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Design manual Geoflex sheet piles

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1. Geoflex

Geoflex is a plastic sheet piling system, used as an alternative for hard wood and steel sheet piling. Geoflex is made of modified hard (unplasticized) PVC also known as uPVC-M, a material with excellent resistance to weather influences and it has a long service life. Moreover, the material will not be affected by natural matters occurring in the ground, rodents, and salt or fresh water. With the help of 'computer aided design' CAD technology an optimal weight/strength proportion has been created, which has provided us with a new generation of sheet piling.

2. uPVC-M properties

2.1 General remarks

Once installed, Geoflex sheet piles are expected to operate efficiently under load, without failure, over long periods of time while simultaneously preserving water quality. uPVC-M raw material formulations used for the manufacturing of Geoflex result in specific and controllable mechanical properties, Geoflex can therefore be engineered to cater for a wide variety of applications and conditions. In particular, the toughness of Geoflex is enhanced by the incorporation of impact modifying additives. The enhanced toughness enables the use of a higher design stress, which results in the significantly reduced mass.
To understand the mechanical properties of Geoflex, it is important to know the properties of un-plasticized uPVC and uPVC-M modified with stabilizers, anti-oxidants and other additives to improve the toughness of the material.
There is a critical difference between plastics and materials like wood or steel in the mechanisms by which they respond to load. uPVC-M may not rupture in bending or compression tests, but will always rupture in tensile tests. Therefore the strength capacity of Geoflex is based on the tensile strength of the PVC, as it is a reliable indicator of the behaviour of Geoflex under load. Other important factors, like creep and temperature, are equally important in keeping the design stresses below the level that induces failure.

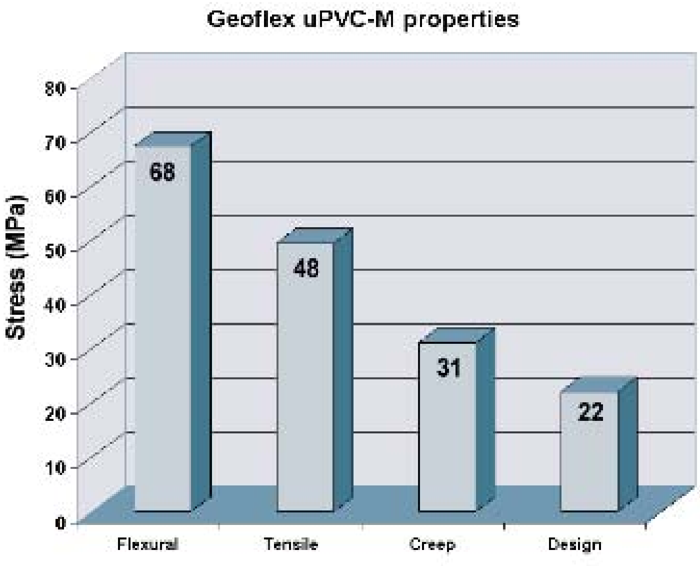


Figure 1: Maximum stresses in uPVC-M

2.2 Stress Redistribution under Loads

An elastic material will fail at the extreme fibre under bending action as follows:

$$\sigma_b = \frac{Mz}{I_x}$$

Where:	
σ_b	Flexural stress in sheet pile (MPa)
M	Bending moment (kNm/m)
I_x	Moment of inertia (m^3/m)
z	Distance to extreme fibre (m) =~ (H/2)

Table 1. Equation for stresses in elastic materials.

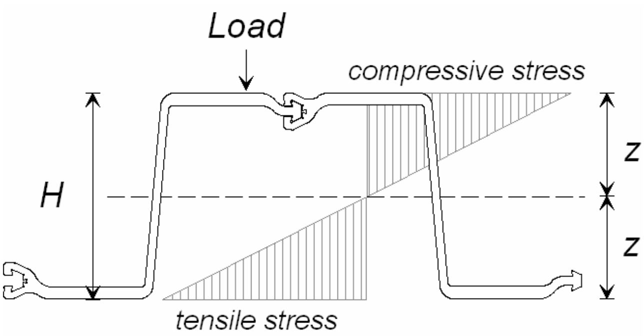


Figure 2: Bending stress distribution for steel sheet pile

Since Geoflex is made of a viscoelastic material, stresses re-distribute as shown in Figure 3 resulting in a higher resisting moment before failure. The figure shown below indicates a loading capability of 50% more than that of non-plastic materials, thus there is a bigger margin between first yield and ultimate strength, and hence higher loads are possible for Geoflex than for profiles made of standard uPVC. The reduction in brittleness also reduces the risk of impact failure during handling and installation. The moment of inertia given for the Geoflex profiles is based on elastic deformation. The value of flexural strength is based on measurements on samples, thus compensating for the low inertia values with a higher flexural strength.

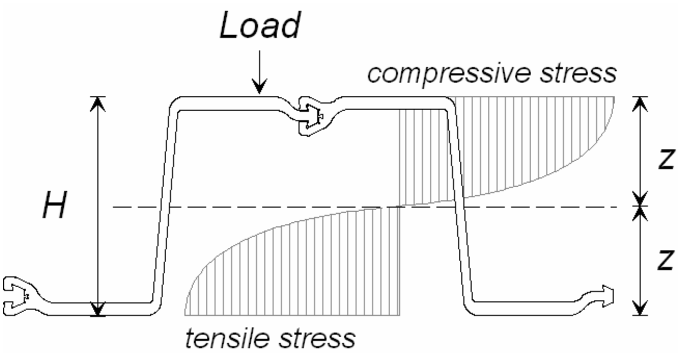


Figure 3: Bending stress re-distribution for Geoflex from uPVC-M

2.3 Flexural Stress

Flexural Stress is the stress in the profile, resulting from bending moments caused by external loads. The flexural stress of the material at any given pressure can be calculated as follows:

$$\sigma_b = \frac{M}{W_b}$$	**Where:**	
	σ_b	Flexural stress in sheet pile (MPa)
	M	Bending moment (kNm/m)
	W_b	Section modulus (mm³/m)

Table 2. Equation for determining flexural strength

Since the section modulus is a mathematical equation based on elastic deformation, it is not the right value for the Geoflex profiles. It should be significant higher because the visco-elastic deformation. Values of flexural strength determined by standard testing equipment however compensate the deviation because they use the same equations to calculate the flexural stress. The flexural strength of uPVC-M that is used for Geoflex is very much influenced by temperature. At 20°C the flexural strength is 68 MPa at a strain of approx. 6%, while at 60°C the flexural strength decreases to 57 MPa at approx 7% strain. Since the highest bending stress occurs at sheet pile construction, either under water or underground, the influence of heating by sun radiation is not an influence on the design.

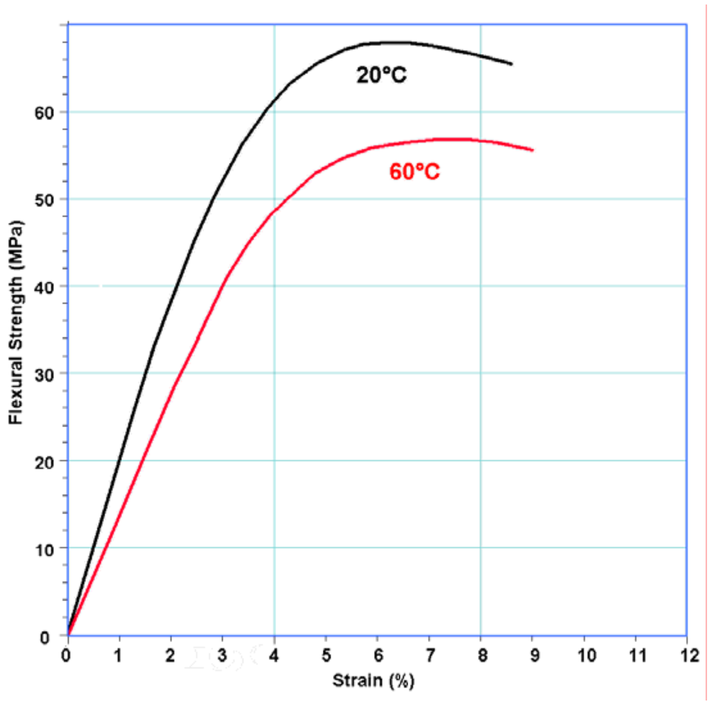
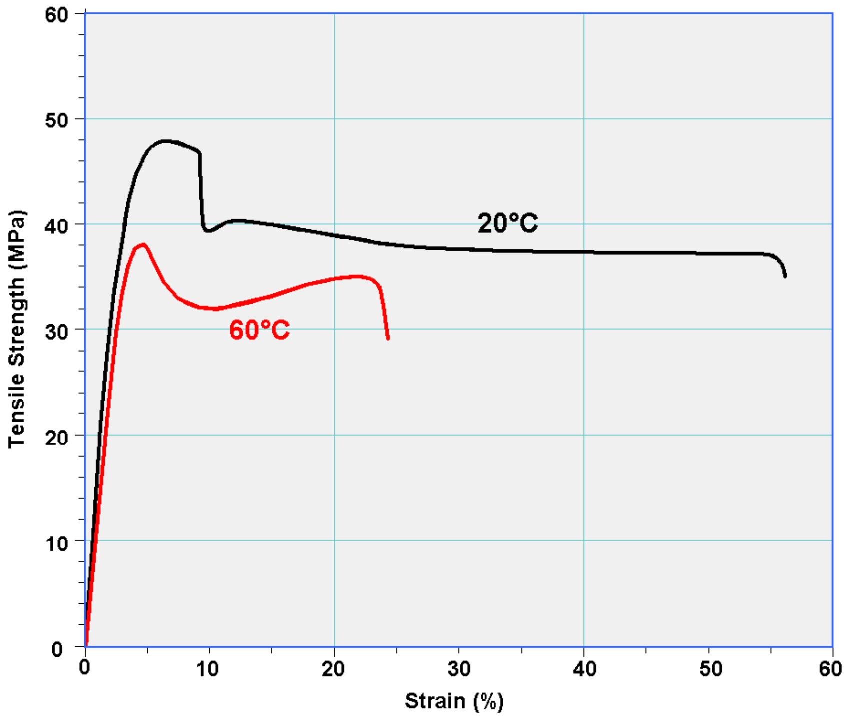


Figure 4: Flexural strength diagram uPVC-M at 20°C and 60°C

2.4 Tensile Stress

The addition of modifying agents reduces the short term strength of PVC but leads to a considerable increase in toughness of uPVC-M, especially the resistance of the material to the propagation of cracks (fracture toughness). The tensile stress and strain are very much dependent of temperature. Figure 4 shows the tensile-strain graph of Geoflex uPVC-M at a temperature of 20°C. At higher temperatures the tensile strength decreases, but not as much as standard uPVC. The Geoflex uPVC-M formula displays short term tensile strength characteristics of 48 MPa at 20°C and 38 MPa 60°C.



<u>Figure 5:</u> Tensile-Strain diagram of Geoflex uPVC-M at 20°C and 60°C.

2.5 Creep Rupture Regression

Creep relates to the dimensional stability of the material under load and is an important factor to consider when evaluating working pressure and its effect on the expected working life of a sheet pile. Creep can be precluded if the stresses are maintained below 2% strain. If the stress of the sample exceeds the tensile strength of the material, the sample will fail. The time in which this creep rupture can occur, decreases as the load increases.

The rate of creep in response to a given stress gradually decreases with the passage of time. From long-term creep tests, a creep rupture or stress regression line on a log scale can be developed. Results obtained from limited time tests can be extrapolated to predict long-term (50 years) behaviour at 20°C using well-proven mathematical procedures.

The stresses are plotted against the time (in hours) to failure, using log scales on both axes. The resultant creep rupture regression lines for Geoflex are given at two different temperatures.

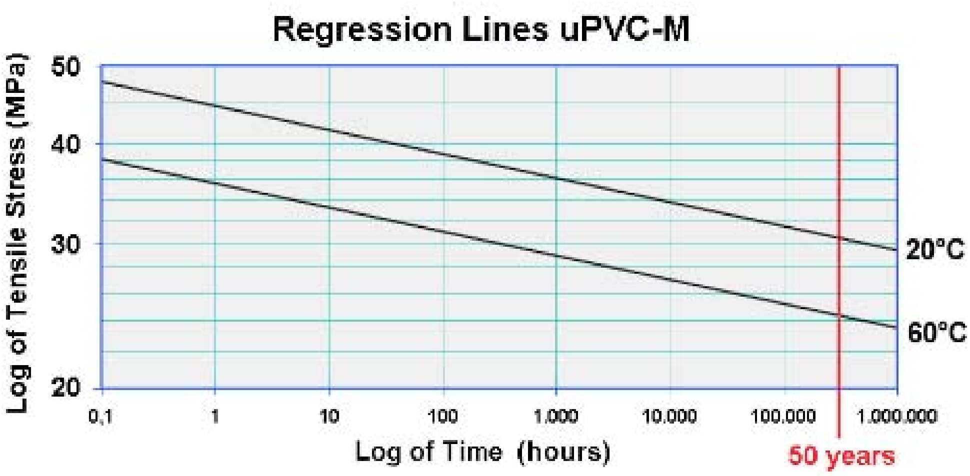


Figure 6. Regression lines Tensile strength.

The 20°C line meets a 100 hour tensile strength according ISO 4422, of 39 MPa, and the 1000 hour tensile strength of DIN 8061, of 36 MPa. This line is extrapolated to give a 50 year failure stress of at least 31 MPa. The 60° regression line tensile stress has a 1000 hour failure stress of 29 MPa as per ISO 4422 and UK Water Industry Spec No. 4-31-06.

2.6 Design Stress and Safety Factors

The design stress is defined as the constant flexural stress that the sheet pile can withstand for 50 years with a specific safety factor.

DESIGN STRESS (MPa)	SAFETY FACTOR (50 YEARS)
22.1	1.4

The higher safety factors employed for uPVC are not necessary for tough materials such as Geoflex uPVC-M, since this material's failure mode is dominated by ductile yielding. The long term, or 50 year failure stress, of at least 31 MPa is maintained, resulting in a safety factor of 1.4. This means that uPVC-M sheet piles can operate at a design stress of 22.1 MPa, i.e. at 40% higher stress levels than for uPVC, whilst maintaining all the advantageous characteristics associated with conventional uPVC. The short-term safety factor for uPVC-M is based on the tensile strength of 48 MPa resulting in a safety factor of 2.17. Sometimes the excessive deformations can occur at the design stress of 22.1 MPa that are not acceptable. With a design program like Geoflex 1.0 these deformations can be calculated and a lower stress can be chosen to keep the deformation within acceptable limits.
Other safety factors are applied to cover contingencies such as:

- Active loads
- Sheet Pile design
- Deficiencies in the design theories or in basic assumptions
- Deficiencies in the workmanship during installation

2.7 Effect of Temperature Change

20°C is the standard design temperature for PVC sheet piles, and rated working loads are usually quoted for this temperature. PVC sheet pile functions perfectly well below 20°C right down to freezing point and can in fact withstand higher loads than those quoted at 20°C. It is recommended, however, that the load at 20°C be applied for waterworks application. Above 25°C, as can be seen from the regression lines, the creep rupture strength diminishes with increasing temperature and working pressures must be down-rated if the same factors of safety are to be maintained. The following reduction factors should be applied:

Working Temperature (°C)	Multiplication Factors
20	1.00
40	0.90
60	0.80

NB: The maximum recommended working temperature is 60°C. Above 60°C the modulus of uPVC drastically decreases to a fraction of the original value. At hot climates the zones with high stresses should be protected, under water or buried.

3. Environmental properties

3.1 Sub Zero Temperatures

Water has been known to freeze in contact with PVC sheet piles without causing fractures, but permanent strain can result, leading to a reduction in the working life of the sheet pile. In most circumstances, however, the active load is compensated by the load created by ice, resulting in lower stresses in the sheet pile wall.

3.2 The Effect of Ultra Violet Light

Most plastics are affected by UV light. Geoflex sheet piles have pigments and light stabilisers incorporated in their formulation which will give sufficient protection, depending on location, for 20-50 years. If sheet piles are exposed for an indefinite period at locations with exceptional UV radiation, they should be painted, preferably with one coat of white alkyd enamel or PVA, or suitable covering should be provided. Paint containing solvent thinners should be avoided.

3.3 Chemical Resistance

The excellent chemical resistance of polyvinyl chloride (PVC) sheet pile makes it suitable for the containment of a large number of chemical solutions, if the material is used as a cut-off barrier in areas where the soil is polluted. PVC sheet piles are also used to create shore protections or cut-off barriers at environments where there are corrosive or saline atmospheres. The resistance of PVC to corrosive soils is also excellent. Chemical attack on PVC differs from that against metals. In the case of metals, damage is usually confined to the surface and involves corrosion and a loss in weight. In general, when a chemical attack occurs on PVC, it involves the absorption of the chemical reagent, which will cause softening and swelling of the sheet pile wall associated with a gain in weight and, in very extreme cases, permeation or failure.

Generally PVC is unsuitable for use in contact with aromatic and chlorinated hydrocarbons, ketones, nitro compounds, esters and cyclic ethers, which penetrate the PVC and cause marked swelling and softening. Some petrol-based fuels containing benzene also cause swelling. These penetrating solvents may be harmful to PVC even when diluted, but as they become further diluted their effects fall off noticeably, and very low concentrations, such as are present in effluents, can be safely handled.

4. Design rules

4.1 Calculations

Geoflex can be designed using the standard sheet-pile calculation methods. On the website www.geotechnics.nl you can find a Windows based program that calculates the required configuration of a sheet pile system according the method Blum. A PVC sheet pile construction should not only be dimensioned on strength, but also on deformation if a large section of the sheet pile is visible.

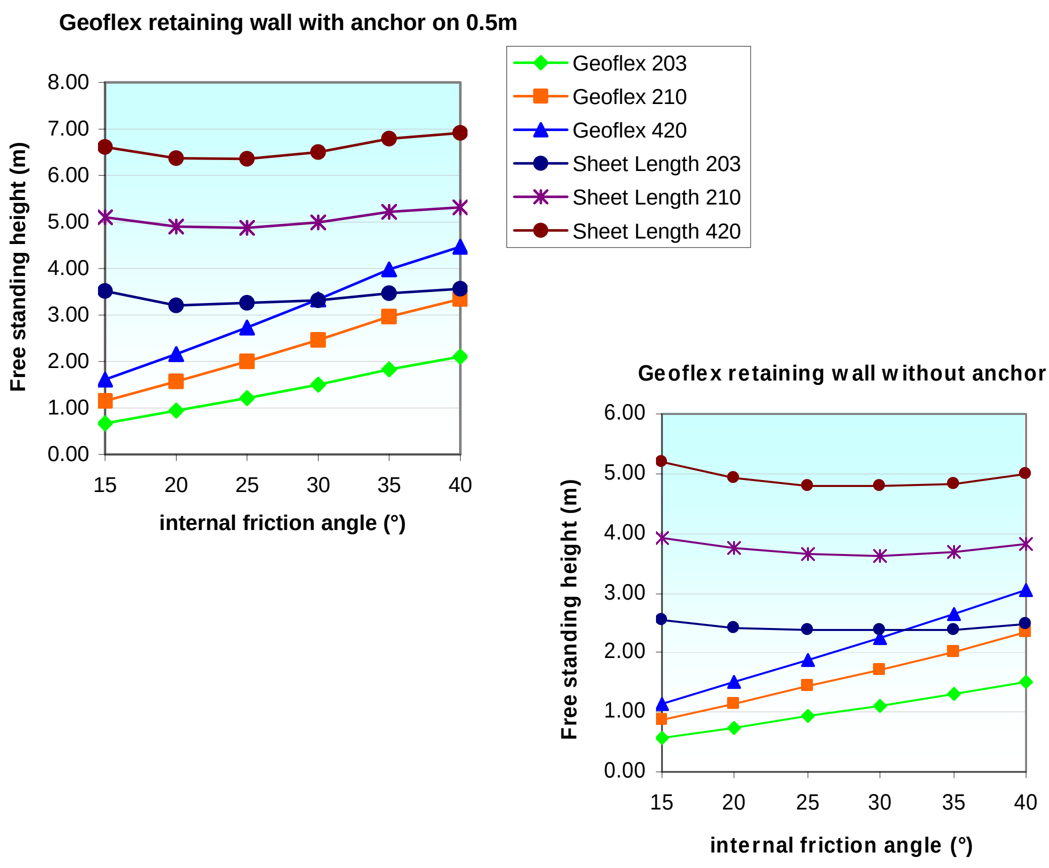


Figure 7. Max. retained height of Geoflex with and without anchor

Figure 7 and 8 give the maximum retained height of Geoflex related to the internal soil friction angle. The diagrams are just for general dimensioning, to choose the right profile for your application. The diagrams cannot be used as design model since water table differences are not incorporated in the calculations.

4.2 Geoflex design software

The Geoflex program, calculates interactive the length of the GEOFLEX-sheet wall, after the method of BLUM. The boundary conditions are:

- Equilibrium of moments
- Equilibrium of horizontal forces
- Fixed sheet wall at bottom
- Non displacement of the anchor
- Homogeneous Soil under bottom level

One of the advances of the BLUM-model above the WINKLER-model is that the length of the sheet wall is calculated instead of making an estimation of the length of the sheet wall. The program is restricted to (preliminary) calculations concerning forces, moments and depths of GEOFLEX sheet wall.

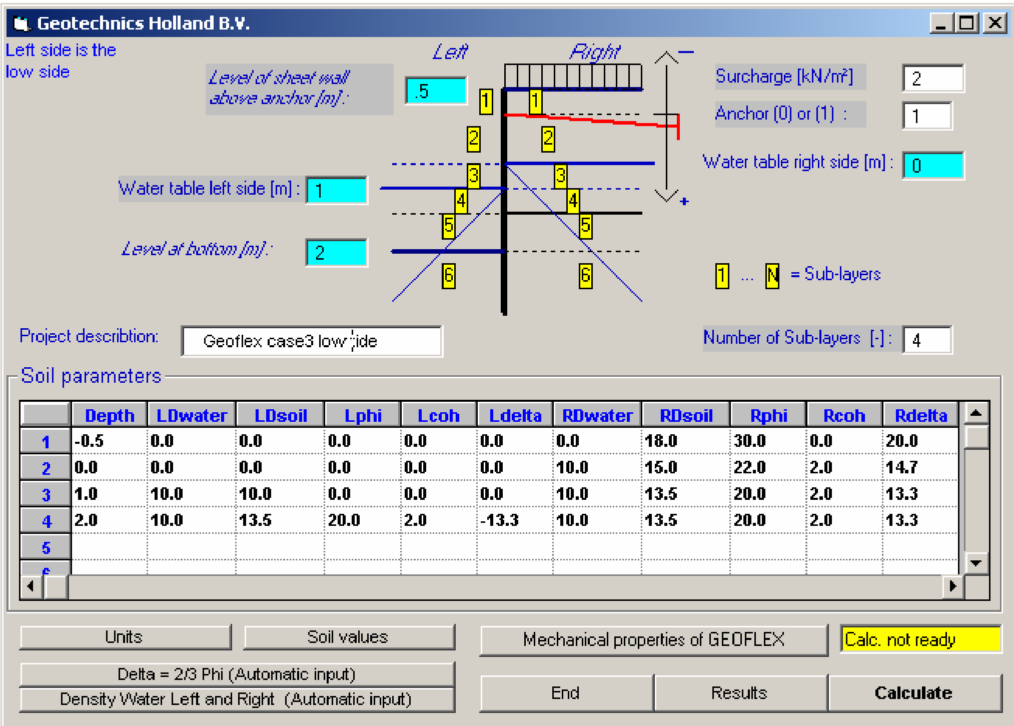


Figure 9. Input window for the Geoflex sheet pile program.

The white cells in the input window can be used to insert the soil parameters and the sheet pile configuration. Delta and Water density values can be put in automatically. After inserting the right values, the calculation button can be clicked and by going to the Results windows you find the following calculated values:

- Moment in sheet pile at anchor level kNm/m
- Anchor force (kN/m)
- Total sheet pile length
- Maximum moment and its location (kNm/m)
- Horizontal force at tip of the sheet pile.

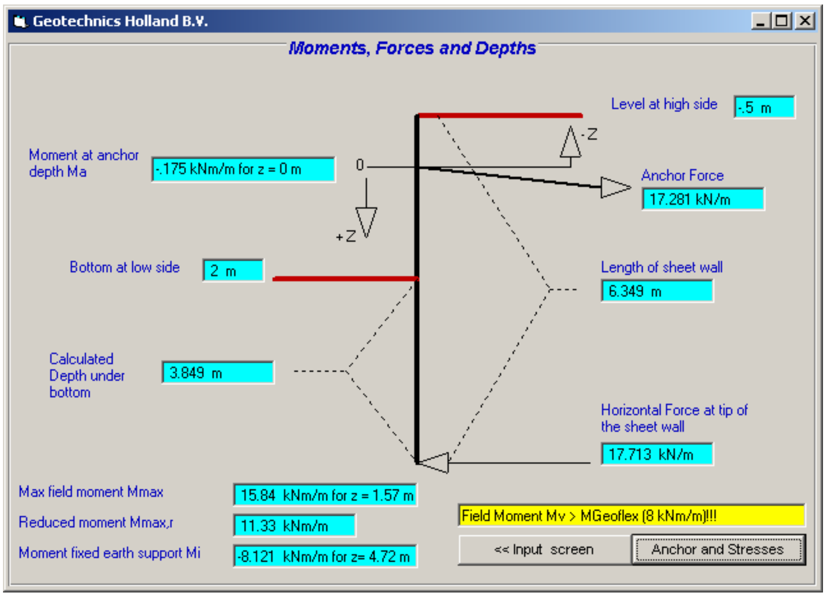


Figure 10. Results Window sheet pile calculation.

By clicking the Anchor and stresses button you get a window where the anchor forces and beam dimensions can be calculated according input values that can be changed to adapt local conditions.

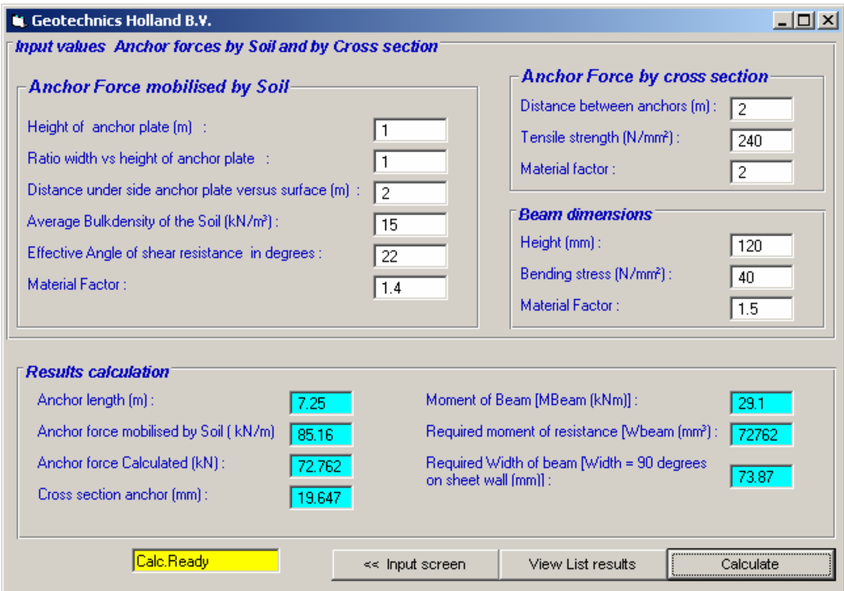


Figure 11. Results anchor and beam calculations.

4.3 Comparison PVC, steel and hard wood

Steel has much better mechanical properties than PVC. It is ten times stronger than PVC and the tensile modulus is even 80 times higher. So in strength and especially in deformation steel beats PVC in every way. There are however some significant advantages for PVC as well. PVC is a very good electric insulator which gives excellent lightning protection. Also aluminium boats like PVC sheet piling much more than steel because of absence of electrolyse in a salt environment. Steel is subject to corrosion. In underground conditions a corrosion rate of 0.015 mm/side/year has to be incorporated in the calculations. In some environments with chemicals of salt water, these rates may even much higher. A total corrosion of 0.09 mm can occur in tidal zones, thus decreasing the strength of light weight sheet-pile in 50 years with 90%, while PVC keeps its design strength during that period.

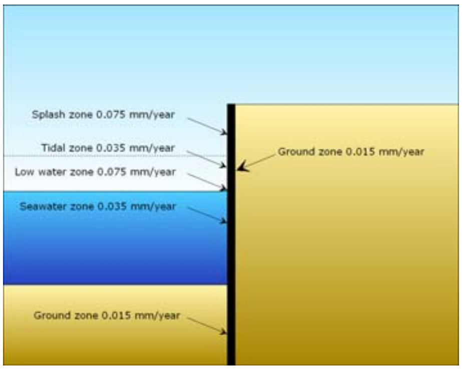


Figure 12. Marine corrosion

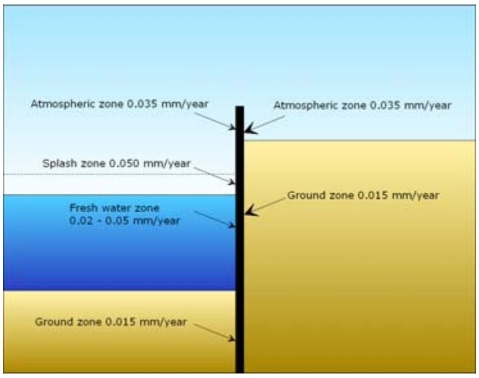
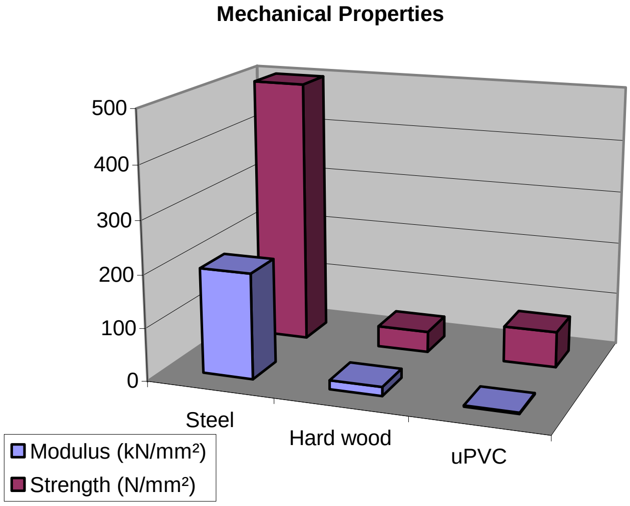


Figure 13. Fresh water corrosion

The flexural strength of hard wood is almost 50% of the strength of PVC while the tensile modulus is approx. 7 times higher. Hard wood is however subject to decay because of weathering and biodegradation. Only the most durable types have a lifetime of more than 25 years. Ten year old PVC sheet pile installations have still no signs of significant degradation in the material, while both steel as well as hard wood are subject to a much faster degradation. Since PVC has to be designed on deformation rather than on strength there will always be a surplus in strength left after decades.



5. Geoflex applications

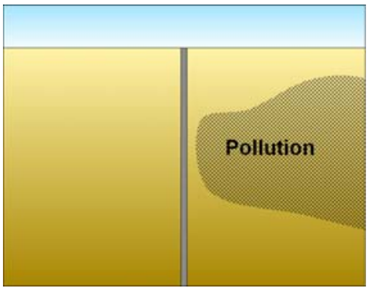
There are a large variety of applications of Geoflex sheet piles. They can be classified as:

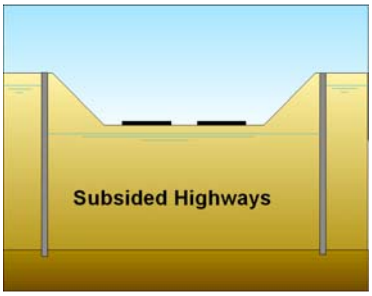
- cut-off barriers
- shore protection
- retaining walls

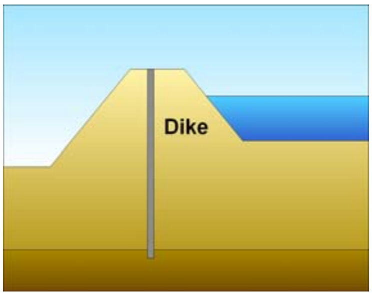
All these application ask for a different design approach. For cut-off barriers the seepage much be avoided while at a retaining wall the drainage should be optimal to avoid excessive pressure.

5.1 Cut-off barriers

Geoflex can be used as cut-off barrier to isolate contaminated areas from the environment. The lock can be provided with a hydrotite swelling cord to minimise the leakage. Since the sheet piles are supported by soil on both sides, there is minimal horizontal load on the sheets and a profile with a very low strength rate can be used. Since PVC is not resistant against all chemicals, especially some hydrocarbons, it cannot be used at all circumstances. For those areas where hydrocarbons are present HDPE Geolock panels can be installed.
Another cut-off barrier application is to seal dikes and avoid perforation by rodents. In this case the chemical resistance is no issue and the strength of the sheet piles can increase the stability of the dike. Geoflex can be used to avoid inundation of the ground under locks or other piled structures that retain soil with different groundwater levels.

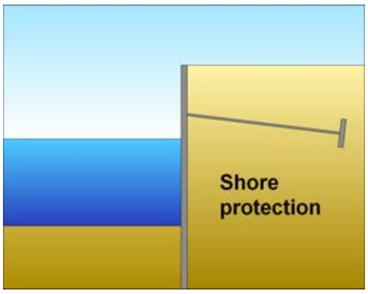


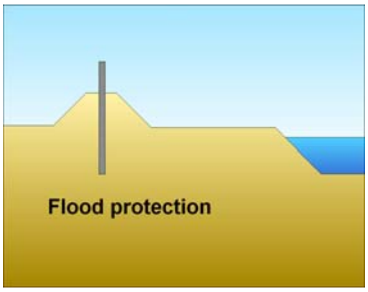


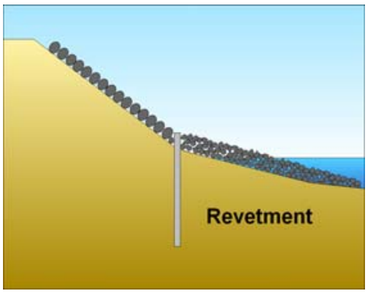


5.2 Shore protection

Geoflex can be used as facing, revetment, bulkhead or flood protection. The sheet piles are used to prevent erosion of the shore line by wave or tidal action. The design should be based on extreme tidal differences. Excessive water pressure behind the wall should be avoided to minimize the load on the sheet piles. Also wave action should be incorporated in the design. Shore protection walls should be anchored if the backpressure of the ground exceeds the maximum load. At flood protection application, higher maximum stresses are allowed since the amount of creep will be limited due to the temporary nature of the load. Geoflex is also an excellent product to stabilise revetment systems. The riprap used to protect the shoreline can be set and washing out of fines is avoided.

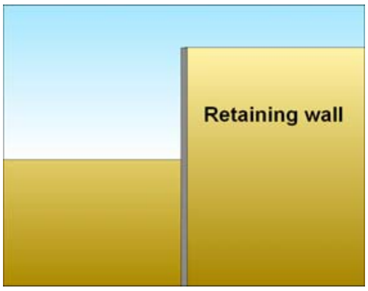


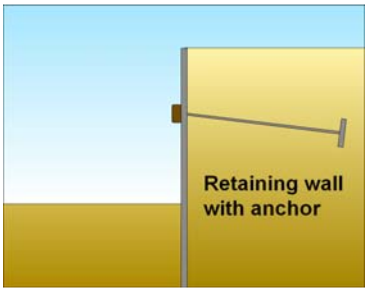


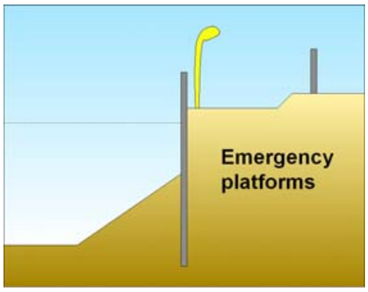


5.3 Retaining wall

Also behind retaining walls the water level in the ground should be controlled by a drainage system to limit the active load. Especially at retaining walls the expected rate of bending should be taken into account, since the sheet piles are visible over the total retaining height and large deformations are not always acceptable. Tables for retaining height can be found in par 4.1. Geoflex is also extremely suitable to construct emergency platforms along highway embankments. It is very simple to install without heavy equipment.

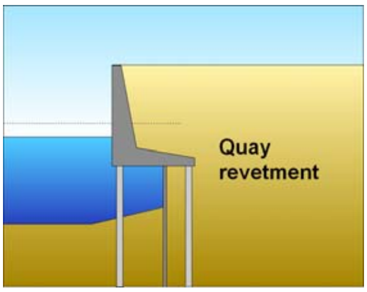


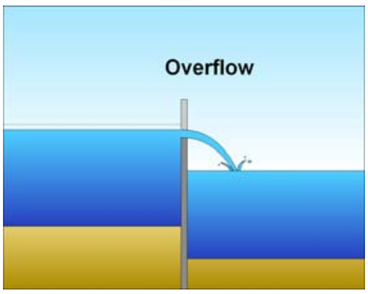


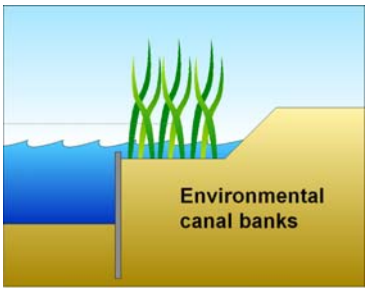


5.4 Special applications

Geoflex can also be used for a number of applications where traditional materials are used.
As retaining wall under a concrete quay construction Geoflex will have a life time of over 100 years without loss of strength.
Small overflows or dams in rivers can be made with Geoflex possibly in combination with a valve that controls the water level..
Geoflex in combination with a low berm, creates an environmental solution that has a attractive appearance. These environmental banks give animals the possibility to escape from the canal.







6. Installation of Geoflex sheet piling

There are a large number of techniques to drive Geoflex sheet piles. The system used is largely depending on the circumstances like:

- Sheet pile length
- Soil conditions
- Obstructions
- On shore or off shore
- Water depth

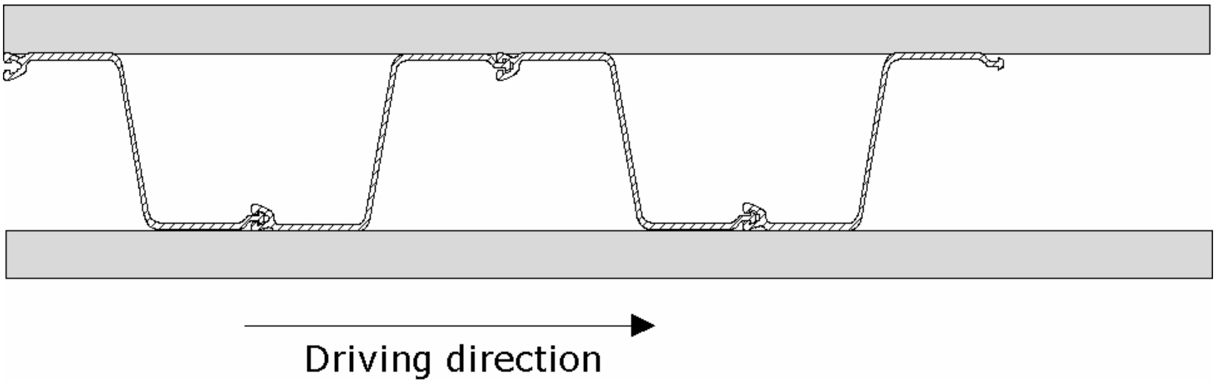
This means that there is no standard installation system available. We can however provide two basic techniques:

- Driving the sheet pile directly
- Driving a steel supporting sheet pile

Driving the sheet pile directly can be done with a standard pneumatic hammer or a light vibrator with or without a clamp. This system is only suitable for driving at light conditions and to a limited depth. For heavy conditions and installation from 4 m up to 8 depth it is advisable to used a steel support sheet pile with exactly the same shape as the Geoflex sheet. Harder soil can be penetrated and installation is speeded up because the hammer does not have to be disconnected from the steel guiding sheet pile.

Please follow the following steps carefully:

- Store the sheet piles so that the locks cannot be damaged or compressed. It will make installation almost impossible if the male lock cannot be easy inserted in the female lock.
- Set up a driving guide system, to provide support of the sheets during installation. Two driving guides make installation even more efficient and accurate.
- Put two sheets together to speed up installation and achieve better support from the temporary driving guides
- See that the installation is done in the right direction. This means that the female is installed over the male lock.
- Clean the female lock with high water pressure if necessary



- See that the installed sheets are plumb. Attach the last driven pile to the guide or attach a clamp to the sheet and keep it tensioned upwards during installation of the next sheet.
- Put the sheet in the steel sheet pile guide and position it above the last driven pile
- Drive the sheet gently in the plumb direction.
- Water jetting can be used to ease installation.
- If obstructions are occurred it may be advisable to loosen up the soil by a trenching machine before installation.

Installation with pneumatic hammer and water jetting	

Installation by vibrator with flat plate	
Installation by vibrator with flat plate	
Installation by vibrator and rig with steel sheet pile guide	

Installation by vibrator and rig with steel sheet pile guide and water jet system	
Installation by vibrator and rig with steel sheet pile guide.	
Cutting of Geoflex sheet pile at the right level	

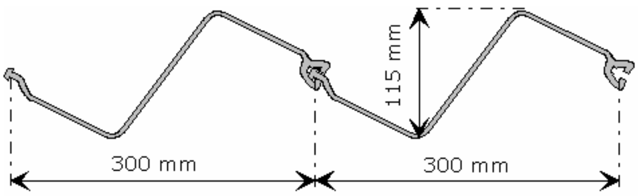
7. Geoflex physical properties

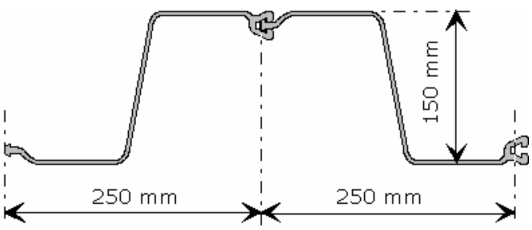
Geoflex is a 300 mm wide extrusion profile. This means that the raw PVC pellets are melted and pressed through a die. The regular shaped profile is then cooled of in water and cut and the desired length. The process guarantees a constant quality and steady sizes. The sheets are provided with a male and female lock that match perfectly and create a high strength connection. The lock is designed with the following philosophy.

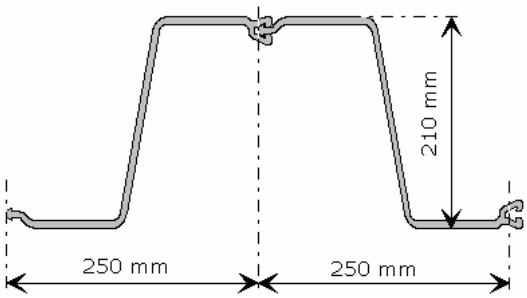
- no geotextile needed to prevent erosion of soil particles
- a certain rotation makes curved shapes possible
- no edge profiles necessary to make right angles
- two different configurations possible with one profile

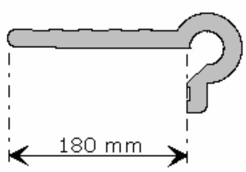
The different configurations give the engineer the possibility to choose between several sheet pile shapes with a large range of flexural strength.

Physical properties	Unit	Corrugated 203	Sheet pile 210	Sheet pile 420	Cap
		Grey	Sand	Brown	Green
Colour of all types					
Material		PVC	PVC	PVC	PVC-foam
Weight sheet	kg/m	2.9	2.9	4.9	5.2
Weight wall	kg/m²	9.7	11.6	19.6	
Width sheet	mm	300	250	250	235
Depth cross-section	mm	115	150	210	180
Wall thickness	mm	3.5/4.5	3.5/4.5	6/8	20
Density	kg/m²	1,450	1,450	1,450	1,100



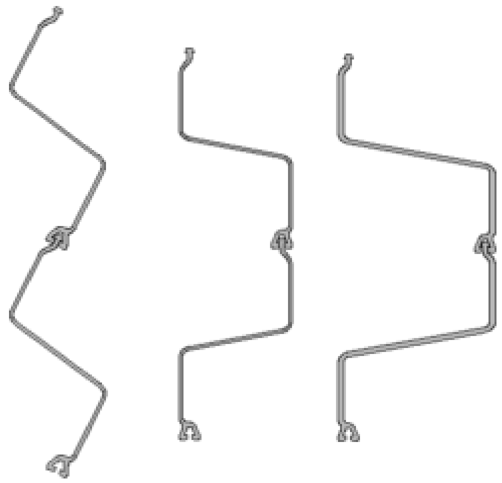






8. Geoflex mechanical properties

All mechanical properties are based on extensive testing on extruded PVC profiles. Design should however not only based on the strength properties of the material. Deformation should be taken into account as well.

		Corrugated 203	Sheet pile 210	Sheet pile 420
Configuration				
Mechanical properties	**Unit**			
Tensile Strength	N/mm²	48	48	48
Strain	%	60	60	60
Flexural strength	N/mm²	68	68	68
Design Stress	MPa	22	22	22
Flexural Modulus	N/mm²	2,300	2,300	2,300
Moment of Inertia	cm^4/m	680	2,950	9,540
Section Modulus	cm^3/m	117	421	932
Max. Bending Moment	kNm/m	8	28	63
Allowable Moment	kNm/m	2.6	9	20.5
Impact strength	kJ/m²	42	42	72