	*GeoGuard 150 to 500*	*GeoGuard 550 to 700*	*C-LOC CL 4500*	*C-LOC CL 9000*	*Series 1900 to 9400*	*Geoflex*	*Superloc™ 1540/1560*
Manufacturer, country	*HL Plastics,UK*		*Materials International Inc, USA*		*Crane Products Limited,USA*		*Northstar Vinyl Products, LLC, USA*	*Geotechnics Holland BV, Holland*	*Lee Composites Inc, USA*
Material	*Recycled uPVC*		*Vinyl sheet*		*Vinyl sheet*		*Vinyl sheet*	*Vinyl sheet*	*Pultruded fibre reinforced polymer*
Configuration	*Panels interlock on their sides*	*Panels interlock front and back*	*Panels have strong interlock front and back* *No ribs*	*Reinforcing ribs*	*Panels interlock on their sides*	*Panels interlock at back*	*Panels interlock front and back*	*Panels interlock front and back*	*Panels interlock at back*
Available length (m)	0.5-6	0.5-6	1.8-5.5	4.3-6.7	Variable	Variable	Variable	0.5-8	Variable
Material thickness (mm)	5	5	5.1-10.2	10.2-11.4	5.7	7.1	5.1-20.3	5/6	3.2/5.1
Section depth (mm)	75	150	127-203	203-254	114	229	163-249	180	102/152
Section coverage (mm)	305	270	267-305	305	305	610	305-457	250	457
Weight (kg/m)	2.8	2.8					3.9-11.2	3	
Weight (kg/m^2)	9.2	10.4	12.7-24.4	26.4-39.1				12	8.8/15.7
Density (kg/m^3)	1450	1450			1400	1420		1450	1700
Section modulus (cm^3/m)	80	350	320-1020	1210-2150	322	878	480-2350	300	160/430
Allowable bending moment (kNm/m)	1.25 3.75 (max)	5.25 13.7 (max)	5.9-18.8	22.2-39.5	4.4	16.4	8.7-41.8	8 24 (max)	24.5/50.1
Flexural strength (MN/m^2)					73	73		80	124 (crosswise) 228 (lengthwise)
Flexural modulus (MN/m^2)	2550-2150	2550-2150	2620	2620	2758	2758		2300	6895 (crosswise) 11032 (lengthwise)
Tensile strength (MN/m^2)	40	40	43	43	46	43		41	69 (crosswise) 228 (lengthwise)
Tensile modulus (MN/m^2)					2586	2551			10342 (crosswise) 24132 (lengthwise)
Impact strength (MNm/m^2)			1.9-2.6	2.6				0.032	

Further product development means that the above properties should be checked with the manufacturer at the time of usage.

then some degree of interlock slip may occur with an associated reduction in stiffness and ultimate strength (Williams, 1989). The strength of the combined section may only develop when the piling is fully driven into the ground. Unless the interlock is a very close fit, friction may still not provide sufficient shear resistance and it may be desirable to crimp or weld the interlock of steel piles in certain cases (British Steel Piling Handbook, 1997) and to heat weld the interlock in the case of plastic piles. A proposed recent amendment to BS8002 (1994) recommends that when shear forces cannot be fully transmitted by the interlocks, this can be taken into account by using a reduced value of the section modulus of the combined section in the design. BS8002 states that whilst this problem often exists with 'trough' shaped steel piles, sections of 'Z' type piling (which often have their interlocks in the flanges) generally develop the full section modulus of an undivided wall of piling under all conditions. Descriptions of the configuration and interlock of the commercially available plastic piling products identified in this review are given in Table 1.

Whilst plastic piles are claimed to be lighter, cheaper and more environmentally friendly than steel, they do not however have as much tensile and flexural strength as steel piles. There are also few exposure data to establish whether the mechanical properties of plastics are stable over the design life of 120 years required for highway structures. Issues of durability and creep under sustained load are discussed in Sections 4 and 6 respectively.

The ability of plastic piling to resist impact damage and the likelihood of an impact occurring need to be ascertained at the design stage for any potential use of plastic piling on highway schemes. It must also be borne in mind that this ability can be seriously reduced by the influence of UV (see Section 4.1). Additives such as acrylate rubber or chlorinated polyethylene are available to improve the resistance to impact but the effects of such additives on the other physical properties of the piles need to be considered.

4 Weathering durability

4.1 Introduction

Examples of statements on durability issues found in the manufacturers' literature and on their web sites are as follows:

- 'The expected useful life of the vinyl sheeting is estimated to be 40 to 50 years' [Rehabilitation of Saltaire Marina Fire Island, New York, Holzmacher, McLendon and Murrell, P.C].
- 'Vinyl will outlast steel every day of the week' [Maurice Ruffin, New Orleans District, US Army Corps of Engineers].
- 'We manufacture with 100%UV stabilised materials' [Materials International Inc (USA)].
- 'Exceptional service life compared to other materials exceeding 100 year design life' [Bruce M Phillips, stream bank restoration design with vinyl sheet pile grade control structures].
- 'The product specification for a non corrosive foundation protection system at the Thomas Jefferson Memorial Washington DC was 100 years and was met by GeoGuard' [Materials International Inc (USA)].
- '….. it's impervious to sunlight ….' [Crane Plastics Co, Ohio].

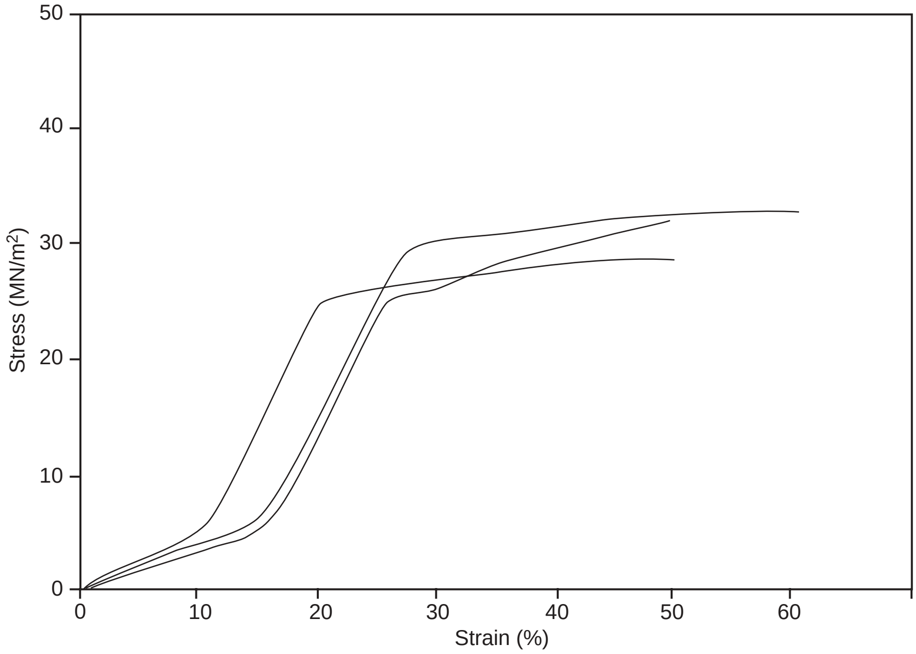
Although some of the above claims may be true, some may be less realistic and are not substantiated by test data. Under the influence of ultra violet light and other weathering factors, PVC has been found to deteriorate over periods as short as 30 years (Brady *et al.*, 1994), its ability to withstand impacts without serious damage being particularly significant. Ultra violet light affects the physical properties of plastics by disturbing the bond structure. Brady *et al*. (1994) reported that specimens of uPVC left for 30 years in ventilated aluminium boxes in a laboratory maintained at temperatures between 18°C and 25°C showed a reduction of 75% in their impact strength. This effect occurred even though the specimens had not been exposed to direct solar radiation. In a highway application, such as that of a retaining wall, direct exposure to solar radiation could speed up this deterioration. They also found that the major part of the reduction took place in the period between 15 years and 30 years. Tensile strength increased while ductility decreased during the 30 year trial. Figure 3 shows stress strain curves for samples of uPVC at age 2.5 years and 30 years. The potentially large reduction in impact strength would need to be taken into account at the design stage in applications, such as grade separated interchanges or scour protection to bridge piers, where impacts might occur.

It must be emphasised however that the uPVC samples used in these trials contained metal carboxylate stabilisers and were chosen from plastics typically in use during the early 1950's. Improvements in polymer technology during the last 50 years may have altered the resistance of current materials to ultra violet degradation. Testing was therefore carried out to determine to what extent this is the case, to establish the authenticity of claims for durability, and to assess the suitability of recycled plastic piles for use on Highways Agency schemes.

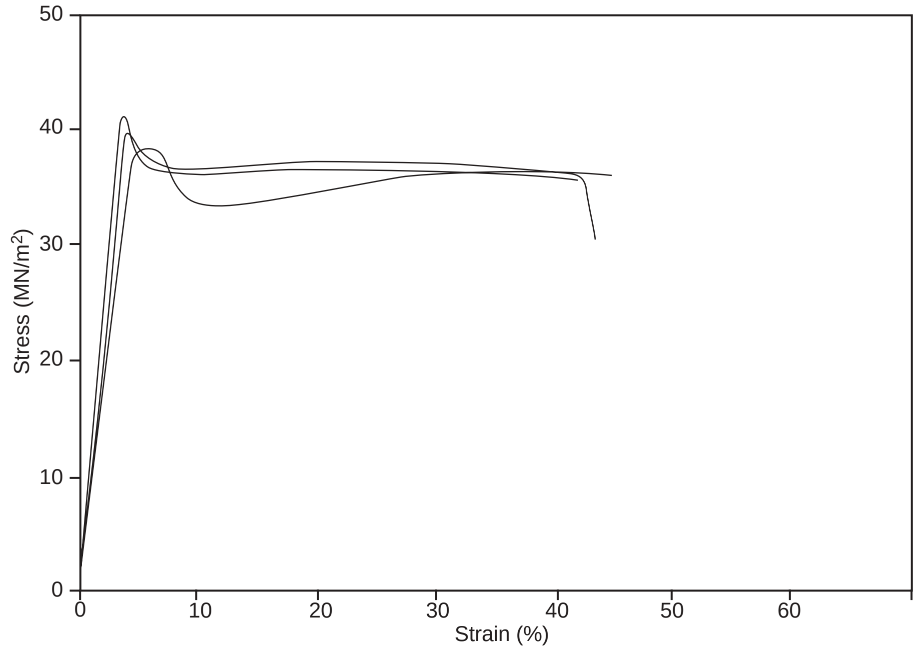
This testing involved subjecting pile material to accelerated weathering followed by determination of any changes in mechanical properties.

4.2 Weathering procedure

Test specimens were cut longitudinally from a flange of a grey plastic pile manufactured from recycled uPVC with a nominal thickness of 5mm. The specimens were exposed for durations of up to 4000 hours in a QUV cyclic ultra-violet weathering tester (manufactured by the Q-Panel Company). The accelerated weathering method complied with BS2782: Part 5: Method 540B, ASTM G151 and ASTM G154 although these standards do not specify exact conditions, but give a range of options. Typical temperature, light and dark, and condensation cycles were therefore adopted for UK conditions, that is 8 hours UVA 340 at 50^{o}C and 4 hours dark with condensation at 40^{o}C. UVA 340 provides a close copy of the UV part of the natural solar spectrum at an intensity similar to that in mid-



(i) Results for 2.5 year old specimens stored in temperate environment



(ii) Results for 30 year old specimens stored in temperate environment

Figure 3 Effect of ageing on tensile test results for uPVC (after Brady *et al*., 1994)

summer in Florida. The temperatures chosen give reasonable acceleration compared with UK conditions without being so extreme that they are likely to induce anomalous effects. There is no definitive correlation of accelerated weathering time to real time although 4000 hours is expected to simulate about 40 years in the UK.

Any degradation in mechanical properties due to accelerated weathering was assessed from tests on the recycled uPVC of the pile specimens which were carried out according to the following schedule:

- Control tests on unweathered specimens.
- Tests after 400, 1000, 2500 and 4000 hours of accelerated weathering.

Details of the mechanical testing procedures follow.

4.3 Mechanical testing schedule

Tensile, instrumented impact and flexural tests were carried out at 23±2°C on sets of samples which had been weathered for different durations of time. All specimens, which were full sheet thickness, were machined from the weathered samples to sizes appropriate for each particular test.

Tensile strength, elongation at yield and elongation at break were determined in accordance with BS EN ISO 527-2 (1996) using type 1B specimens and a test speed of 50mm/min. Each set of tests comprised five specimens.

Flexural modulus and strength were determined in accordance with BS EN ISO 178 (1997) using a test speed of 2mm/min. Each set consisted of three specimens tested exposed side up and three tested exposed side down.

Instrumented drop weight impact strength was determined in accordance with BS EN ISO 6603-2 (2000) using a 20mm diameter hemispherical striker and an impact velocity of 4.4m/s. The deviation from strict accordance is only due to a difference in calibration method. Again, each set consisted of three specimens tested exposed side up and three tested exposed side down. The geometry of this test is that the sample is clamped over a 40mm diameter hole in a flat plate, using a 40mm diameter clamping ring. Hence, the action of forcing a 20mm diameter striker through the sample applies tension to both the bottom surface below the striker and the top surface near the clamping ring.

4.4 Discussion of results from mechanical testing

Results from tensile and flexural strength tests are shown in Table 2; those from instrumented impact tests are given in Table 3. Tensile, flexural and impact strengths all show an initial increase over the first 400 hours of accelerated weathering. Although the reason for this is unclear, it is possibly due to small quantities of plasticiser or processing aid being driven off by the heat associated with UV exposure. It should be noted that the impact strength of 'unplasticised' PVC is reduced by the presence of small quantities of plasticiser, even though larger quantities would be expected to dramatically improve impact resistance.

The tensile results indicate very little subsequent change in strength or elongation at yield (that is damage initiation), but significant progressive reduction in elongation at break with increasing exposure. This latter property has little practical relevance in a material as once yielding has commenced, serviceability is probably already lost.

Table 2 shows that flexural properties of the pile samples are virtually unaffected beyond 400 hours and up to the maximum exposure duration of 4000 hours. No significant difference was detected between samples tested 'exposed side up' and those tested 'exposed side down' and so the data have been presented in combined form.

Table 3 Results from instrumented impact tests

Ageing period (hours)	*Exposed face (up or down)*	*Instrumented drop weight impact strength at 23°C (J)*	*Deformation at peak (mm)*
Un-aged	n/a	127.6 (23.3)	14.7
400	Up	157.3 (13.7)	16.5
	Down	134.6 (43.2)	13.1
1000	Up	159.0 (9.3)	16.6
	Down	118.0 (74.9)	13.5
2500	Up	168.1 (28.9)	16.0
	Down	167.4 (20.0)	15.7
4000	Up	78.6 (20.1)	11.3
	Down	171.9* (6.9)	16.8

Numbers in brackets indicate the standard deviation of the results.
** Three specimens were tested but only two valid results were obtained.*

Impact strength is generally quite variable, but shows no significant trends between 400 and 2500 hours, with all samples being basically ductile. However, the 4000 hour 'exposed face up' samples were brittle, giving a large reduction in both energy and displacement to failure. Example photographs of an un-aged ductile sample and a brittle 4000 hour sample are shown in Figures 4 and 5.

Although the percentage reduction in impact strength is significant, the 4000 hour samples were still quite tough. For reference, although the test methods are different, the acceptability limit for uPVC window frame material after 2250 hours UV exposure, as specified in BS7413, is a 30% loss in impact strength as opposed to the 38% recorded here at 4000 hours. The average value of 125J at 4000 hours is virtually unchanged from the original value. However it must be noted that it is generally the exposed face which is subjected to impact.

During the course of the accelerated weathering it was observed that the exposed surfaces started to discolour between 400 and 1000 hours exposure, developing a yellowish hue.

5 Chemical, biological and fire resistance

5.1 Chemical and biological resistance

Materials close to highway traffic are likely to come into contact with chemicals either used deliberately by highway authorities for such operations as de-icing and resurfacing or due to accidental spillages. Carder and Card (1997)

Table 2 Results from tensile and flexural strength tests

Ageing period (hours)	*Tensile strength (MPa)*	*Elongation at yield (%)*	*Elongation at break (%)*	*Flexural modulus (MPa)*	*Flexural strength (MPa)*
Un-aged	41.9 (0.20)	2.3 (0.37)	33 (3.1)	2890 (219)	62.9 (1.9)
400	46.0 (0.51)	2.4 (0.31)	20 (1.2)	2860 (150)	70.4 (0.6)
1000	47.2 (0.38)	2.6 (0.24)	19* (1.4)	2860 (70)	70.3 (2.5)
2500	46.0 (0.48)	3.1 (0.31)	3.1 (0.3)	2740 (271)	70.7 (2.0)
4000	46.6 (0.46)	2.4 (0.18)	2.4 (0.2)	2710 (73)	69.8 (1.4)

Numbers in brackets indicate the standard deviation of the results.
** Five specimens were tested but only three valid results were obtained.*

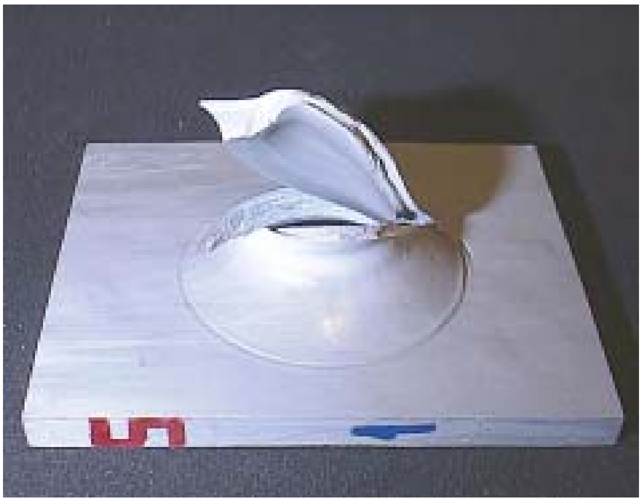


Figure 4 Un-aged sample showing ductile impact failure

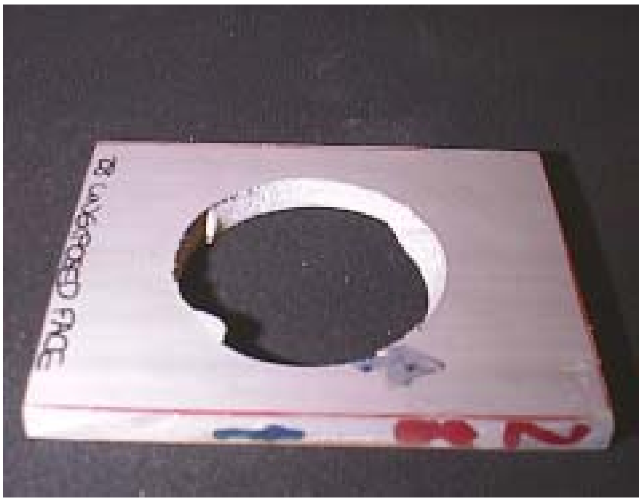


Figure 5 4000 hour sample showing brittle impact failure

suggested that plastics for use as innovative structural backfills to bridges should be resistant to chemical and biological attack from agents such as de-icing salts, acids, alkalis, sulphates and chlorides, as well as petroleum hydrocarbons and other organic compounds. Darley and Carder (1998) in a consultation document concerning the use of compressible layers for use in integral bridges identified the standards relevant to the durability of plastic materials: these are listed in Table 4. However verification that tests included in these standards are appropriate for assessing the durability of plastic sheet piling is beyond the scope of this report.

Table 4 Standards relevant to the durability of plastics

Factor affecting material	*Test standard*
Rain, runoff, liquid chemical spills	ISO 175
Fungi, bacteria	ISO 846
Temperature, fire resistance	ISO 2578
Damp heat, water spray, salt mist	ISO 4611
Environmental stress cracking	ISO 4599

2.2 Fire resistance

In some circumstances such as a traffic accident, plastic piling may be exposed to fires from spilled fuel and/or chemicals being transported on the highway. It may therefore be necessary to ascertain the resistance of plastic piling to various sources of ignition and in addition the potential for release of hazardous fumes such as hydrogen chloride and dioxins from such a fire.

Claims for the fire resistance of PVC made by the European Vinyls Corporation (1995) include the following:

i PVC is difficult to ignite.

ii Because of its excellent fire retardant properties, PVC is specified for fluorescent light diffuser panels.

iii PVC conveyor belting is specified as essential safety equipment in coal mines because it is flame retardant.

The inherent flame retardant properties of PVC are mainly by virtue of its chlorine content and special formulations can be made to further enhance this property. PVC will generally not continue to burn once the heat source has been removed. However a more detailed assessment of fire risk and the potential for release of hazardous fumes where burning is considered worthy of further investigation is given in Appendix A.

Generally it was concluded in Appendix A that the probability of an event leading to a fire occurring on the highway network involving uPVC sheet piling appears remote. Furthermore if any fire were to occur it is likely to be short lived and the effects of any combustion by-products are expected to be less hazardous than those from, for example, a burning fuel spillage or vehicle.

6 Creep tests under sustained loading

6.1 Introduction

Plastics are viscoelastic materials, but they generally respond to short term loads in a reasonably elastic manner. When kept under sustained loading for a long time, creep deformation may however occur. The magnitude of the creep deformation will depend primarily on the applied load and calculations were therefore carried out to determine the lateral loads produced by a range of ground and water conditions for different retained heights of sheet pile walls.

For effective stress design of permanent structures, the horizontal effective stress developed on the sheet pile wall at a depth z from the retained ground can be determined using the usual equation:

$$P_a' = K_a(\gamma z - u) - K_{ac}c'$$

where K_a and K_{ac} are the coefficients of active earth pressure, γ is the bulk density of the soil, and c' is the effective cohesion. The value of K_a is related to the angle of internal friction of the soil (φ') and the value of K_{ac} is calculated from K_a and the magnitude of wall and soil adhesion. Values of K_a and K_{ac} may be determined based on the work of Caquot and Kerisel (1948). The pore water pressure (u) is added to the effective horizontal stress to give the total stress acting on the wall. From the distribution of horizontal stress, the bending moments developed in the sheet pile wall can then be calculated.

Typical distributions of bending moment with depth for granular soils with φ′ values of 30° and 40° are shown in Figure 6. Water tables on the retained side of the wall which are (a) below that of the dredge level and (b) at 1m depth below ground level, are separately investigated. Similar calculations were also carried out for cohesive soils with φ′ equal to 20° and c′ of either 5 or 10kPa: these results are shown in Figure 7. In these latter cases no tension was allowed to develop at the top of the retained clay with negative pressures being reduced to zero. Both sets of calculations assume no wall friction or adhesion, and unfactored loads have been used in determining bending moments such as is appropriate for serviceability limit state design.

The maximum and allowable bending moments recommended by the manufacturer for the particular plastic piling being tested are also indicated in Figures 6 and 7. It must be noted that the magnitudes of these two moments will vary according to the section modulus of the selected pile.

For the purpose of this project, three different loading cases were investigated for the creep testing as follows:

1 Wall height of 1m retaining granular soil (φ′ of 30°) with water table at 1m depth below retained ground level.
2 Wall height of 1.6m retaining granular soil (φ′ of 30°) with water table at 1m depth below retained ground level.
3 Wall height of 2.55m retaining cohesive soil (φ′ of 20°, c′ of 10kPa) with water table at 1m depth below retained ground level.

These cases were considered representative of a wide range of different loading conditions likely to occur against low height retaining walls constructed from plastic sheet piling. Bending moments developed in temporary structures retaining cohesive soils (case 3) are likely to be less severe if undrained rather than effective stress soil parameters are employed in the calculations.

6.2 Test procedure

All testing was carried out in a laboratory with the temperature controlled to 23±2°C. Plastic sheet piling manufactured from recycled uPVC with a nominal material thickness of 5mm and section modulus of 350cm^3/m was used for the tests. Each test was carried out using a pair of plastic piles (interlocked at the back) so as to form a completed trough shape.

Schematic drawings of the test set-ups for the three different load cases are shown in Figure 8. The loading arrangement was actually with the sheet pile horizontal rather than vertical, as it would be in practice. This enabled one end of the pile to be fixed by loading with kentledge of concrete blocks; the shape of the sheet pile configuration was retained beneath the kentledge by specially cast concrete formers into which the pile was seated. Vertical loading was then applied onto 80mm wide saddles that were also specially cast from concrete. These saddles maintained the cross-section of the pile which otherwise would have flattened under the load so producing an unwanted change in the section modulus of the pile. As the saddles were relatively narrow it was deemed that their influence on longitudinal bending was small enough to be ignored. Where the loads were smaller than 30kg, they were applied directly without using a saddle. The combinations of vertical loads, which include

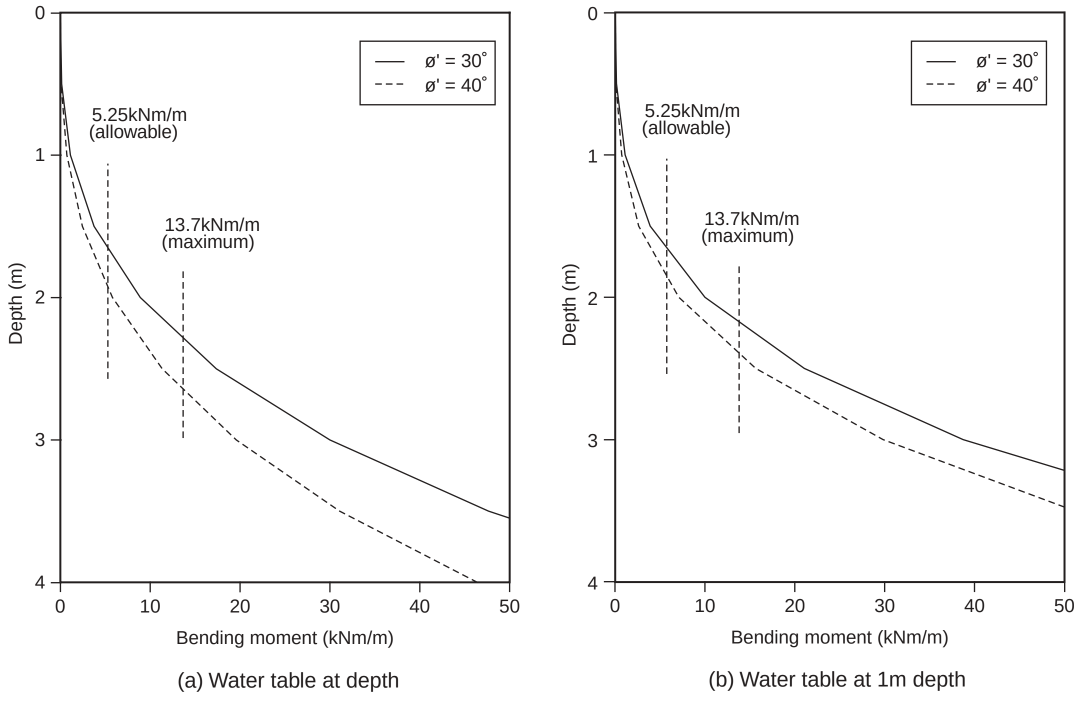


Figure 6 Bending moment in granular soil

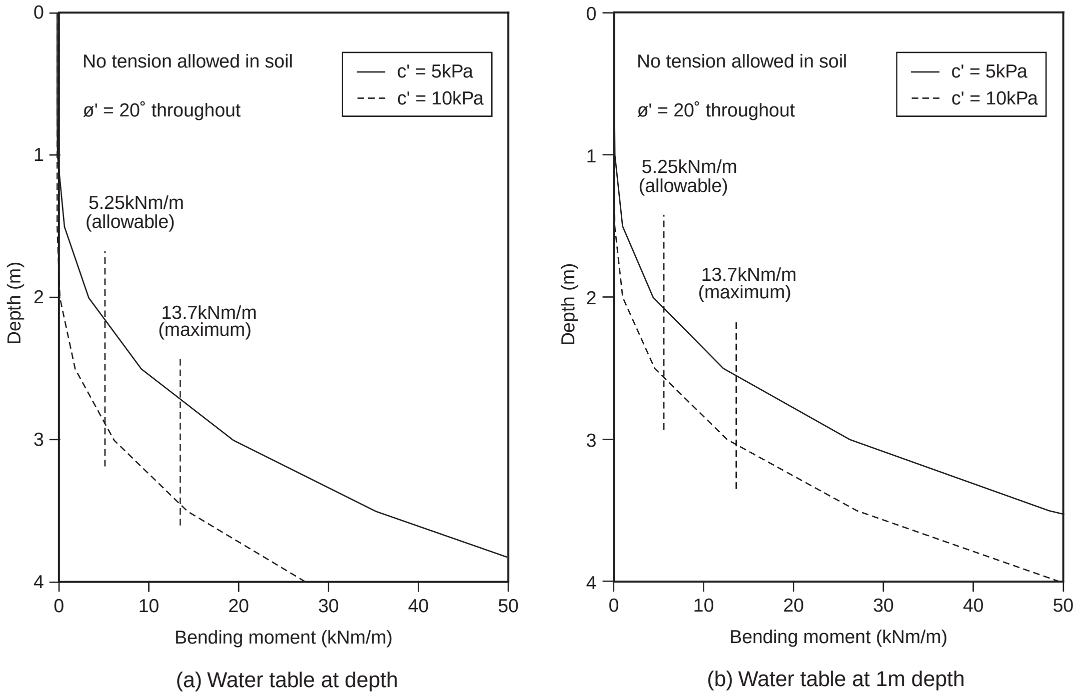


Figure 7 Bending moment in cohesive soil

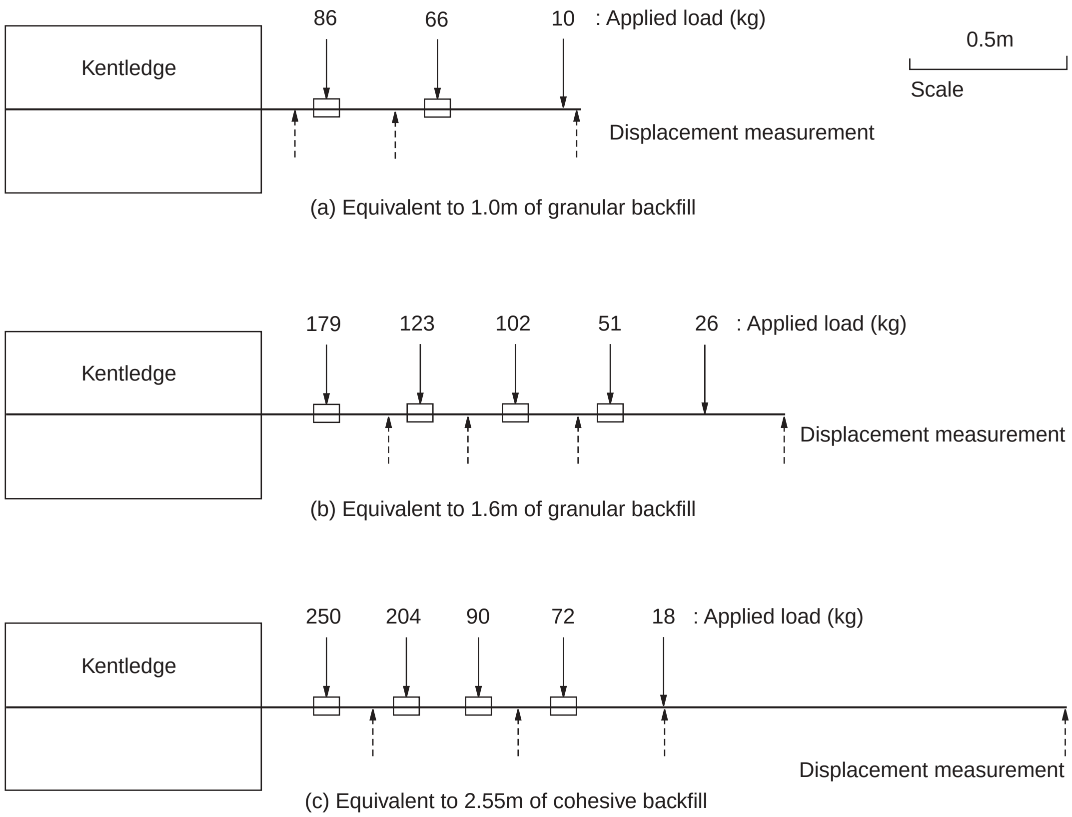


Figure 8 Loading arrangement for creep tests

the weight of the saddles where appropriate, to simulate the lateral soil loading on a sheet piled wall are shown in Figure 8. It was not practical to apply all the vertical loads simultaneously, although loading was generally completed within a period of a few hours.

The vertical deflections under sustained loading were measured using dial gauges at 3 or 4 locations beneath the sheet pile as indicated in Figure 8. The distances of these locations from the fixed part of the pile varied according to the test as the measurements had to be made between loading saddles. Creep deformation was monitored for a minimum duration of 1000 hours for each of the three load cases.

6.3 Discussion of results from creep tests

The deformation with time was recorded from a datum established immediately after the application of the full loading and the results are shown in Figures 9a, 10a and 11a for the three tests. In each case, the rate of creep was initially fast but slowed with time.

Long term performance is usually of concern to a designer and therefore creep behaviour is more usually expressed (as in Figures 9b, 10b and 11b) by the relation between deformation and the logarithm of time. In the latter plots a sharp increase in deformation would be anticipated as rupture approaches. This was not observed in any of the three tests and behaviour of the pile remained plastic with no definite indication of approaching failure.

Other forms of presentation can be derived from semi-logarithmic relations for the creep of geosynthetics and these are discussed by Watts *et al.* (1998). One of these is a Sherby-Dorn diagram (Sherby and Dorn, 1956) which presents relations between the strain and the logarithm of the rate of strain. Such a diagram can be used to identify the point at which the rate attains a minimum constant value before increasing as rupture is approached. Strain is not measured in these particular creep tests and therefore displacement has been plotted in its place in the Sherby-Dorn type plots given in Figures 9c, 10c and 11c. There is no indication of any of these plots reaching a minimum constant value, which confirms that rupture is not imminent.

Figure 12 compares the deflected shape of the three piles after 1000 hours under sustained loading. As would be expected creep of the plastic piling under a loading equivalent to 1m of granular backfill (maximum bending moment of 1.1kNm/m) was small and the pile remained serviceable. When the retained height was increased to 1.6m, a maximum bending moment of 4.8kNm/m, the situation became more marginal. Significantly more creep deformation was recorded when the load case equivalent to 2.55m of cohesive backfill was modelled. This latter case gave a maximum bending moment of 5.25kNm/m, which was the same value as quoted by the manufacturer for the allowable moment. Deformation in this case would probably result in eventual loss of serviceability of the structure.

It was generally concluded therefore that, for these particular piles, a safe retained height when using granular backfill (φ' of 30^{o}; water table at 1m depth) would be around 1.5m. Detailed design would need to take account of any variation of the soil strength parameters and water table conditions from those assumed. Similarly for the typical cohesive backfill (c' of 10kPa; φ' of 20^{o}; water table at 1m depth) simulated in this report, effective stress design would probably limit the retained height to around 2.4m. Designs for temporary works relying on the undrained strength of clay would of course permit greater retained heights.

Generally to avoid problems with the particular pile type tested, a sensible limit for the maximum bending moment in serviceability limit state design would be about 4kNm/m. However it should be noted that there are a number of options which would increase the scope for using plastic sheet piling, these include the following:

- an increase in the section modulus and/or thickness of the pile;
- the use of pile stiffeners (either steel or plastic) to improve the section modulus;
- propping the sheet piled wall near the top using plastic walings and ground anchors or soil nails; this reduces the wall bending moment significantly.

7 Driveability

Standard driving techniques for steel sheet piles include impact, vibratory or hydraulic drivers. Damage to the heads of the piles may occur and a small additional length is normally allowed so that the head may be trimmed if necessary. Impact methods generate the highest stresses during driving and are suitable for all soil types. Vibratory and hydraulic drivers do not generate such high stresses in the piles during their installation but may not be suitable in all ground conditions. Both the driving technique and the ground conditions need to be considered in confirming the adequacy of the pile section to withstand the driving forces. Because of the tendency to go off-line and lose verticality, piles are often driven in pairs and between two walings to control their advance.

Some manufacturers of plastic piles claim that standard piling rigs can be used for driving their particular piles. Although this may be the case in some ground conditions, special rigs have been developed by other manufacturers to minimise the stresses on the plastic piles which are inherently less robust than steel piles. The successes in driving plastic piles are best illustrated by some examples that have been extracted from the literature:

i The US Corps of Engineering used a 3400lb vibrating hammer and achieved a driving rate of two 16 foot sheets in 90 seconds.

ii VJE Construction (USA) used a crew of 8 with a 90lb air hammer to drive 2100 linear feet of vinyl piles at a rate of 250 linear feet per week.

iii At Long Bay Pointe Marina (USA) 3,300 linear feet of vinyl sheet piling were driven using a vibratory hammer to drive through clay, rocks and tree stumps (Chesapeake Angler Magazine).

iv In Holland and the USA water jetting has been used to install plastic piles in some soils.

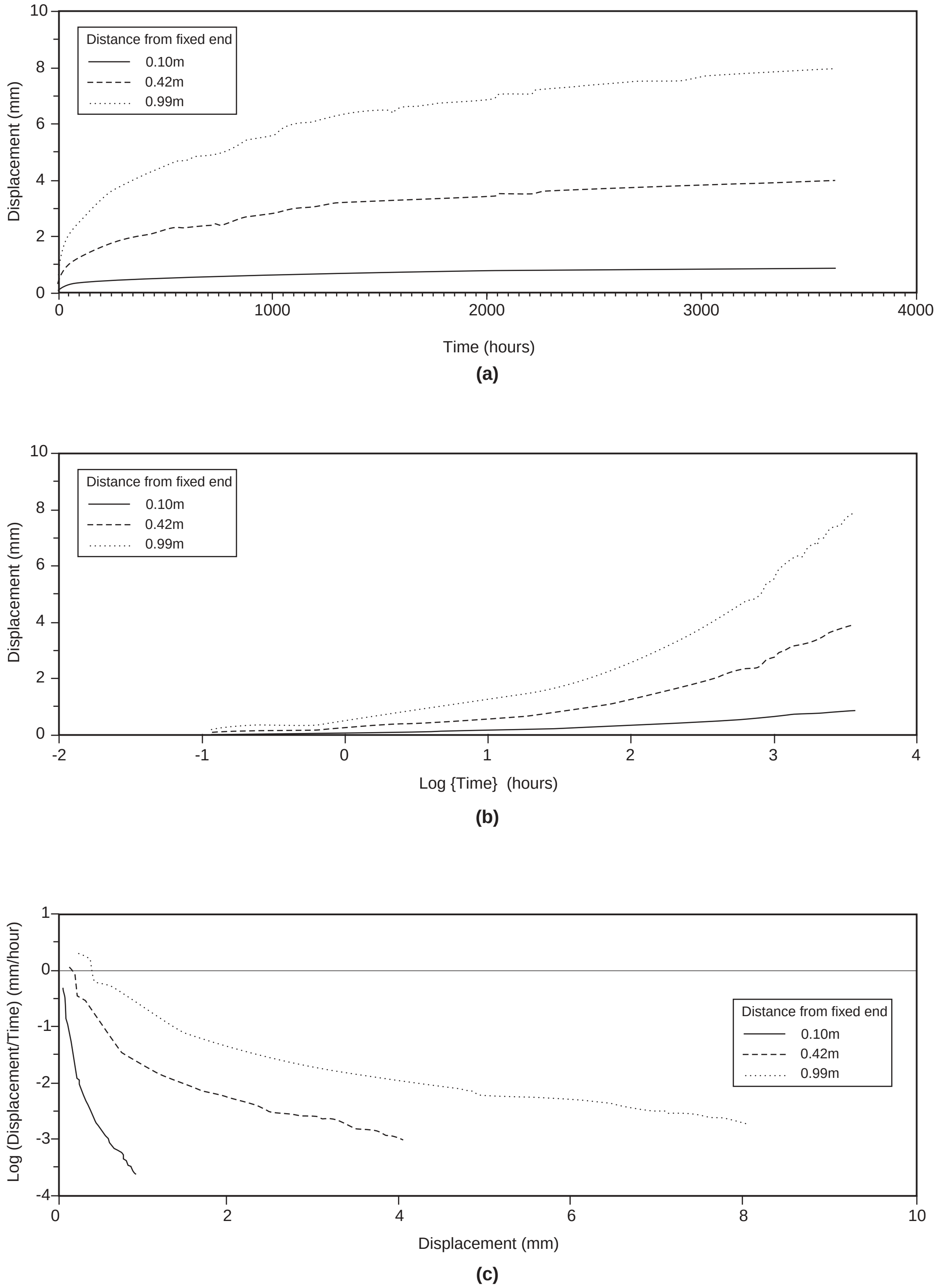


Figure 9 Creep under sustained load equivalent to 1.0m of granular backfill

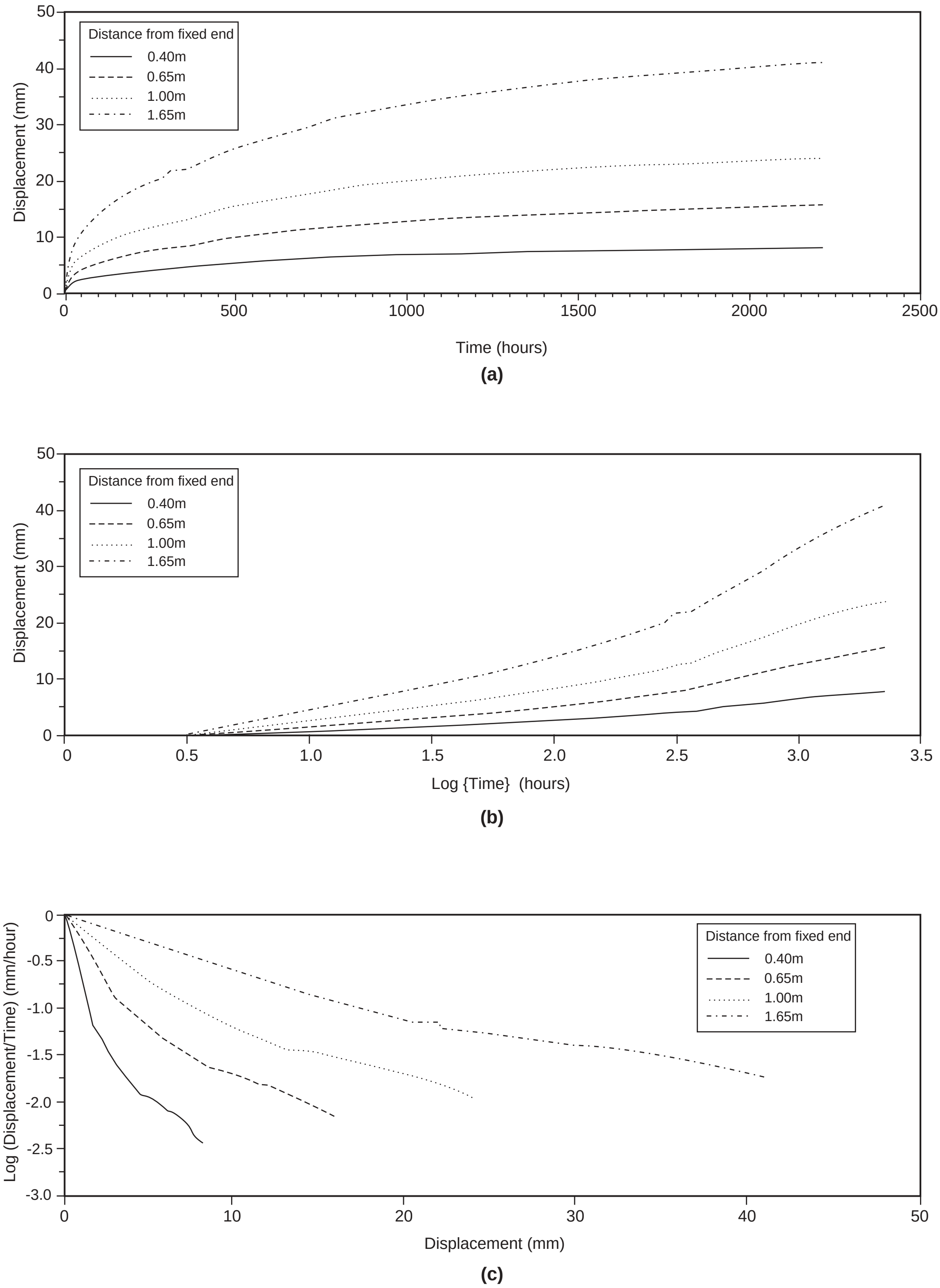


Figure 10 Creep under sustained load equivalent to 1.6m of granular backfill

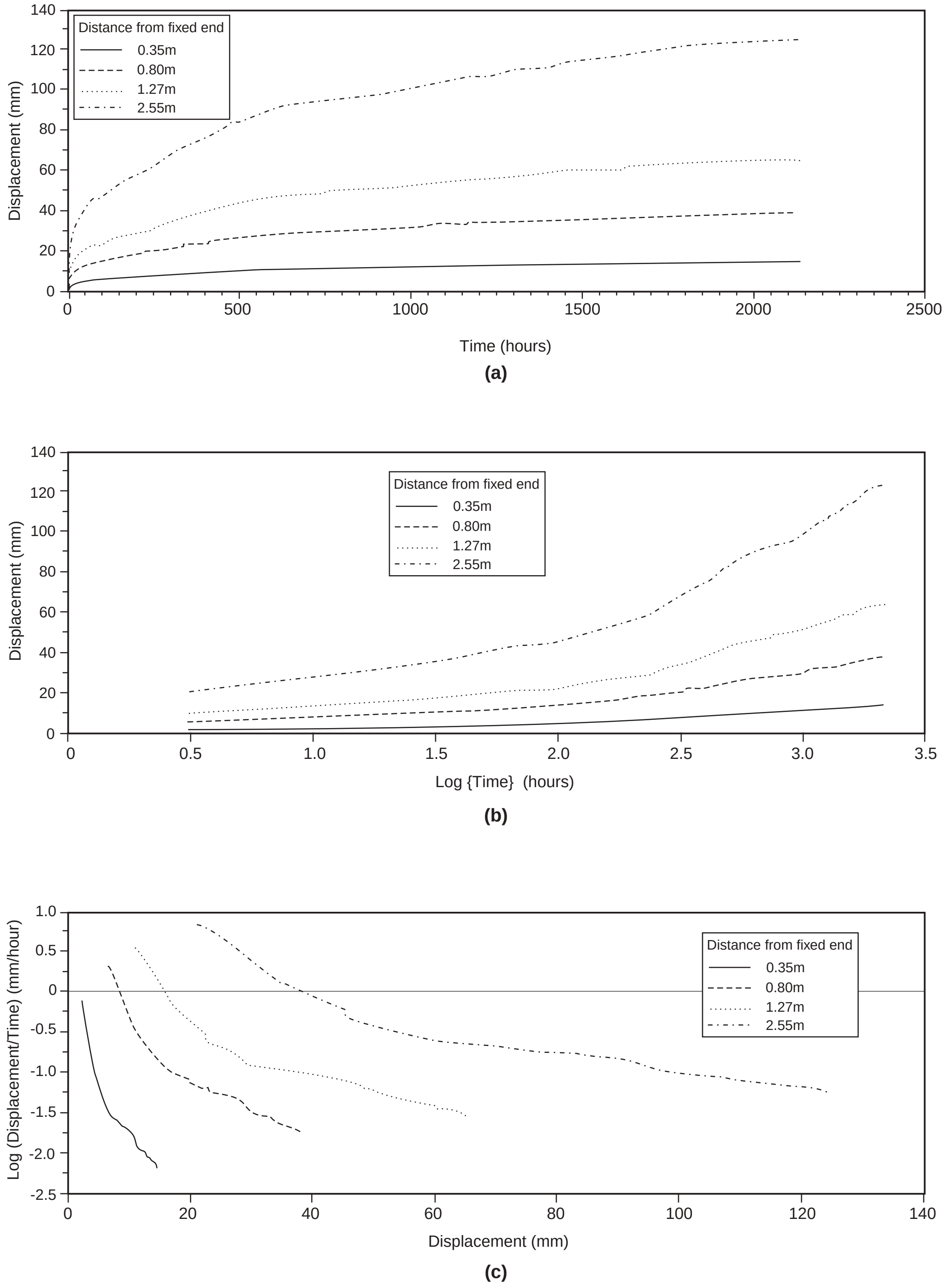


Figure 11 Creep under sustained load equivalent to 2.55m of cohesive backfill

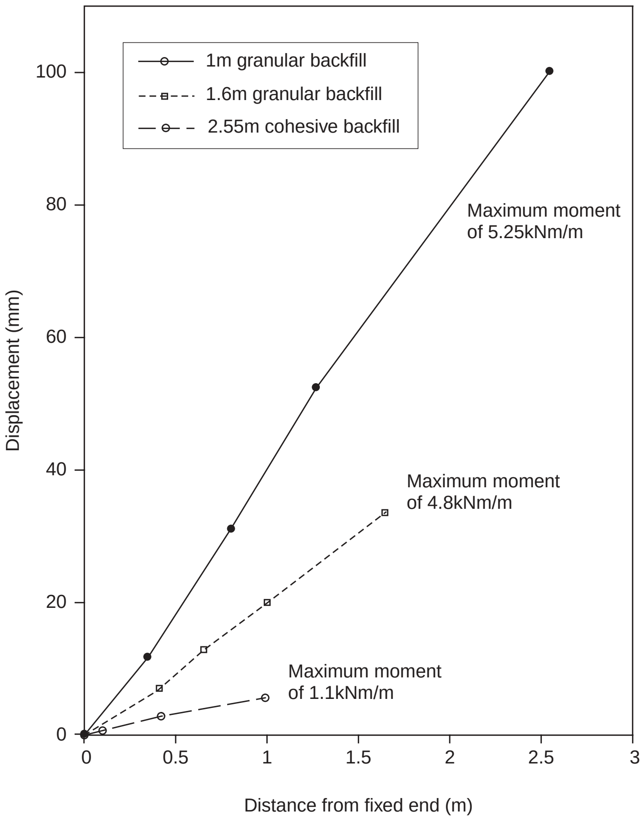


Figure 12 Comparison of creep test results at 1000 hours

Finally, in the UK several types of installation plant are already in use and others are in varying stages of development. Generally it is viewed that a reasonable amount of power and the ability to vary between impact and vibratory mechanism is required to ensure that a plastic pile is driven to 4m depth (say) in all ground conditions. Such hammers are better machine mounted although, for these sorts of depth, mini-excavators may provide adequate mounting (Figure 13).

As with both steel and plastic piles, the ease of driving depends upon the type of strata encountered, the required penetration, and the flexural rigidity of the pile. In hard driving conditions it may be necessary to increase the section size to prevent deformation of the pile toe and the pile going off line. This problem is likely to be more acute with the more flexible plastic piles however, because of their lower bending moment capacity, the required penetrations are often less.

Materials International Inc (USA) claim to have overcome the problem of pile flexibility during driving by introducing a patented system of ‘I-beam lock’ and ‘strong back ribs’ to their plastic piles. In the UK, piles are frequently slotted together and a group then driven in an attempt to increase the driveability of the piling and produce a more uniform finished product. The need for this partly arises because piles in the UK are fabricated as a ‘half trough’ section and then slotted together to give either a ‘trough’ or a ‘Z’ configuration as required. Piles manufactured in the US are generally extruded in a full ‘trough’ section and hence of greater rigidity because the ‘single pile’ section modulus is greater. This assists in keeping line and verticality during driving.

A visit was made to observe plastic piles being driven at a small site at Vann Lake: these observations are reported in Appendix B.

8 Potential highway related uses for plastic piling

Plastic piling has been employed in the UK in schemes for the Environment Agency, English Nature, British Waterways Board, Cotswold Water Park, English Heritage, Cumbria Wildlife Trust, Northumbria Wildlife Trust, Cheshire Wildlife Trust and others. These applications have been mainly in a waterway, lake or marine environment. Based on information from these schemes, manufacturers and searches through the worldwide web, the following potential applications have been identified which are highways related:

- Earth retaining structures.
- Temporary works (eg. for deep trenching).
- Slope stabilisation.
- Noise barriers.
- Channel linings.
- Anti-scour around bridge foundations.
- Balancing pond walls.
- Flood control walls.
- Cut-off and slurry walls.

These potential applications are now discussed in more detail.

Figure 13 Pile driving on a highway scheme

8.1 Earth retaining structures

As more integration of the transport network takes place the need to accommodate more vehicles and different modes of transport into the available space is likely to result in an increased need for grade separated routes and interchanges. Earth retaining structures will be increasingly needed and plastic piling could offer a cost effective and environmentally friendly solution to their provision. In addition earthwork slopes on the highway and rail networks may need to be steepened in order to accommodate additional traffic lanes without needing to acquire extra land.

The use of plastic piling for permanent highway works is expected to be mainly for structures with a low retained height because of the limitations in bending moment resistance, creep and driveability discussed earlier.

8.2 Temporary works

A significant proportion of sewer renewal, replacement and new construction involves deep trenching works in urban areas. Traditionally steel piling is used for this application to provide safe access and minimise ground movements that may damage adjacent buried utilities and the adjoining carriageway surface. In deep trenching the low flexural rigidity of plastic may not be an issue because sheet piles are often used in conjunction with stiff proprietary propping systems which carry the load. Furthermore in many cases a considerable part of the ground movement occurs during pile extraction (Symons *et al*., 1981) and the use of cheaper recycled plastic piling raises the possibility that the piling could be left permanently in place so avoiding this additional movement.

The use of plastic piling may also provide a low cost alternative to steel piling in many other temporary works situations met during the civil engineering construction of bridges, tunnels, drainage systems, manholes, etc.

8.3 Slope stabilisation

As the clay slopes, both cutting and embankment, on the highway network get older the number of slope failures is likely to increase. Many techniques for the repair or prevention of serious failures exist. Steel sheet piling is often used in this situation either at the top or toe of the slope to limit damage to the adjoining carriageway.

The possibility exists therefore that plastic piling might be suitable as an alternative to the heavier and more expensive steel piles. However the lower ability of plastic piles to accommodate bending forces needs to be taken into account in the design and would preclude their use for some schemes. It may also be economically advantageous to use plastic piles if they could be employed in conjunction with a suitable anchoring or nailing system so that pile bending moments are minimised.

It is suggested that successive rows of plastic piles driven into the slope face may also offer a method of stabilising a clay slope against shallow failures at depths of up to 2m, although no reports of the use of this technique could be located in the literature. An outline drawing of a suggested scheme is shown in Figure 14. By utilising successive rows of piles, each row is only called on to retain a few metres height of soil. This scheme is only suitable for preventing or remediating shallow failures as the embedment of the piles into underlying firm strata is necessary for their stability. Gaps would probably be needed at intervals in each pile row to prevent water build-up.

8.4 Noise barriers

As the volume of traffic on both road and rail increases, the adverse effects of noise on those living and working close to roads and railways will inevitably grow. Pressure to provide absorbing barriers to reduce the nuisance from both those directly affected by the noise and campaigners for environmental improvement will increase. The relatively low weight and cost of plastic piles could result in simpler and cheaper installation of such barriers especially in those locations where access for heavy plant and equipment needed for more conventional structures is either difficult, and hence expensive, or impossible.

Barriers using conventional materials (such as wood and concrete) deplete natural resources and the use of plastic

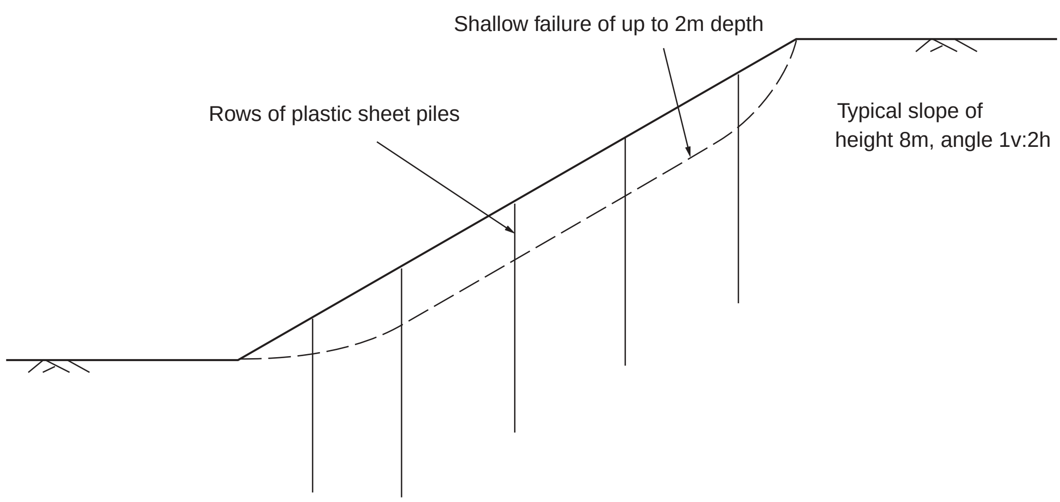


Figure 14 Stabilising a clay slope against shallow failure

waste is therefore functionally and environmentally logical. This approach has already been adopted in North America where plastic lumber has been used in the construction of a full scale noise barrier (Roschke and Esche, 1999). It must be noted that the lumber was produced from the recycling of mixed plastics and that the columns between which the lumber was placed were steel reinforced. There would appear to be no technical reason why structural plastic sheet piling could not fulfil the same role as a noise barrier.

8.5 Channel linings

Much of the current use of plastic piling both in the UK and worldwide is in applications involving water. The construction of water channels using plastic piling instead of expensive steel piles or cast in-situ concrete linings could prove to have economic and environmental benefits such as reduced construction and maintenance costs and a more visually attractive appearance.

8.6 Anti-scour around bridge foundations

Where a highway crosses a river or watercourse, one or more of the piers supporting the bridge are frequently founded in its bed. Several major and a larger number of minor bridge failures have been attributed to scour undermining the pier leading to over loading of the remaining supports and eventually collapse of the structure. Various methods of alleviating this problem exist one of which is the use of steel sheet piling. The alternative of plastic sheet piling has been successfully employed in the USA as a solution to this problem and could be feasible in the UK.

However one potential disadvantage of using plastic rather than steel is its lower resistance to impact damage. Although it is envisaged that its strength may be adequate to resist impact from waterborne debris, measures might need to be taken to prevent river traffic colliding with the plastic piling. On the other hand plastic piling has a much greater resistance to corrosion than steel. Manufacturers also claim that it does not release toxic substances into the water and is resistant to attack by rodents and bacteria.

8.7 Balancing pond walls

In many highway schemes the large volumes of water running off the impervious road surface during heavy rain are much higher than the local streams and rivers are able to disperse without flooding the surrounding area. In order to accommodate this water, balancing ponds are commonly constructed to collect the water and release it at a controlled rate. Such ponds could be conveniently constructed from plastic piling rather than the more conventional methods currently employed.

8.8 Flood control walls

In the light of the increased frequency of long periods of heavy rain occurring in the UK which have resulted in severe and repeated flooding there may be a greater need for flood control measures to be incorporated into highway related schemes. The use of plastic piling in the construction of such flood protection measures could result in a more economic and aesthetically pleasing form of construction.

8.9 Cut-off and slurry walls

Cut-off walls can be used to prevent the movement of materials into areas where they are not wanted or to keep them in place. ‘Over 1400 linear feet of GeoGuard was used by the New York Port Authority as a cut-off wall to prevent the migration of soil from under the concrete relieving platform (foundation) under the transfer cranes that load the freighters’ (Materials International Inc). In highway schemes they might be used to stabilise temporary works platforms on which heavy plant is operating for significant periods of time.

Manufacturers, such as Materials International Inc, suggest that plastic piling could be used as an alternative or to assist in the construction of slurry walls used to control groundwater or prevent the flow of contaminants. However no examples of actual projects could be located.

9 Summary

Plastic sheet piling manufactured from either polyvinyl chloride or fibre reinforced polymer has been extensively used for soil retention in North America and Europe particularly for waterway and marine applications. Production of sheet piling from recycled polyvinyl chloride has recently been introduced into the UK and appears to have potential for use in highways related applications in offering a cost effective and environmentally friendly solution to the provision of low height retaining walls. The manufacturing process, dimensions and properties of commercially available products, and potential applications in a highway situation have been reviewed in this report.

Plastic piling has many apparent advantages which include ease of handling and transportation of the lightweight piles, good corrosion resistance to both fresh and salt water, good resistance to chemicals, good fire resistance, and the opportunity to use recycled materials in manufacture. However some of the perceived performance concerns about using plastic sheet piling in a highway situation are durability issues of whether plastics have adequate resistance to both ultra-violet degradation and also to creep under sustained load. This report gives the results from weathering and creep tests carried out on recycled uPVC piles and the following main conclusions were reached.

i The tensile strength and elongation at yield of the pile material were virtually unaffected by 4000 hours of accelerated weathering. This accelerated weathering period is expected to simulate about 40 years in the UK. The only noticeable change observed during the tensile tests was a progressive reduction in elongation at break with increasing exposure. This latter property has little practical relevance in design.

ii The flexural properties of the pile samples were virtually unaffected by 4000 hours of accelerated weathering. No significant difference was detected between samples tested 'exposed face up' and 'exposed face down'.

iii Impact tests showed no deterioration in strength after up to 2500 hours of accelerated weathering with all samples being basically ductile. However, the 4000 hour 'exposed face up' samples although still quite tough were brittle showing a large reduction in both energy and displacement to failure from previous test results. The average energy value from both faces of 125J at 4000 hours is virtually unchanged from that of unweathered samples, although it must be noted that it is generally the exposed face that is subjected to impact.

iv Creep tests were undertaken simulating the effect of sustained lateral loading on plastic sheet piling from different heights of retained ground. The creep deformation under a loading equivalent to 1m of granular backfill (maximum bending moment of 1.1kNm/m) was small and the pile remained serviceable. When the retained height was increased to 1.6m, a maximum bending moment of 4.8kNm/m, the situation became more marginal. Significantly more creep deformation was recorded when the load case equivalent to 2.55m of cohesive backfill was modelled. This latter case gave a maximum bending moment of 5.25kNm/m, which was the same value as quoted by the manufacturer for the allowable moment for this particular product. Deformation in this case would probably result in eventual loss of serviceability of the structure.

v Generally to avoid problems when using this particular pile, a sensible limit for the maximum bending moment in serviceability limit state design would be about 4kNm/m. However a range of similar products exist which will have different bending moment capacity. For example, this limit will increase if the plastic piles are manufactured with a higher section modulus or if pile stiffeners (either steel or plastic) are incorporated either at manufacture or subsequently. Increased retained heights are also achievable if the piled wall is propped near the top using ground anchors or soil nails bearing on plastic walings; this reduces the wall bending moments significantly.

It must be noted that the above findings, although expected to be relevant to this generic type of recycled uPVC pile, were carried out on sheet piles from a single source. Sheet piles from different sources may need further investigation.

The use of plastic piling for permanent highway works is expected to be mainly for structures with a low retained height because of the limitations in bending moment resistance, driveability and creep performance. Other uses which were identified during the course of the study include temporary works (eg. for deep trenching), slope stabilisation, noise barriers, channel linings, scour protection around bridge foundations, balancing pond and flood control walls, and cut-off and slurry walls.

Monitored trials of performance are required to give the civil engineering industry further confidence in the use of plastic sheet piling in highway applications. These trials could take place by monitoring the construction and subsequent performance of either a short length of experimental low height piled wall or alternatively a trial structure on the highway network.

10 Acknowledgements

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The accelerated weathering tests were carried out at Rapra Technology Ltd (North-East Centre) and the advice of Mr A Hamilton of that organisation was particularly appreciated. Rapra Technology Ltd is a UKAS Testing Laboratory (No 0921) and tensile and flexural tests complied with this accreditation. Instrumented impact testing is not UKAS accredited, but was carried out within an ISO 9000 accredited quality system. Accelerated weathering is not included on the accredited scope of Rapra Technology Ltd, or any other laboratory.

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Northstar Vinyl Products:	www.northstarvinyl.com
RBF Consulting:	www.rbf.com
Saltaire:	www.saltaire.org
United States Army Corps of Engineers:	www.mvn.usace.army.mil and www.hq.usace.mil

Appendix A: Assessment of fire risks and any associated hazardous fumes

A1 Assessment of fire risk in a highway situation

It is generally acknowledged that PVC is a material that is not easy to ignite and one that tends to extinguish itself when the source of ignition is removed. PVC products are inherently flame retardant due to their chlorine base. For these reasons it is often recommended for use in mines where the consequences of even a small fire in such a confined space with limited escape routes could be disastrous. The extensive use of PVC in window production has also led to extensive research on fire resistance which has confirmed that PVC products will not continue to burn once a flame source has been removed. As PVC is commonly used in these two situations where fire risks need to be minimised, the use of plastic sheet piling in a highway environment is not expected to be especially controversial or risky.

In a civil engineering application, plastic sheet piling would primarily be used for the retention of soil or water and would therefore normally have only a limited area of exposed face and often be installed in an open area rather than a confined space. Thus the scope for development of any fire would be limited and, in the unlikely event of an incident, road users and others would generally be able to escape from a relatively open area without the risk of being physically trapped. The combustion products produced by the fire would also be expected to disperse from an open area. As there is already a widespread use of plastics and other flammable materials in modern vehicles, the situation for those trapped in burning vehicles is likely to be more hazardous for this reason than for the small additional risk of the burning vehicle ending up against plastic sheet piling.

An assessment of the risks of fire igniting plastic sheet piling in various engineering applications is given in Table A1. Generally the risk of an incident involving impact of a vehicle is considered low. For example, the Swedish National Testing and Research Institute (Arvidson *et al*., 1997) suggest that vehicle fires are rare, less than one fire per thousand registered vehicles. Of those fires only 5% are as a result of a crash or collision, and that the trend for this cause is decreasing. Given that most of this 5% is likely to be vehicles in collision with other vehicles and not with structures forming part of the highway, the assessment of there being a low probability of a uPVC sheet piling fire would seem justified.

In a highway situation, any plastic sheet piling is most likely to be either installed some distance up a cutting slope (or down an embankment slope) to improve slope stability. If the piling forms a low height retaining wall close to the carriageway, a safety barrier may well protect it. For these reasons, the location of any sheet piling is probably such that risk of vehicle impact would appear relatively slight. In addition a significant part of each pile would be below ground and therefore only one face would be exposed to any fire. The scenario of plastic sheet piling burning for a prolonged duration through contact with a vehicle on fire, or one that burst into flames on impact, is thus considered unlikely.

A further scenario is that of burning fuel or other flammable liquid coming into contact with plastic sheet piling. In Table A1 the risk of an incident of this nature is again generally assessed as low because of the likely location of the piles. The possible exceptions to this are in a drainage channel or balancing reservoir constructed using plastic piling. In these cases, the presence of the piles is unlikely to contribute significantly in prolonging any fire incident.

Table A1 also assesses the occurrence of a vegetation fire on a slope as being a medium risk. As the ignition

Table A1 Assessment of the risks of fire according to engineering application

Location of sheet piles *Risk*	*Probability of incident*	*Comment on probability of the piles prolonging any fire*
Behind safety barrier		
Vehicle impact	Low	Burning vehicle is unlikely to be in prolonged contact
Fuel/chemical spillage	Low	Presence of piles will not contribute to prolonging the fire
Within cutting or embankment slope		
Vehicle impact	Low	Burning vehicle is unlikely to be in prolonged contact
Fuel/chemical spillage	Low	Presence of piles will not contribute to prolonging the fire
Vegetation fire	Medium	Piles unlikely to ignite, but if they do fire is easily extinguished
Walls of drainage channel		
Vehicle impact	Low	Burning vehicle is unlikely to be in prolonged contact
Fuel/chemical spillage	Medium	Presence of piles will not contribute to prolonging the fire
Walls of balancing reservoir		
Fuel/chemical spillage	Medium	Presence of piles will not contribute to prolonging the fire, fire is unlikely to ignite wet surface
Anti-scour protection to bridge pier		
River traffic impact	Low	Burning boat is unlikely to be in prolonged contact, fire is unlikely to ignite wet surface
Fuel/chemical spillage	Low	Presence of piles will not contribute to prolonging the fire

temperature of PVC is about 150°C higher than that of wood, it is not clear that the exposed face of plastic sheet piling would ignite in a vegetation fire. However if combustion of the pile did occur it would cease once the source of the fire was extinguished.

It would seem therefore, that the risk of a fire involving uPVC sheet piling occurring in the highway situation is small. For such a fire to burn for a significant period of time would appear to be even less likely given the few combinations of circumstances that could give rise to such an occurrence. Thus the use of plastic sheet piling in the highway environment would generally not provide a significantly increase in the fire risks faced by road users.

A2 Potential hazards in the event of a fire

Although the risk of fire is small, in the unlikely event of it materialising, the main hazards to highway users (apart from the flames themselves) would arise from smoke, gases and vapours. The Canadian Building Digest (1978) defines these as follows:

- Smoke is particulate matter consisting of very fine particles and condensed vapour; it constitutes the visible part of the combustion products.
- Gas is a product of combustion that remains gaseous even when cooled to normal temperatures.
- Vapour is a gas when produced by the fire but reverts to a solid or liquid state on cooling.

One of the main dangers from smoke would be the reduction of visibility for other road users, those escaping from the fire and the rescue services. Such hazards would be present at any serious fire whether or not plastic material was present. Smoke being visible is expected to be relatively easy to escape from in a highway situation provided that it is not in a tunnel. The density of smoke produced when PVC burns is to some extent dependent on the particular flame-retardant additives and the plasticisers used in its formulation.

In contrast to the particulate matter of smoke, gases and vapours are in general invisible, sometimes odourless, and often highly toxic to humans and animals. They can also spread out much faster than flames from a fire. The gases most widely described as occurring in PVC fires are hydrogen chloride, carbon monoxide, dioxins and furans.

The effects of significant inhalation of either of the first two gases, namely hydrogen chloride and carbon monoxide would be rapid, whilst those from dioxins and furans are alleged to cause deleterious effects on human health in the longer term. The maximum short-term exposure limit for hydrogen chloride stated in the COSHH regulations for occupational exposure (10 minute reference period) is 5ppm; the gas is toxic and lethal if inhaled. Carbon monoxide is colourless, odourless and, whilst apparently not as toxic (COSHH short term limit 300ppm) as hydrogen chloride, it is still lethal to human beings and animals.

Greenpeace claim dioxin and related compounds to be the most toxic chemicals yet known. The human body cannot rid itself of these organo-chlorine compounds and they therefore accumulate over time. However as PVC products are so widely distributed and routinely incinerated in the environment the effect of the very small quantities of dioxins and/or furans likely to be produced from PVC sheet piling fires would seem likely to be immeasurably small. As both dioxins and furans have been discovered in the chimneys of wood burning stoves (Paddock, 1989) it might be suggested that, if wooden highway fencing caught fire, small quantities of these organo-chlorine chemicals would also be produced.

When PVC burns, hydrocarbons such as benzene and higher order aromatics are also present as vapours in the smoke. The amounts of these chemicals that are present depend on the additives used in the PVC (Hull, 2000). Benzene inhalation can result in such effects as nausea, tremors, drowsiness, dizziness, headache and confusion. These effects have been observed in people exposed to 300ppm for 30 minutes. It has been suggested that, in the long term, exposure to benzene can lead to leukemia and other cancers. Benzene is generally considered to be a ‘non-threshold’ toxicant, ie. in theory there is no ‘threshold value’ below which it cannot cause an increased risk of cancers. The mechanisms are as yet not well understood. However as benzene is used in petrol as an anti-knock agent and in tyre manufacture, it would already be expected to be present in the emissions from any vehicle fire (Southam Environment Group, 1999). The effect on the concentrations of these pollutants in the atmosphere attributable to any unexpected uPVC sheet piling fires on the highway network are therefore likely to be immeasurably small.

The above discussion is summarised in Table A2.

A3 Summary

The probability of an event leading to a fire occurring on the highway network involving uPVC sheet piling appears remote. The chances of such a fire occurring, and continuing to burn for any length of time seems even less likely. The additional effects attributable to combustion products of uPVC sheet piling on anyone involved in an accident leading to a prolonged fire are expected to be small given the amount of PVC and flammable materials used in modern vehicles. The various potential hazards produced by a burning plastic sheet pile would also be present in the combustion products of any vehicle fire from sources on the vehicle such as plastics, tyres, fuel, and wiring insulation.

Plastic sheet piling is generally not likely to be used in a confined space (with the possible exception of a tunnel situation) and the products of combustion would therefore be able to disperse relatively freely. Other than for those physically trapped, escape from a fire and the associated hazards of smoke, gases and vapours would be relatively straightforward.

It is therefore concluded that the use of uPVC sheet piling on the highway network would not contribute any significantly increased risk to road users from fires and their associated emissions.

Table A2 Assessment of fire hazards from uPVC sheet piles

Hazard *Person(s) likely to be at risk*	*Effects on those exposed*	*Comment on level of risk*
Flames Trapped motorists, other road users whose vehicles could ignite. Rescue services. Local population.	Serious burns/death.	PVC has flame retardant properties and does not burn if flame source is removed. Little extra risk from that normally incurred.
Smoke All road users. Rescue services. Local population.	Lack of visibility, loss of control of vehicle due to inhalation effects such as choking and dizziness.	PVC produces more smoke in the flaming mode than wood. Effects should be localised in an open area of highway.
Carbon monoxide Road users and any others close to fire. Rescue services. Local population.	Loss of consciousness, potentially fatal.	Carbon monoxide is produced by all organic materials on combustion. PVC is no worse than other organic materials.
Hydrogen chloride Road users and any others close to fire. Rescue services. Local population.	Corrosive, potentially fatal.	When burning, corrosive gas is emitted. Effects should be localised in an open area of highway.
Benzene and other hydrocarbons Road users and any others close to fire. Rescue services Local population.	Nausea, tremors, drowsiness, dizziness, headache and confusion, maybe carcinogenic.	Concerns have been expressed about emissions on incineration. Studies suggest that toxicity is low, although further research is needed. Many materials may produce these toxins on combustion and extra risks may be small. Exhaust emissions also contribute. Effects should be localised in an open area of highway.
Dioxins Road users and any others close to fire. Rescue services. Local population.	Many suggested long term effects on health, carcinogenic.	Ditto.
Furans Road users and any others close to fire. Rescue services. Local population.	Many suggested long term effects on health, carcinogenic.	Ditto.

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Appendix B: Observation of pile driving at Vann Lake

A site visit was made to observe plastic piles being driven at Vann Lake spillway (OS grid reference: 515500m, 139310m) on 12 August 2000. The spillway is approximately 1km south east of Ockley in Surrey and forms part of a man-made lake in the grounds of Vann House.

The client for the work was the Surrey Wildlife Trust who commissioned Binnie, Black and Veatch to design a new spillway as the existing spillway is beyond reasonable and economical repair. As part of the new design, plastic sheet piles were selected to form part of the upper section of the spillway to minimise scour and erosion of the bank. The piling contractor was Breheny Ltd.

The project entailed the installation of fifty-one lengths of recycled uPVC pile in ‘trough’ shaped configuration. Each pile was 4.5m long and was driven to a penetration of 3.1m; after some backfilling the required height of the retained ground behind the piles was 1.2m. After driving 200mm was trimmed off the pile head so that any damage caused during pile driving was removed.

Prior to driving, a pair of piles were placed in position using a temporary wooden frame to aid alignment and level. An initial trial was carried out using a 90kg pneumatic hammer mounted on a small excavator boom. This was mounted on one of the piles of the pair and this single pile was then partly driven. The hammer was then moved to the adjacent pile which was driven part of the way. This process was repeated until the required penetration was achieved. A further trial drive was carried out using a 270kg hammer to drive a pair of piles simultaneously to the required depth. This latter approach was found more effective and therefore adopted for the subsequent driving. Figure B1 shows the pile driving operation in progress.

Although the visit was of only limited duration, some site specific observations were made. These were as follows:

i Although the piles were light enough to be picked up by hand, the 4.5m length of the piles was awkward to handle in terms of joining to a pre-driven sheet.

ii The flexibility of the sheet piles was such that significant bending occurred during driving of a single pile. This was not such a problem when the piles were driven as a pair and further improvements could probably have been made by providing more support to the piles.

iii On one occasion the pile appeared to strike something below ground, but was withdrawn and successfully reinstalled on a slightly different line.

iv Only restricted access was available to the site which limited the size of plant being used. The close proximity to the water meant that scaffolding access was not feasible.

v No site investigation was undertaken before driving because the construction scheme was only small, some risk was therefore taken in assuming that driving would be possible and that no large boulders or flints were present in the ground.

Figure B1 Driving plastic sheet piles at Vann Lake

Abstract

Plastic sheet piling manufactured from either polyvinyl chloride or fibre reinforced polymer has been extensively used for soil retention in North America and Europe particularly for waterway and marine applications. Production of sheet piling from recycled polyvinyl chloride has recently been introduced into the UK and appears to have potential for use in highways related applications in offering a cost effective and environmentally friendly solution to the provision of low height retaining walls. This report reviews the experiences gained in the use of plastic piling and compares the physical properties of commercially available products. Some of the perceived performance concerns are whether plastic piles have adequate resistance to both ultra-violet degradation and also to creep under sustained load. This report gives the results from weathering and creep tests carried out to provide more information on behaviour. Issues of driveability and the potential applications for plastic piling in highway schemes are also discussed.

Related publications

TRL328 *Consultation document on suitability tests for stress absorbing layers behind integral bridge abutments* by P Darley and D R Carder. 1998 (price £20, code A)

TRL319 *The creep of geosynthetics* by G R A Watts, K C Brady and M J Greene. 1998 (price £35, code H)

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