Organic Materials in Civil Engineering
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Chapter 4

Manufactured Products

Manufactured organic products constitute what users usually call plastic materials or more simply plastics. The development of these materials during the second half of the 20th century was remarkably spectacular and figuratively invaded the most varied of fields, including those where traditional occupations were deeply established and where the stakeholders had the easy tendency of slowing down the inescapable developments of technology.

Civil engineering was also caught in this sweeping wave, in particular geotechnics with geosynthetics, cellular structures and the more general field of waterproofing. Other applications like fluid conveyance systems, drainage, road equipments or civil engineering structures have also turned to these new materials.

In these various applications, the material generally does not appear alone. Most often, it forms a part of a complex structure or system where it plays one of the roles assigned to the whole. This is a new approach, which makes it possible to make the most of the remarkable qualities of organic materials without having to suffer from their weaknesses.

In addition, an old material that had been neglected for a long time in construction and public works is currently making efforts to make a comeback in the field. This is structural timber, still called industrial wood, which we believe should be mentioned in this chapter because it is also an organic material and, though its origin is a gift of nature, its use requires processing in a factory. Its use had almost disappeared from the field of civil engineering in many industrialized countries like France but it has recently made a comeback thanks to two favorable events:

ecological thrust, developments in processing and assembling techniques, as well as the drastic modernization of professional structures.

4.1. Organic materials and the waterproofing of structures

Water, essential for life, is also perceived by humanity as a threat when it is not tamed. Builders and project managers are well aware of this and must take this into account in their projects, whether they are short or long-term. In fact, pure water, when it circulates inside a material or a structure, can generate physicochemical degradations likely to jeopardize the structure itself and polluted water, if not retained perfectly, can cause considerable damage to the environment. This is a major concern for a project manager.

We can classify waterproofing materials and systems under various groups according to their origin and the technologies used to implement them, but for the sake of simplicity, it is more interesting to define them based on the three fields where they are used:

– bridges and viaducts where the element concerned is the deck of the structure;

– underground tunnels and structures;

– surface structures which include hydraulic structures: water retention basins, dams, canals and tanks as well as structures intended for environmental protection: lagooning ponds or reservoirs for surface water coming from the pavements, tanks and reservoirs for chemicals and structures for the storage of waste.

4.1.1. *Materials, products and systems for waterproofing the decks of civil engineering structures*

Here we are interested in the field of road or railway bridges and viaducts, even aqueducts, whose structure can be in masonry, metal, reinforced or pre-stressed or mixed concrete.

Should a bridge be waterproofed? The question is not innocent as it has received two types of answers based on economic criteria: the first, which was not to provide any protective cover on the structures, initially led to significant savings and accepted the risk of having to replace the structure at the end of a period considered as its lifespan; the second, opted for by the French administration, systematically included a waterproofing layer in the construction of structures. With 50 years of hindsight, there is no doubt that it is the second solution that proves to be more economical, at least because the manager generally expects from the structure a real lifespan markedly longer than the one envisaged at the time of its construction …

The French experience gave rise to a series of articles on the state of the art published in the *Bulletin des Laboratoires des Ponts et Chaussées* in 1989 [BON 89] and to a synthesis [BIC 93] whose main conclusions will be stated here.

Rainwater does not practically contain any mineral salts, but it dissolves carbon dioxide, a compound present in the air as long as there is life, which makes it slightly acidic. It is therefore very aggressive on concrete because it can dissolve the soluble minerals present in the cement matrix, in particular crystallized lime in portlandite, which in the long term results in a reduction of the pH and the corrosion sensitivity of the reinforcements. Surface water charged with various salts is generally less aggressive than pure water, except when it brings with it deicing products which are nearly always chlorides, ions that favor the corrosion of steel, or in factory sites when the atmosphere is acidic as a result of the presence of sulfur dioxide and nitrogen oxides, for instance.

The objective of waterproofing a road bridge is *to prevent any penetration of water into the structure via the upper surface of the deck.*

The initial question thus becomes: must all civil engineering structures like bridges or viaducts be waterproofed?

There is no need to study the case of *metal structures* whose manufacturers all know about their corrosion sensitivity. The installation of a waterproofing layer is a natural reflex for them.

For *reinforced concrete structures*, the answer is clearly yes. As we mentioned above, both the concrete material as well as the reinforcements is water sensitive, all the more so if the environment is more aggressive (industrial or marine environment, common practice of salting in winter, etc.).

For *pre-stressed concrete structures*, the first idea is to rely on a better compactness of the concrete, which as a result is more closed, if not waterproof. However, experience has shown that there are always defects in the structure and that these are then much more dangerous than in the case of reinforced concrete. The existence of a protective layer becomes indispensable.

Masonry structures must not be forgotten. They were considered for a long time as capable of withstanding water circulation by themselves, but it has been observed that the wear of the filling material resulted particularly in the plugging of the weepholes and the loading of infiltrated water, which led to serious damages and the corrosion of the stone.

Technically, we can understand the need for providing waterproofing for all these structures, i.e. the construction of a layer. It should be added that such an operation must receive all the care of the project manager, including during the decision-making process, because nothing is worse than poor waterproofing: the costs incurred by repairs are not proportionate to a good installation during construction through a serious enterprise that is worth its price.

The properties expected from a waterproofing layer are as follows [STE 81]:

– *impermeability*;

– resistance to *aggressive agents*;

– resistance to *cracking*;

– *bonding with the support and the wearing courses*. Here we come across a particular problem: the layer must ensure the transmission of the strains due to traffic, but also manage the appearance of water vapor from the support, either by resisting the tension created by this vapor or by ensuring its diffusion. This point is specific to concrete works. The appearance of water vapor occurs following a heat gain on the surface, which vaporizes the water present in the concrete pores and causes the development of bubbles, blisters or sacs that can burst and annul the waterproofing locally. This phenomenon can occur during the placement of the layer as well as the placement of the wearing course on the structure in service;

– *adaptability to the surface condition of the support*. The deck of the structure delivered by the manufacturer is supposed to have a texture compatible with the nature of the protection layer. This texture is defined for each family by standard plaques of the surface condition. In addition, it must be possible to install the waterproofing system on a wet or water loaded support, as is the case with hydraulic concrete, whose minimum age can be two weeks depending on the waterproofing techniques. However, it must be remembered that it is only after 28 days that the performance of the concrete is measured and the concrete is considered to have achieved most of its resistance. It is therefore believed that the water necessary for the hardening is trapped and that the remaining interstitial water evaporates, which makes it possible to place the protective layer with the minimum risk of bubbling and blistering.

We can point out in this context the delicate problem caused by the *curing of concrete*: for the hardening to take place correctly, both on the surfaces and deep below, surface desiccation must be avoided during the initial hours and for this, it is recommended to spread a *curing agent*, a form of temporary protective paint or varnish, which will be eliminated by mechanical degradation (due to traffic) or photochemical degradation (sun), but which does not always disappear as well as desired. Therefore, brushing is done, which is not always as effective as required (see section 4.2.5.3). The placement of a protective layer on a concrete surface that has been covered with a good curing agent is a problem which is not always well addressed nowadays because it is absolutely necessary to make the cover adhere to the concrete and the residues of the curing agent act as impurities between the two surfaces to be bonded:

– *impact resistance and resistance to punching*, resistance to traffic conditions;

– *temperature resistance*. The waterproofing system must maintain its efficiency following the placement of the wearing course (130-170°C for bituminous concretes) and within the service temperature range of the structure (-20 to +50°C in Metropolitan France).

Based on these requirements, professionals have proposed a wide range of waterproofing materials and systems, which can be classified into four families:

– asphalts and “prefabricated monolayer membrane + asphalt” systems;

– thin films adhering to the support (FMBS);

– prefabricated monolayer membranes (MPM);

– waterproofing complexes processed by high production rate roadworks equipments (HPRE).

The French regulation has developed a procedure for technical evaluation documents on the solutions suggested, entrusted to SETRA (the French Roads and Motorways Engineering Department).

4.1.1.1. *Asphalt materials*

The technique used here consists of hot casting (220 < T < 250°C) a full granular mixture in the presence of a suitable bituminous binder. The product obtained is thermoplastic but reasonably stable in service temperatures.

Strictly speaking, asphalt (the word being taken in its strict French meaning) is actually a mastic made up of a powder of natural asphalt impregnated with a bituminous binder (*natural asphalt mastic*) and if necessary sand whose granularity has been adjusted to obtain both good processing and good compactness after cooling (*sanded cast asphalts, graveled cast asphalts*).

We can add polymers or rubber to this mastic to get *polymer asphalt mastic*. Lastly, because the mining of asphalt rocks is not very widespread (in France, there is only one mine, in Saint Jean de Marvejols), this phase is often replaced by specially chosen fines and this is called *synthetic asphalt* in all the above formulations.

The system is applied without compaction, by simple hot spreading.

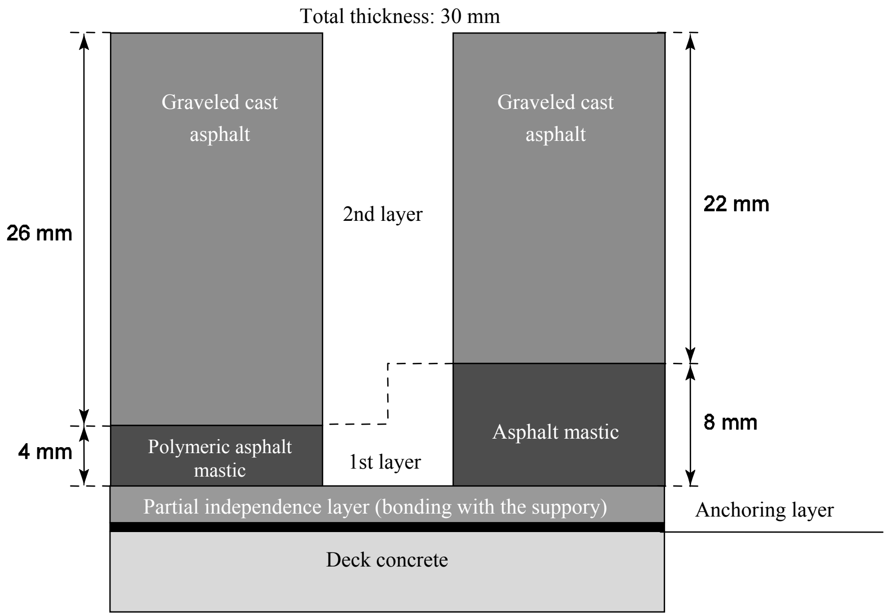


Figure 4.1. *Examples of waterproofing system made of asphalt materials*

A system of road waterproofing that has proved itself reliable is installed as below (Figure 4.1):

– an anchoring layer made up of a bituminous varnish or a bituminous emulsion;

– an independence layer (kraft paper for instance) or semi-independence layer (perforated kraft paper or glass lattice);

– a waterproofing layer in pure or polymer asphalt mastic;

– a protection layer in graveled asphalt.

But the most interesting technique that has been very successful is *mixed waterproofing systems* where graveled asphalt mastic is associated with a prefabricated membrane with a view to preventing the bubbling of the first asphalt layer and allowing a bridging of the cracks thanks to the continuity of its structure.

The tests performed usually to characterize asphalts and asphalt materials concern:

– the composition of the compound (using standards relating to asphalt powders, asphalt materials or hydrocarbon binders as the case may be, binder content and grading curve);

– the consistency defined by the specific indentation test [NF T 66-002].

This system combines the mechanical and more precisely rheological approach with a markedly physicochemical support represented by the constancy of the expected composition.

4.1.1.2. *Thin films bonding with the support (FMBS)*

These waterproofing systems are based on two interesting properties of some cross-linked polymers: their excellent impermeability in very low thicknesses and their very good adhesion to concrete (combined with good specific mechanical characteristics) which enable them to resist tangential stresses very well. In addition, they are relatively not sensitive to blistering caused by solar radiation. Initially, epoxy-amine resins were used with a filler made of coal-tar pitch ("pitch-epoxy" systems). Then, polyurethanes were used, followed by epoxy-polyurethanes, epoxy-silicones, etc.

This technique developed rapidly in the 1960s and reached its apogee in France in the 1970s. This success contributed paradoxically to its decline in the wake of a fierce competition between the various stakeholders, very often at the expense of the quality of the products and the processing.

If the latter aspect – the quality of the processing and particularly the qualification of application personnel – is important in all fields, it is of primary importance in this case where the techniques used are not traditional, as is the case of mortar mixing for example, although they have existed for 40 years. The target set by the waterproofing is a *zero defect barrier*. It is not, however, the only drawback: the surface condition of unsurfaced concrete delivered by the company for the waterproofing layer to be placed is seldom flat and, if the surface roughness is too high, it must be planed or finished. The total cost of the waterproofing is thus greatly affected. But the problem of surface condition is not specific to FMBSs; it occurs in prefabricated membranes, which are also sensitive to the surface condition of the concrete.

FMBSs, however, represent a very interesting technique. We can mention the development of pulverizable reactive polyurethane layers [CHA 89] and the recent arrival of methacrylic resins. This design of products polymerizing in a few minutes compulsorily requires a mechanization of the processing, which makes it possible to save time and correctly treat singular points of civil engineering structures.

The tests used to characterize them concern:

– the composition of the film: conditioning of the products, chemical characterization by IR spectroscopy and functional indices;

– mechanical characterizations: adhesion to the support, resistance to prolonged cracking, tensile characteristics, Shore hardness, bonding with the subsequent coating, fatigue strength.

4.1.1.3. *Monolayer prefabricated membranes (MPM)*

Designers had the idea of adapting the techniques used in construction to civil engineering structures. The main advantage of prefabricated materials is in terms of quality, greater ease of control in the workshop than when the mixing is done in the building site. But the transposition was possible only after the arrival on the market of the modified bitumens (PmB): traditional oxidized asphalts used for the waterproofing of terrace roofs proved to be insufficient to meet the requirements of waterproofing layers in civil engineering structures.

Prefabricated membranes are used in a *waterproofing system* which includes:

– an impregnation coat, bituminous emulsion anchoring primer;

– bonding level;

– the waterproofing membrane, strictly speaking;

– a protection.

The waterproofing membrane is generally a composite whose matrix is a PmB and whose reinforcement is a glass fiber fabric or a non-woven polyester fabric. It can also include a protection – a synthetic or metallic film with a slight chipping if necessary. Lastly, it is itself protected during its delivery and storage period by an adhesive resistant film on the underside.

The processing is done by hot welding with the blowtorch, completed compulsorily by roller-processing. It is the asphalt in the membrane that is used to ensure the bonding level required in the system, but it is also possible to use filler asphalt.

The evaluation criteria and the tests used to characterize the membrane concern:

– the composition;

– the mechanical characteristics: traction, adhesion to the support, perforating strength, resistance to simple cracking and after fatigue, bonding with the coating;

– hydraulic characteristics: impermeability, water absorption.

These products are processed manually in the traditional manner. For structures with difficult access, this technique has advantages, but in the case of large-scale structures, it presents serious drawbacks for the efficiency of the processing. To this we must add the fact that for large surfaces, the number of transverse and horizontal joints increases very quickly.

To solve these problems, completely mechanized placement systems have been developed, such as the unwinding and continuous welding of the membrane, without contact of the flame with the membrane, continuous heating temperature control and roller-pressing of the membrane. This also makes it possible to use much longer rolls and thus reduce the number of joints.

The membranes are very sensitive to sunlight, which causes blisters: the heating of the surface area in the concrete results in the vaporization of the water present, which is then trapped by the membrane. They must therefore be quickly covered by the wearing course. We can also apply a resin film called *sealer*, in epoxy or polyurethane, bonded with the concrete to prevent the rising of the vapor. This technique has been used for several years in Germany, but its development in France is hindered by the extra cost incurred by the operation.

4.1.1.4. *Waterproofing products processed at high production rate with roadworks equipment (HPRE)*

The waterproofing processes applied at high production rate, which have been used since the end of the 1980s [MIG 89], are primarily used to install waterproofing within very short timeframes, often incompatible with traditional techniques, except if these have been effectively mechanized.

They have been made possible thanks to the development of modified bitumens or asphalts cements (PmB) and to the capacity to spread viscous binders with reliable equipment thanks to the progress made in road equipments [STE 81-1].

The main characteristic of these processes is to associate the installation of the waterproofing and the wearing course in the same project, by the same company. The system is thus based on the following principles:

– all the layers of the system constitute the waterproofing;

– the binder used is PmB, often rich in polymer;

– they are processed using mechanical roadworks equipment.

This technical advance is interesting, but its future depends primarily on the attitude of enterprises towards the waterproofing function, which must absolutely be regarded as a priority.

The traditional waterproofing firm constantly thinks about the need for the absence of any defect likely to compromise its entire work. It seeks *zero defect* performance.

The enterprise that is ready to provide waterproofing by HPRE must include this reflex among its major concerns.

4.1.1.5. *Comparison of traditional types of products*

Their main characteristics are summarized schematically in Tables 4.1 and 4.2.

Appreciation criteria	**Bilayer asphalt**	**FMBS**	**MPM**	
			with protection integrated in the membrane	**with protection by graveled asphalt**
SUPPORT				
Surface quality	Average	Very good (=> possible reprise)	Very good	
Preparation of the support	Relatively not important	Very important	Important	
Geometry	Avoid water circulation under the protective layer => raisings and special provisions	Not important	Requires raisings in the notches and special provisions perpendicular to the penetrations (heads, fastenings, etc.) as there is a moderate risk of water circulation under the protective layer	
ENTERPRISE				
Place of manufacture	Fixed factory often far away	Prepacked products and prepared on site	Manufacture in factory and delivery to site in pallets in advance	
				In fixed factory for graveled asphalt
Qualification of the personnel	Moderate	Very high	High	
METEOROLOGY				
Of the site (rigorous climate if T < 8°C)	To be verified	Possible after selection of the products (appreciation tests)	Possible after selection of the products (appreciation tests)	Possible but must be verified
For the application	T > 2°C No rain	T > 5°C No moisture, but not too much sun	T > 5°C No moisture, but not too much sun	
After the processing	Relatively not sensitive/cold; to be protected/strong sunlight	Sensitive to low T and to moisture	Very sensitive to sunshine	Sensitive to strong sunlight

Table 4.1. *Main appreciation criteria for waterproofing techniques, first part (based on [BIC 93])*

Appreciation criteria	Bilayer asphalt	FMBS	MPM	
			with protection integrated in the membrane	with protection by graveled asphalt
WORKSITE				
Application equipment	Heavy (trucks, kneader)	Very less (agitator, float, light machine)	Relatively less (heater, torch blow-pipe, light machine)	This is the case for asphalt again
Layer thickness	About 30 mm	About 3 mm	4 to 5 mm	About 30 mm
Adhesion to the support	Semi-independence	Very good	Moderate anchoring	
Average output per day and per team	70 to 100 m²	100 to 200 m²	100 to 200 m²	80 to 150 m²
Continuity of the waterproofing	Few joints hot processed, no extra thicknesses	No joints, no extra thicknesses	Many transversal and longitudinal coatings with extra thicknesses	Coatings, extra thicknesses masked by the asphalt
Possible defects to be monitored	Excess of liquid varnish, bubbling, folds, semi-independence	Bubbling, pinholes, inadequate anchoring of the gravel	Inadequate bonding, folding, blistering	Blistering during the processing of the asphalt
Worksite traffic	Possible	Possible subject to reserve for LV	To be avoided	Possible
Min. time before placement of the wearing course	1 day	7 days	1 day	1 day
NATURE of the WEARING COURSE and RISKS OF DISORDER				
Graveled bilayer	Possible	Possible if resin binder	No	Possible
Bituminous concrete	Possible	Possible	Possible	Possible
Cast bituminous concrete	Possible	To be studied	To be prohibited	Possible
Risks of disorder	Creep	Sliding	Sliding blistering	Creep

Table 4.2. *Main appreciation criteria for waterproofing techniques, second part (based on [BIC 93])*

We can add the following comments:

– *Asphalt*, by virtue of its thickness, best withstands the surface defects of the concrete support, is the only one that accepts the site traffic provided a few precautions are taken and is easy to deposit (semi-adhesion). But its effectiveness largely depends on the homogeneity of its manufacture and its transport conditions. Lastly, some precautions must be taken in the event of prolonged exposure to the sun.

– *Thin film adhering to support* (FMBS), generally based on pitch mixed with an epoxy resin (pitch is generally present in the "hardener" component and the reaction with the "base" is done *in situ*), is the only product that really bonds with the concrete, which supports the prolonged solar exposure quite well and whose local rehandling is fairly easy to carry out. However, it is very sensitive to the surface condition of the support, it does not support site traffic without protection, its bonding with the wearing course is done by gravelling and, in case of repair, its removal is difficult. Lastly, it must be placed by a qualified firm.

– *Monolayer prefabricated membrane (MPM)* allows a good bridging of the cracks and a good preparing of the parts which cannot be removed during repairs. Its processing does not require heavy human or material means. Moreover, it supports the immediate interruptions of the placement in case of rain. However, it requires a good finishing of the concrete substrate, and has to be avoided in the case of considerable solar exposure and does not withstand worksite traffic.

4.1.2. *Waterproofing materials, products and systems for underground structures*

The problem with the waterproofing of underground structures is markedly different from what we discussed above insofar as the objective is no longer to protect the structure from rainwater or runoff, but from the water present or circulating in groundwater, possibly under pressure.

We must understand that on the scale of the traversed massif, a tunnel behaves like a drain, which therefore tends to collect all underground water likely to converge towards it. Besides, the geometry of the waterproofing system prohibits the use of materials likely to creep by gravity. Here only large-scale membranes are used, in other words, geomembranes, generally included in a *waterproofing system*, which we will define now.

To help engineers to control the whole problem, a group of experts from the various professions concerned met in the 1970s under the aegis of the French Association for Underground Works (AFTES) in view of drafting recommendations. The basic text [REI 79] was completed with other recommendations related to various aspects and the technological advances in the field considered, in line with the official texts [Part 67 Title III of the CCTG].

4.1.2.1. *Design of the waterproofing system*

There are several ways to waterproof an underground structure. The choice is made by the project manager according to the terrain and the operating constraints. Thus, we can differentiate two main methods of waterproofing depending on whether we want to channel the water out of the space to be protected or prevent water from penetrating into the structure. It is with this second mode, very widely used, that use of waterproofing systems is associated, which we will now describe.

A *waterproofing system* is defined as a set of products used in contact with or inside the structure to be sealed. It can include surface waterproofing (*waterproofing system*) and a waterproofing of discontinuities (*waterproofing joints*).

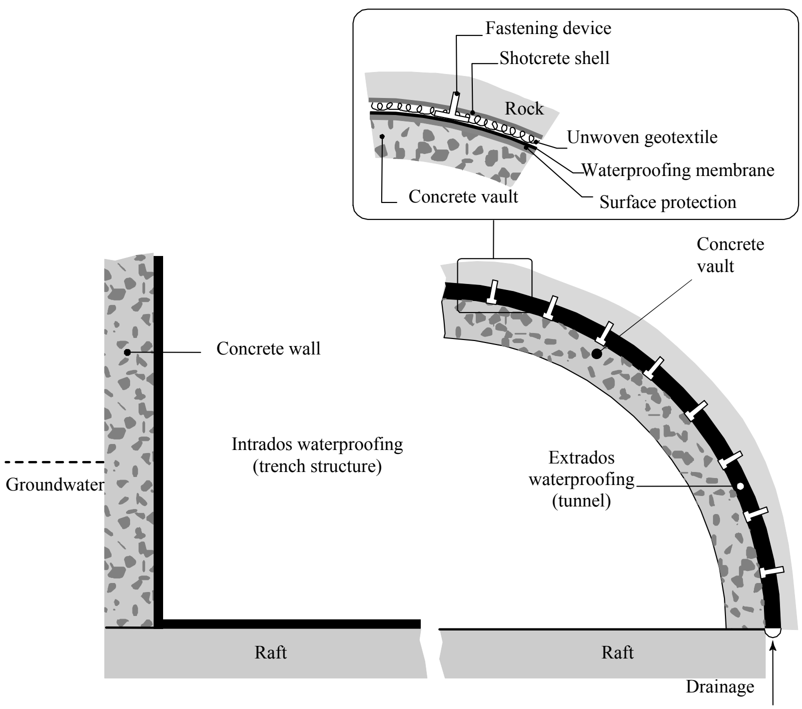


Figure 4.2. *Intrados waterproofing and extrados waterproofing*

The *location of the waterproofing system* can be *upstream* to the structure with respect to the direction of the percolation of water, i.e. *extrados* for road or railway tunnels, or *downstream*, therefore *intrados* for these same structures. It may be noted that for underground galleries, the upstream-extrados and downstream-intrados correspondences are reversed (Figure 4.2).

4.1.2.2. *Intrados waterproofing systems*

Downstream location can be considered only if it is able, after its installation, to resist a possible cracking of the support. It thus supposes a particularly resistant system and cracks with relatively small openings; if not, it is vital to treat them. That is why it is used practically only for urban trenches, hoppers and urban underground structures immersed (partly or entirely) in groundwater.

For this, we use films based on "flexible" epoxy resins, formulated specially for this purpose, or polyurethanes which must provide practically the same functional characteristics as for the decks of civil engineering structures.

In this context, two important points must be borne in mind:

– the intrados waterproofing system must bond perfectly with the support and must be able to resist water backpressures;

– it is more vulnerable than extrados waterproofing but the damages that occur are visible and reparable, which is not possible in the other case.

4.1.2.3. *Extrados waterproofing systems*

Excepting the above cases, it is practically always upstream location that is chosen, even if it is more costly than downstream location.

The function required from the waterproofing system is primarily to be watertight under a given water pressure and to preserve its watertightness in the course of time. This supposes sufficient tensile mechanical characteristics and chemical characteristics that confer on it good resistance to aging in water.

This last point deserves our attention. It brings into play:

– a chemical inertia of the membrane with respect to the other materials with which it is in contact: dissociation and protection shields, concrete whose alkalinity is high (pH > 12);

– good resistance to the action of micro-organisms (bacteria, fungus);

– possible resistance to the action of the petrol and fuels likely to percolate through the cover embankment after an accidental spilling.

The intrinsic characteristics of the membranes must also take into account the processing modalities.

We can thus understand that we must reason in terms of associations of materials as there is none that by itself can meet all the requirements listed above. The *waterproofing system* or GLS (geomembrane lining system, a term that we will define further below in connection with surface waterproofing and which is now used in underground structures) is installed as follows:

– preparation of the support using a shotscrete bed to minimize the asperities of the rock;

– placement of the *dissociation layer*, in this case unwoven geotextile, which is nailed on the wall in order to protect the geomembrane that will be placed from the static punching caused by the wall of the support, mainly during the concreting phase (see section 4.2.2);

– placement of the *waterproofing membrane* or *geomembrane*, a material that provides the sealing; this membrane is fitted using specific devices made up of plastic washers onto which the geomembrane is welded and which are manufactured specially to guarantee the overall watertightness of the system; they also play the role of a "fuse", i.e. of breaking before the membrane cracks in the event of a strong water pressure during the work phase;

– placement, if necessary, of a *surface protection layer*, to reduce the risks of tearing by impact (dynamic punching) which can occur during the subsequent operations of reinforcement and the placement of formwork necessary for the installation of the tunnel's coating concrete.

The elementary waterproofing membranes are welded together *in situ*, by surface melting when they are made of PVC-P (plasticized polyvinylchloride). The welding area must be watertight and must preserve this watertightness as long as the running part of the membrane. To solve this problem, we generally carry out a double welding by means of a hot air automatic machine or heating blade which helps, during inspections, to detect possible leaks when a colored liquid is sent between the two weld beads.

It must be possible to carry out the welding under difficult conditions: climate (up to 0°C and 95% relative humidity), in the presence of surface moisture (there are always sudden inflows of water into a tunnel; it is not possible to work with perfectly dry equipment), with membranes whose cleanliness is not absolutely guaranteed on all their surface, and under complex geometrical conditions (connections that are difficult to reach).

In addition, the weldability of the material should not be affected by a storage for several months under normal conditions of conservation and protection.

The total surface of the membrane is partitioned into compartments of 100 to 200 m^2 by means of thermoplastic sections known as sub-divisions, welded on the one hand onto the membrane and comprising on the other hand pins for integrating them into the structural concrete of the structure. This technique facilitates the injections necessary for plugging possible leaks.

Lastly, the durability of the waterproofing barrier depends on its resistance to puncture, the most probable causes of which are the various asperities of the concrete, clashing or falling of tools on the membrane and especially the installation of fabrics of metal reinforcements which always have sharp edges.

4.1.2.4. *Main products used (extrados waterproofing)*

Based on this, manufacturers have proposed several types of products, bituminous membranes, based on oxidized asphalt or PmB and polymer synthetic membranes.

The current trend in France is to use in preference translucent PVC-P membranes, weldable by simple heating and whose processing is easy to control by the process of double welding described above.

The durability of these systems obviously depends on quality on the processing and the intrinsic properties on the constitutive materials. With regard to PVC-P membranes, we will see in section 4.2.3.7 that studies have demonstrated the satisfactory resistance of this material over time, but the problem encountered here is the absolute impossibility to directly observe the material in place over time since it is drowned in the structure (Figure 4.2). We must therefore rely on the simulations made in the laboratory and the observations gathered from the other uses of this material.

All these considerations show the importance of a good overall diagnosis of the state of the structure in the event of damage in order to be able to choose the most relevant solution that is best suited to the case in question [HEM 88].

4.1.3. *Waterproofing materials, products and systems for surface structures: statement of the problem*

Preventing water from crossing a barrier can have various reasons. When it is good quality water, and therefore invaluable, we must prevent it from being lost in the terrains that it crosses. This is the problem of water conveyance or the management of canals and dams. When the water is polluted, it is the soil that we must protect and this is the problem of containment, which is one of the solutions used for waste management. But in general, it is always the watertight barrier effect that is sought.

It is in this context that geomembranes were introduced and developed. Then came the concept of *geosynthetics*, because it was soon necessary to reinforce geomembranes which exhibited mechanical weaknesses compared to the constraints imposed on them, and other materials that had appeared recently on the market, namely geotextiles which were also developing rapidly, were used.

This context allows us to temporarily pause the development of our subject – the study of waterproofing materials for surface structures – to present all the materials denoted by the term "geosynthetics". We will resume this subject, waterproofing, in section 4.2.3.

4.2. Geosynthetics

The concept of *geosynthetics* was introduced relatively recently into technical vocabulary. It was created to denote all the synthetic materials used in geotechnics for works intended for the reinforcement and draining of the strata. The French Geosynthetics Committee (CFG) has defined the functions of these types of materials [COL 95]:

– *waterproofing*: minimization of the transfers of liquid or gas;

– *protection*: cushioning of external aggressions on a structure in order to preserve its functional characteristics;

– *drainage*: collection and evacuation of liquids and gases;

– *filtration*: retention of a calibrated fraction of soil, waste or suspended matter while allowing fluids to circulate freely;

– *separation*: prevention of the mixing by mechanical action of two adjacent different materials (soil, wastes, granular materials, etc.);

– *reinforcement*: improvement of the stability and resistance of a structure by the use of the mechanical properties of a component;

– *resistance to external erosion*: prevention of the degradation of a material by the erosion of particles caused by climatic aggressions.

Geosynthetic materials are therefore defined as *manufactured polymer materials, in the form of a fabric, used in geotechnical and civil engineering applications, and performing one or more of the functions defined above*.

From this, we can immediately see what basically differentiates geotextiles from geomembranes, historically at the origin of geosynthetic materials: their *behavior with respect to water*. Thus, permeable products are called geotextiles and related products, whereas impermeable products include geomembranes and bentonite geosynthetic materials, although the relation between these has not received consensus of opinion from the experts. These systems associate with geosynthetic materials a bentonite filler, which swells in the presence of water in order to produce the sealing barrier.

Geosynthetic materials include the following families, summarized in Figure 4.3:

– *geomembranes,* which are thin, but with a thickness greater than one millimeter – below this, they are called geofilms – flexible, continuous, watertight, even under operating strains, mainly under traction.

The *concept of waterproofing* is thus defined as follows: “the water flow crossing a plane geomembrane (without joints) under the measurement conditions of the standard NF P 84-515 must be lower than 10^{-4} $m^3.m^{-2}.j^{-1}$ (i.e. $10^{-4}m.j^{-1}$).”

To minimize the number of welds, a minimal width of 1.5 m is required. Currently, products are available with widths up to 11 m.

The geomembrane is generally included in a complex structure called a *geomembrane lining system (GLS)*, which is a “system of components comprising a support structure, if necessary, the waterproofing structure and a protective structure, if necessary” according to the diagram in Figure 4.4. By way of example, we can mention the case of “arsenic tombs”, containment structures for arsenical wastes, whose construction applies all these principles:

– *geotextiles*, permeable materials, which can be woven, unwoven or knitted, used in various geotechnical and civil engineering applications; the functions concerned are of two types: mechanical (separation, reinforcement, protection, resistance to internal erosion) and hydraulic (filtration, drainage);

– *geogrids*, plane structures made up of an open network of tensile resistant elements linked to one another according to a regular pattern, used mainly as reinforcement;

– *geospacers*, three-dimensional polymeric structures used to maintain the space between two materials, particularly for drainage.

Geogrids and geospacers are used in particular to decrease the hydrostatic pressure on each side of a structure:

– *geocontainers*, three-dimensional structures allowing containment, stability and reinforcement of a filling material;

– *geocomposites* lastly, composite materials comprising at least one of five geosynthetic materials defined above.

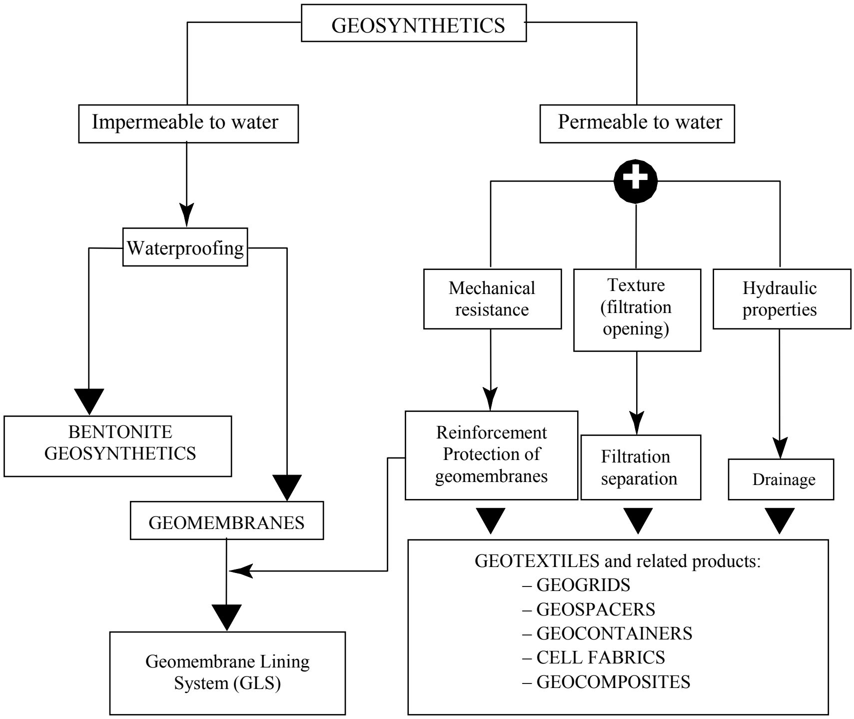


Figure 4.3. *General presentation of geosynthetic materials*

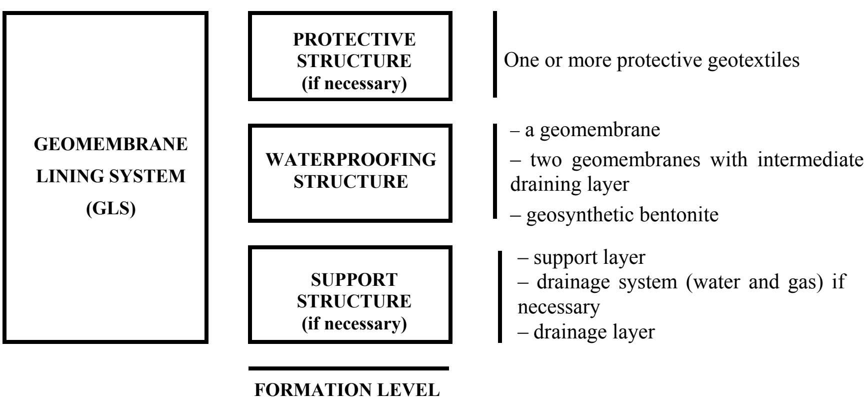


Figure 4.4. *Principle of a GLS based on the French standard NF P 84 500 and [COL 95]*

Generally, and as schema illustrated by this diagram, waterproofing comes first in the list of functions assigned to geosynthetic materials. We saw in the first part of this chapter that geomembranes occupy an important place in the list of materials used. It may be noted that the very term geomembrane is especially used by geotechnicians in connection with earthworks in the broadest sense. For tunnels, we still speak about waterproofing membranes as well as protective covers for bridges and viaducts, but this cultural distinction will grow blurred in the future because they generally refer to the same types of materials.

4.2.1. ***Geosynthetic materials for waterproofing: geomembranes and geosynthetic bentonite materials***

4.2.1.1. *Geomembranes*

These materials have been discussed in the first part of this chapter. They are the most widely used products in waterproofing works. They have been classified into various types according to several criteria (NF P 84-500): reinforced or not, composite or not, mono-fold or multi-fold, manufactured or cast *in situ* and in the first case, according to the type of manufacture (calendering, extrusion or impregnation, coating). However, in the list of available products, it must be noted that bituminous geomembranes exist practically only in the category of products manufactured by impregnation and reinforced. In all other cases, they are synthetic materials, i.e. polymers formulated for a given function, most often manufactured by calendering or extrusion and generally not reinforced. Some geomembranes, called composite geomebranes, are the result of an intimate association between a geomembrane and a geotextile, carried out in a factory. The system is interdependent whereas in a GLS, the two components are independent.

We saw in connection with underground structures that if the waterproofing membrane comes into contact with a soil or a natural substrate, the term “geomembrane” gradually replaces the term “waterproofing membrane” but still refers to the same function: forming a barrier to prevent the penetration of water into the protected area and thus preventing the development of degradations or pollutions. Conversely, we will see in connection with environmental protection that the barrier can confine polluted water and direct it towards a discharge system intended to collect it.

We must lastly study these materials from the physicochemical point of view, which can be relevant to explore problems related to processing and durability. These elements, which must take into account geomembranes in their generality, will be discussed at the end of the section on geosynthetic materials.

4.2.1.2. *Bentonite geosynthetics (BGS)*

These systems are in the form of an association between a geosynthetic material and bentonite filler, montmorillonite clay that swells in the presence of water. They have been dealt with in a manual of recommendations prepared by the CFG [COL 98].

The composition of these products combines the swelling properties of the clay which fills the space to be sealed and the trapping of the water present with the impermeability of a geofilm for creating waterproofing barriers. These materials have the advantage of being self-healing. The hydrated bentonite provides an expansion of 500% compared to its dry volume such that, when a breach occurs, it is theoretically clogged immediately by the expansion of the material.

Particular attention must however be given to the effectiveness and the functional durability of these materials according to the conditions of initial saturation, thermal variations and the effect of ion exchange, which can also play on the swelling characteristics in the relatively long term.

4.2.2. *Geotextiles and related products*

Figure 4.3 shows the various functions required from geotextiles and related products, which we will now discuss.

4.2.2.1. *Functions provided*

In the usual classification of the functions provided by geotextiles, water is still used as reference: we speak about the mechanical role and the hydraulic role. It may be noted however in Figure 4.3 that this distinction has its limits. If reinforcement and protection are clearly mechanical functions, and drainage is a clearly hydraulic function, filtration (hydraulic) and separation (mechanical) have many points in common (texture of the product in particular).

The mechanical functions in question are as follows:

– *reinforcement*: improvement of the stability and the resistance of a structure by the use of the mechanical properties of the geotextile. In a soil fill, a very resistant geotextile or several fabrics placed at regular intervals bear the tensile strains and increase the breaking strength of the fill;

– *protection*: cushioning of the external aggressions on a structure in order to preserve its functional characteristics. Placed between a geomembrane and a support material (or the material that covers it), the geotextile absorbs the localized stresses and thus protects the geomembrane from perforations. This function is related to the *support role* that the geotextile can play. Thus, placed on the slope of a jetty or a bank, the geotextile fabric contributes to the stability of the material layer (for example when concrete slabs must be placed on an inclined surface) to which it is fixed by fastening or gluing. It can also fulfill a particular function described below;

– *resistance to external erosion*: prevention of the degradation of a material by the erosion of particles due to climatic aggressions. If the above functions primarily rely on the material's properties of mechanical resistance, the following function also brings into play the texture of the finished product;

– s*eparation*: prevention of the mixing, by mechanical action, of two adjacent different materials such as soils, solid wastes, granular materials. Interposed between two different materials like clay and gravel, the geotextile prevents their mixing due to the effect of loads and enables each material to preserve its properties.

The hydraulic functions considered are as follows:

– *filtration*: retention of a calibrated fraction of soil, waste or suspended matter while allowing fluids to circulate freely. The fibrous structure of geotextiles enables them to be very permeable and at the same time prevent the passage of fine particles; in hydraulic structures, they advantageously replace filters of granular materials that are difficult and expensive to produce. We can clearly see the close relationship between the materials performing this function and separation materials. But it is certain that the reference to their behavior with respect to water is unavoidable;

– *drainage*: collection and evacuation of liquids and gases. Thick and highly porous geotextiles can transport significant water flows in their thickness and can thus be used to drain the soils where they are placed.

4.2.2.2. *Constitutive materials*

The textile fibers used for the manufacture of geotextiles are obtained by spinning then drawing molten polymers. The diameter of threads obtained is about 10 to 30 µm.

We mainly come across four types of fibers:

– polypropylene (PP), which is used the most;

– polyethylene (primarily HDPE);

– a saturated polyester, ethylene glycol polyterephthalate (PET);

– polyamides, primarily the PA-6,6.

4.2.2.3. *Assembling modes*

We can distinguish two assembling modes: woven and unwoven.

Unwoven geotextiles are in the form of fabrics made up of continuous filaments or cut fibers, arranged randomly and linked by various mechanical, thermal or chemical processes. Needle punching is a purely mechanical process, which is done using a specific machine, the needle loom, and a press, thermowelding, which uses a hot compression and chemical assembly which uses a filler binder, which makes it expensive and consequently little used.

Woven geotextiles are fabrics made up of an interlacing of fabrics of threads or strips. They are very resistant but sometimes insufficiently deformable.

4.2.2.4. *Durability of geotextiles*

As for other types of materials, the study of the aging of geotextiles requires the association of two traditional methods: macroscopic or global on the one hand and microscopic or analytical on the other hand [LEF 88]. The difficulty encountered here lies in the fact that the global solution requires a large number of observations over rather long periods of time, whereas the use of these materials is too recent for a feedback to provide sufficient matter to draw statistically useable results. Nevertheless, the French experience shows in particular that geotextiles observed on the worksites and experimental sites do not exhibit any chemical or biochemical change in the course of time following their contact with natural soils. We must therefore examine the durability of the basic materials, polymers with well known properties whose quality depends primarily on their manufacture.

4.2.3. ***Waterproofing materials, products and systems for surface structures: different uses***

We saw in section 4.1.2 that this field covers hydraulic structures strictly speaking, retention basins, dams, canals and tanks as well as structures intended for environmental protection, lagooning or retaining tanks for runoff from roadways, tanks and reservoirs of chemicals and structures for the storage of wastes.

It will be noted here that the environmental issue does not change the physicochemical approach of the materials considered. They are generally the same as those that we have seen above, but as the objectives are different, the selection criteria can also be different and that is why it is preferable to investigate them separately.

4.2.3.1. *Hydraulic structures strictly speaking*

The early manufacturers of canals and dams, who obviously did not know about geomembranes or GLSs, used argillaceous materials to obtain the impermeable layers that formed the banks and revetments of these structures. The advent on the market of geosynthetics and especially organic geomembranes changed the technical landscape considerably. Thus, in the general report of the Paris conference on the s*urface sealing of tanks, dams and canals* in 1983, Gamski drew up the first list of the main materials used and their intrinsic characteristics to be taken into account in the choice of the geomembrane [GAM 83]. He presented them in the form of a table, according to a classification that has evolved slightly since then (Table 4.3) but whose basis remains the same. Today, we would speak rather about plastomers than thermoplastics, and would rather classify vinyl ethylene acetate copolymers (EVA) under the first category, but on the whole the panorama presented here still remains valid 20 years after its publication.

Thermoplastics	**Thermoplastic elastomers**	**Cast or sprayed membranes**
CPE (black) *Chlorinated polyethylene*	CSM (transparent or colored) *Chlorosulfoned polyethylene*	MB (black) *Cast asphalt mastic*
ECB (black or colored) *Bituminous ethylene copolymer*	EVA (white) *Ethylene vinylacetate*	EP (gray or colored) *Epoxy*
FIB (black) *Fibers impregnated bitumen*	EPDM (black) *Ethylene propylene diene*	ED (brown, black) *Epoxy diene*
PE (transparent, colored, black) *Polyethylene*	EPDR (black) *Ethylene propylene rubber*	PUR (white or colored, brown) *Polyurethane*
PIB (black) *Polyisobutylene*	CR (black) *Polychloroprene*	UPE (colored) *Unsaturated polyester*
PVC (colored, black, flexible) *Polyvinylchloride*	IIR (black) *Isoprene isobutylene*	PA (colored) *Acrylics*
BM (black, flexible) *Modified bitumen*		

Table 4.3. *First classification of surface sealing membranes according to [GAM 83]*

The characteristics described below are also presented in four classes:

– mechanical characteristics relate to the tensile curve and its evolution in the temperature range between -20 to +80°C, the reversibility of the deformation, tear and perforation behavior, creep and the evolution of stiffness with temperature;

– the physical characteristics taken into account are firstly the glass transition temperature (Tg), then dimensional stability, the coefficient of permeability, steam permeability (μ) and water absorption (porosity), the coefficients of thermal expansion (α) and conductivity (λ);

– physicochemical characteristics relate to particular aggressions, for instance, cracking resistance under tension in the presence of surface-active agents, swelling of the membrane in the presence of pollutants (oils, solvents), conservation of mechanical properties after exposure to sunrays;

– biological characteristics, i.e. resistance to micro-organisms, the perforation of roots, even resistance to rodents ...

Based on this data and the research that it gave rise to, a *geomembrane certification procedure* was defined under the aegis of SETRA [COL 99] to give the project manager a guarantee on the quality of the products used and the skills of the staff in charge of the execution. The technical features required are therefore as follows:

Property	Threshold	Tolerance	Standard
Conventional waterproofing level (flow)	$< 0.1\ l.j^{-1}.m^{-2}$	+ 0%	NF P 84-515
Functional thickness	≥ 1 mm	- 0%	NF P 84-512
Production lengths	≥ 1.5 m	- 0.05 m	NF EN 1848
Static punching			NF P 84-507
Stress and strain			NF P 84-501

The values observed by approved laboratories on the samples taken in the factory by the technical auditor conform to the nominal value expected by the producer and within the specified relative deviation range of 95%.

Table 4.4. *Technical characteristics of ASQUAL certified geomembranes*

4.2.3.2. *Structures for road surface water*

The waterproofing types studied so far relate primarily to the protection of civil engineering structures, whether aerial or underground, and incidentally the comfort of users in the concern for the protection of natural environments and more generally the environment.

This last concern has, however, been present in France since the 1970s. It has grown constantly and has given rise to research, resulting in the publication of laws and technical guides intended to help the various stakeholders to manage the problems encountered. We can mention in particular a series of fascicules on "Water and road" [COL 93] and a technical guide on "Waterproofing by geomembrane of structures for road surface water" [BEN 00].

Pollution due to surface water can have several aspects:

– chronic pollution, relating to transport by rain surface water of various wastes and residues present on the pavement;

– accidental pollution related to discharges of chemicals among which most common are hydrocarbons and fuels;

– seasonal pollution in winter due to the spreading of deicing products (chlorides);

– temporary pollution, arising from works for the realization of the infrastructure.

In this, all cases do not have the same severity. It is believed that waterproofing is necessary only in the following cases:

– vulnerability of the natural environment into which the pollutants are released is average or high;

– function of sequestrating an accidental pollution is necessary;

– for the water retention basins when the operating mode and the structure require the presence of a permanent strip.

This refers to in particular retention pits, shoulders, medians, storage and sequestration basins.

The structures used for the collection and treatment of polluted surface water are primarily built of earth, with parts in concrete. They include:

– retention structures, to ensure the temporary containment of pollutants and control of flows; these are watertight basins, sometimes pits or canals;

– collection structures, pits and gutters that evacuate water from platforms towards the retention structures; they are watertight in the areas where the natural environment is vulnerable and where no infiltration can be allowed (catchment areas, for example);

– intermediate structures, particularly those such as shoulders, base of cut slopes, medians and fill slopes which can be waterproofed by a geomembrane fitted with a protective structure.

The GLSs used are thin products (less than one centimeter thick), comprising a membrane with a functional thickness of more than one millimeter, flexible, watertight and continuous on its entire surface.

We must point out in addition another family of products that have appeared recently, bentonite geosynthetics, where the waterproofing is ensured by a mineral barrier, bentonite (swelling clay). These materials are not currently regarded as geomembranes, but their use is the object of specific recommendations such as traditional geomembranes [CFG 98].

The geomembranes used in GLSs for road surface water are primarily manufactured products, packaged in rolls or fabrics and whose surface can reach 1,000 m^2.

We can also use geomembranes manufactured *in situ* based on cross-linkable systems like FMBS (see section 4.2.1.2), but the same kinds of problems occur (*in situ* laying of membranes of constant thickness and perfectly continuous on irregular supports and under suitable economic conditions). Their use is marginal.

The most frequently used geomembranes belong to either one of the following two families:

– bituminous geomembranes, based on oxidized bitumen or PmB;

– synthetic polymer geomembranes, mainly plasticized PVC, HDPE, flexible PP, EPDM.

4.2.3.3. *Lagooning ponds*

Here we confront the same types of problems as for hydraulic structures and more particularly retention structures for road surface water. The difference lies in the size of the pond and the fact that it is constantly in water. The characteristics of the GLSs used for these installations and the materials used are therefore practically the same as in this last case.

4.2.3.4. *Tanks and reservoirs for chemicals*

It is generally considered that, in addition to large-scale structures, the field of civil engineering encompasses large industrial facilities, which include large tanks for solvents or raw materials whose containment must be ensured for environmental protection and safety in general. This same logic governs the construction of retention basins in the event of an accidental leak.

The characteristics of waterproofing systems used in this case are quite different from the preceding systems insofar as we must use materials insensitive to the chemical attack of the product to be contained. For this, for large tanks used in refineries, we use membranes made of fuel-resistant materials, products similar to the materials described in Chapter 2 in connection with binders for the coating of airport runways.

4.2.3.5. *Structures for the containment of wastes*

Containment of wastes has become today a vital necessity in the management of the planet, which can no longer manage by itself what it has tolerated for a long time because the population has exceeded the tolerable threshold and continues to grow. The awareness regarding this phenomenon during the last quarter of the 20^{th} century led to the construction of special structures to address the problem. These structures must evidently be watertight ...

To help manufacturers and the sanitation departments of the various communities to develop and manage such structures, the French Agency for the Environment and Energy Control (ADEME) has published a technical guide [SOY 99], which defines *containment* as "any technique, or combination of techniques, designed to maintain within a given space and for a given duration a pollution likely to affect the surrounding soil, water and atmosphere".

This technique corresponds to one of the three solutions currently used to prevent the underground migration of pollutants, the others being:

– destruction or degradation of the pollutants by the use of a depollution technique;

– immobilization in mass.

The purpose of containment is therefore to create around the source of pollution a low permeability shield to minimize the flow of pollutants towards the outside. We can mention in this context the example of "arsenic tombs" used to contain wastes with high arsenic content. This implies associating with the containment structure strictly speaking the installation of maintained pumps or *drainages* as well as a wastewater treatment system.

This obligation is fundamental and clearly differentiates the waste storage centers from other fields of application of waterproofing structures. It therefore becomes necessary to combine with the waterproofing system (generally a GLS) a *geosynthetic drainage system* or GDS.

This structure is similar in its principle to a GLS system, but its function is different (Figure 4.5).

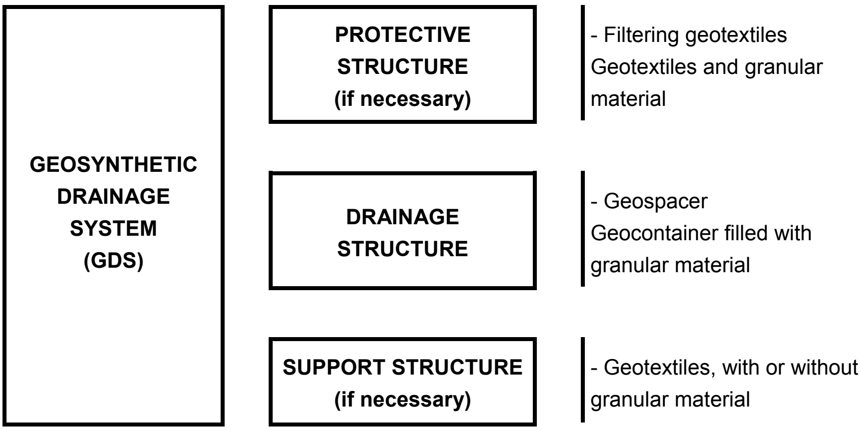


Figure 4.5. *Principle of a geosynthetic drainage system (GDS)*

It will be noted that, when the GDS's support structure is made up of a GLS, it is called a *geosynthetic waterproofing and drainage system*.

Those systems are therefore installed by associating several structures that fulfill the various functions desired, in this case, waterproofing, protection, drainage, filtration, separation, reinforcement and resistance to external erosion.

4.2.3.6. *Conclusions on geomembranes: installation and durability*

The processing of products in rolls is relatively easy when we know how to solve the problems of continuity, in other words welding or gluing between the breadths. This supposes the knowledge of an assembling technique suitable to the material and a method to check the absence of leaks.

We must therefore start by listing the main polymers used for the formulation of these products. Table 4.5 updates the Gamski list presented in Table 4.3.

Plastomers	Classic elastomers	Elastomer thermoplastics	Bituminous geomembranes
Plasticized PVC *LDPE*, HDPE Flexible PP *Flexible polyolefines*	EPDM *Butyl rubber* *Chlorosulfoned PE*	*EPDM-PP mixture* PVC alloys	PmB (SBS, EVA or atactic PP)

Table 4.5. *Geomembranes. Main constitutive polymers (the terms in italics are used rarely)*

The physicochemical properties of these polymers require specific assembly methods, which are summarized in Table 4.6.

<table>
<tr><th rowspan="2"></th><th colspan="4">Synthetic geomembrane</th><th rowspan="2">Bituminous geomembrane</th></tr>
<tr><th>P-PVC</th><th>HDPE</th><th>F-PP</th><th>EPDM</th></tr>
<tr><td rowspan="2">Common mode of realization</td><td colspan="3">Thermal welding</td><td rowspan="2">Glue or tape (in factory: vulcanization or tape)</td><td rowspan="2">Thermal welding by propane torch (partial melting)</td></tr>
<tr><td>Automatic: hot air of hot iron
Manual: hot air</td><td>Automatic: hot iron
Manual: extrusion</td><td>Automatic: hot iron
Manual: hot air</td></tr>
<tr><td>Time before mechanical load</td><td colspan="3">Almost immediate</td><td>Several days of drying</td><td>On cooling (one to a few hours)</td></tr>
<tr><td>Possibility of double weld for control</td><td colspan="3">YES</td><td colspan="2">NO</td></tr>
<tr><td>Repairability</td><td>Difficult</td><td>Moderate</td><td>Not known</td><td>Moderate</td><td>Easy to moderate</td></tr>
</table>

Table 4.6. *Modes for bonding geomembrane lengths (based on [BEN 00])*

The study of the durability of *geomembranes* is similar to that of geotextiles (see section 4.2.2.4), but the important difference lies in the medium in which the material is bathed, which is much more aggressive for geomembranes than for geotextiles.

The analytical approach to the problem was the subject of an important research undertaken by a partnership between ADEME, CETE of Lyon (LRPC Rhone-Alps), INERIS and LCPC [BEN 96] and dealing with the three most widely used geomembranes, namely, P-PVC, HDPE and bituminous geomembranes.

For *P-PVC membranes* where the presence of plasticizers is essential, four methods have been particularly suitable (see Chapter 6):

– the departure of the plasticizer can be identified by DSC thermal analysis (change in the glass transition temperature) and by extraction by a solvent when the phenomenon has made good progress;

– the measurement of concentration gradients of the plasticizer in the thickness of the membrane, which helps detect significant surface losses, is possible by microscopic infra-red spectrometry, with current IRTF devices used for this kind of measurement;

– when the plasticizer is a mixture, gas chromatography can provide invaluable information on the variation in the composition of this mixture in the course of time, particularly the release of the most volatile compounds.

For *HDPE membranes*, the tests conducted by the various infra-red spectrometry methods and by various other methods have proved to be unfruitful, which confirms that this chemically inert material hardly evolves at all.

For *bituminous membranes* lastly, the same methods used for pure bitumens are used when this is the case; but the problem becomes complicated when we have modified bitumens or bitumens to which fillers are added where the entire research is yet to be finalized.

This system should not overlook the use of basic, simple and effective measurements such as variations in weight and volume of the sample during its aging. These measurements can highlight phenomena such as degradations or dissolutions for example.

We can conclude the general presentation on geomembranes with a table summarizing their various uses in the field of civil engineering (Table 4.7).

Field	Type of works	Applications or desired objectives
Road and railway works	Waterproofing of underground structures	Tunnels and hoppers
		Foundations
	Protection of roadfills	Fight against the erosion by rainwater
		Protection against the upswelling of groundwater
	Waterproofing of appurtenant structures	Storm basins
		Surface water drainage pits
	Protection of the ballast by placing a geomembrane under it	Drainage of rainwater (hence the reduction in the thickness of the foundation layers) + prevent the upswelling of fines
Hydraulic works (water supply, irrigation, development)	Waterproofing coatings	Water retention basins
		Managed canals and rivers
	Watertight revetments	Dykes and dams
	Construction of water bodies	Leisure centers
		Landscaping
Protection of the environment by placing geomembranes in various facilities	Source treatment of animal, vegetable or chemical wastes	Lagooning ponds, pits Food industries, paper mills Chemical industries
	Isolation of discharges containing household or industrial wastes	Drop-off centers Treatment of drilling mud and brine (decantation)
	Prevention by creation of perfectly watertight overflow tanks	Treatment of the accidental break of tanks or accidental spilling of hazardous products
Industry	Creation of water tanks	Fight against fire and industrial usage
	Storage areas for aggressive leachates	Recycling of leachates Protection of the environment (sub-soil)
Aquaculture	Waterproofing of tanks	Animal husbandry (fish, crustaceans) and cultivation (algae)

Table 4.7. *The various usages of geomembranes in civil engineering*

4.3. Products for light geotechnical structures

Let us suppose that I am asked to build a road bypass through a valley where the river has deposited particularly unstable alluvia. I first build the bridge by laying a foundation of piles deeply into this soil, and then the access embankment in the conventional manner. The embankment packs (i.e. “stairs” that we come across sometimes when we arrive at a bridge ...). If I refill it, it packs again. I must therefore decrease the pressure on the soft ground. Should I act on the surface or on the weight? With traditional materials, the only option is to increase the surface, but with organic materials, I can solve the problem by decreasing the weight. And, in the final analysis, it is relatively economical too!

The first organic materials used to build embankments on bad quality soils are peat and especially barks, which Norwegian engineers largely used before they came to know about more powerful and more durable materials, namely, expanded clay and expanded polystyrene (1972).

4.3.1. *Expanded polystyrene (EPS) embankments*

The use of expanded polystyrene for the installation of light embankments on compressible soil (Figure 3.5) has spread to almost the whole world and particularly in France, where the need was quickly felt to draft recommendations [COL 85] and a technical guide to facilitate its use [MAG 90].

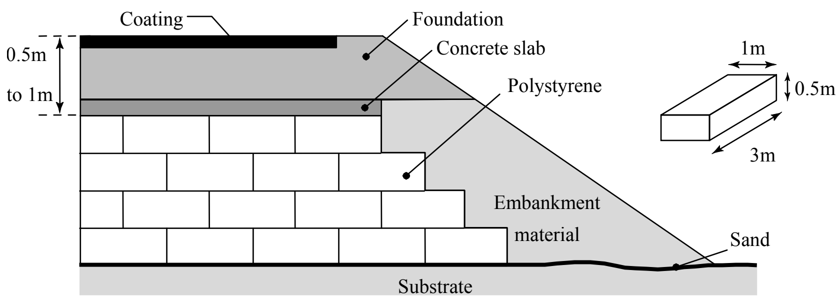


Figure 4.6. *Structure of an EPS embankment on soft soil*

The *fields of application* of EPS are:

– lightening of embankments on soft soil;

– lightening of the embankments on unstable slopes or during the repair of a road after a landslide;

– reduction of the thrust on the supports or to limit the weight of an embankment on a buried culvert or structure;

– protection of the pavements against freezing.

The *installation* of EPS blocks is made easier by virtue of their low weight, but it obeys strict rules, both storage or laying (securing the blocks in case of wind, prohibition to smoke, for instance). We will see in connection with durability that important precautions must be taken for on-site storage, especially if it is for a long period.

As regard *durability*, the following significant factors must be taken:

– solubility of the PS in oil hydrocarbons and other organic solvents;

– inflammability, fire sensitivity;

– sensitivity to ultraviolet radiation (sunlight);

– sensitivity to erosion by wind and rain;

– appreciated by rodents.

We can appreciate the following characteristics:

– resistance to biological aggressions (enzymes and bacteria);

– no "chemical aging" expected within service temperature range;

– no "aging by fatigue" expected within the range of service loads, as long as the loads remain less than 50% of the compressive strength;

– very good water resistance, low absorption and very low capillary rise of water into the EPS.

Protection against hydrocarbons

The solution generally adopted is to lay on the top part (under the pavement layers) a concrete slab that, in addition to its protective role, distributes the strains during the passage of vehicles, and laterally, either a simple argillaceous embankment or a polyethylene film surrounding the blocks (Figure 3.3).

Protection against fire, ultraviolet radiation, wind and rain

In these three cases, it is primarily the construction site that we have in mind. The embankment in place has no chance of burning, UV rays do not penetrate into the built embankment; as regards rain, we saw that PS is relatively water insensitive. Durability is therefore not affected by these parameters.

Protection against rodents

Current experience shows that this risk does not follow the same reasoning as the first three. Rodents digging galleries in search of EPS have not yet been observed.

4.3.2. *Ultra-light cellular structures (ULCS)*

Besides the EPS technique, experimental worksites have been conducted with other types of light materials. Thus, a cellular polypropylene structure (Figure 4.7 based on [MON 86]) has proved to be very interesting from the technical point of view though with a considerably high cost of materials. However, its compressive strength allows savings in terms of concrete slabs. These are extra-light cell structures or ULCS, which have given rise to in-depth studies at the Center for Road Studies in Rouen [PER 92].

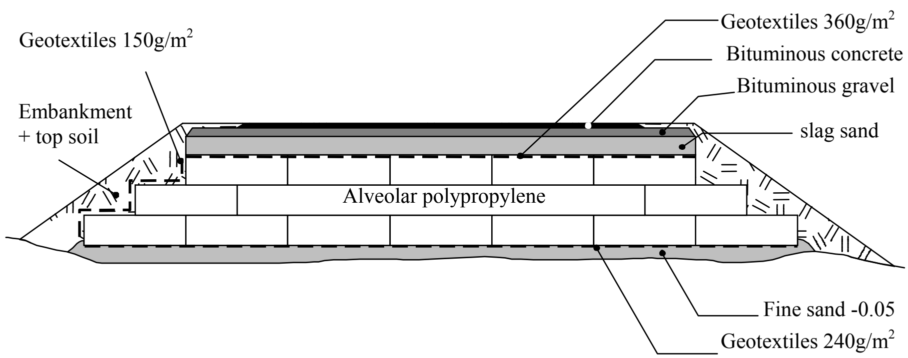


Figure 4.7. *Alveolar polypropylene embankment*

A first use for these structures is to form an alternative to expanded polystyrene in the construction of light material embankments with the feature of allowing water to rise into them in the event of flood.

Their fields of application in geotechnics are therefore the same as for expanded polystyrene (excepting protection against freezing, which is not an objective of ULCS) but we will see further below that they have other applications in the field of water management.

Two ULCS were have been offered by the profession:

– a cellular thermoplastic honeycomb structure obtained by extrusion of polypropylene;

– a hexagonal cell structure obtained from thermoformed PVC sheets assembled by gluing.

However, they retain their properties of lightness only if they are protected from the arrival of backfill fines. Therefore, a geotextile is installed all around the lightened fill to play the role of a filter.

Their properties are summarized in Table 4.8.

Properties	**ULCS 1**	**ULCS 2**
Constitutive polymer	Polypropylene (PP)	Polyvinylchloride (PVC)
Density (kg.m^{-3})	42	50
Dimensions of the blocks (m):		
Length	2.00	2.00
Width	1.00	1.00
Height	0.48	0.50
Vertical compression resistance R_{cv} (kPa)	400	400
Initial modulus E_i (MPa)	30-35	30-35
Lateral compression resistance R_{ct} (kPa)	20	30
Angle of friction block on block	24°	35°
UV resistance during storage	Sensitive beyond 3 months	Good
Resistance to common hydrocarbons	Good	Good
Fire resistance	Sensitive	Good
Porosity	95%	95%

Table 4.8. *General properties of the two ULCS studied by the Center for Road Studies in Rouen (based on [PER 92] and [RAI 98])*

But, unlike expanded polystyrene, ULCSs have a second field of application: rainwater drainage. This application developed so significantly and rapidly in the 1990s that there was an urgent need to prepare a technical guide [RAI 98], which highlights the contribution of organic materials to the systems used.

The issue of the development of reservoir pavements in urban areas is relatively recent. This involves replacing the traditional solutions that consist of evacuating the increasingly large quantities of water to relatively distant discharge systems ("any pipe" solutions) by "pipe-less" new solutions that are more eco-friendly.

Thus, drainage techniques were developed, whose aim is to control surface water at the source, with or without infiltration. ULCS are used directly in these techniques for their capacity to store and control rainwater. Their lightness, their very high void fraction (95%) and their great mechanical resistance confer on them a number of advantages:

– lightness and modular design, which make them easy to process and adaptable to the topographic difficulties that might arise;

– an underground tank is very economical in site coverage and the very high void fraction of the ULCSs help to limit the total volume of cuts necessary;

– their good mechanical resistance makes it possible to install the tank under moving loads;

– their low resistance to the passage of water allows a quick filling in the event of a storm.

These materials are very attractive, both for their technical performances and their contribution to environmental management. We might expect their durability to be good (the basic polymers are well-known and have good intrinsic durability) provided the processing and the storage management on the site have been handled correctly, but it is perhaps a little early to quantify their actual durability because feedback is still too meager. The first example can be regarded as encouraging [RAI 00], but it is clear that here, as in the case of the draining coatings mentioned in Chapter 2, the filling of porous structure is the enemy that we must know to fight.

4.3.3. *Structures based on recovered tires*

Besides the noble products described above, other organic materials have imposed their use in the treatment of supporting structures or pavement structures in general. They are recovered tires permanently available in all countries and whose reuse can only benefit the environment.

A first process [NGU 85] associating these tires, complete or partially cut up, with the native soil has been developed successfully in various applications:

– creation of light embankments, as with materials described previously; the installation method is specific, but the overall result is similar, with a material that has the advantage of not floating in the event of immersion without leading to a heavier system, if we take into account the weight of the cover-slabs and the lateral embankments, than an embankment made of synthetic materials; it is insensitive to rodents and hydrocarbons;

– installation of supporting structures, fills with direct action or intended to reduce thrusts behind a retaining wall;

– creation of an arching to reduce the loads on a pipe crossing an embankment of great height;

– creation of facilities or energy absorbent walls, ranging from the protection of automobile circuits to that of sites in unstable areas using barricades built with these materials to protect them from the fall of rocks; in this case, a geotextile must also be used to maintain the stability of the system;

– pavement foundations in cold areas, etc.

4.4. Other uses of synthetic organic materials in civil engineering

Organic materials also made inroads into small volume but important markets because of their impact on the durability of structures, comfort and the safety of road users.

Thus, with regard to bridges and viaducts, we will mention bearings but also cornices where polyester now competes with traditional materials. Along the roads, we can notice anti-noise walls where wood and organic glass co-exist with concrete and mineral glass, traffic signs and equipment fixtures where metal mingles with organic polymers. When entering a bridge, we sometimes notice, when wear-and-tear has taken its toll, the existence of rubber seals between the elements of the structure that must be replaced. To these traditional sectors, we can add the localization of buried networks in urban zones using warning systems – polypropylene ribbons with colors specific to the fluids to be identified.

These applications are not very old but we now have some feedback enabling us to direct research towards increasingly more efficient materials, not only in their ease of use and their durability but also their environmental impact and their recycling capacity.

By way of illustration, we will describe three of these applications briefly.

4.4.1. *Bearings of civil engineering structures*

The design of today's bridges generally relies on the assumption that the supports are free from small displacements (up to a few centimeters for the high ranges) and possibly small rotations while ensuring load transfers from the structure towards its support: the deal load of the structure, permanent loads and variable loads due to traffic. We can add to these actions the dimensional effects of daily and seasonal variations in temperature. Lastly, concerns regarding resistance to earthquakes added to the requirement of giving the support effective degrees of freedom in accordance with structural analysis.

To meet these requirements, we interpose between the bearings themselves and the support (abutment, pile), specific systems that transmit the vertical and horizontal reactions while accepting, without significant deformation, small horizontal displacements and possibly small rotations. These *bearings* are generally made up of a laminated composite of hooped elastomer. The French Association for Construction (AFPC) has defined the general problem and the installation in a booklet devoted to road equipment [FRA 94]. It distinguishes several classes of products:

– fixed bearings that allow rotations on the support whole acting against the displacements of the structure;

– one-way mobile bearings where rotations on the support as well as displacements in only one direction are allowed;

– multidirectional bearings where not only rotations on the support but also displacements in both directions are allowed.

The techniques used to produce these devices are classified into four types:

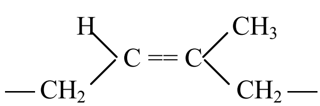
– metallic, fixed bearings with beam or joints, mobile made up of a roller between two plates;

– hooped elastomer bearings, mobile or fixed (in this case, grip blocks are added);

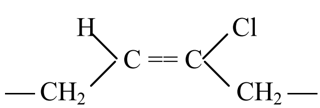
– pot bearings, fixed or made mobile by the addition of a sliding range using a stainless steel plate and a PTFE sheet (polytetrafluoroethylene);

– fixed concrete bearings made up of a narrowed concrete section forming a joint.

In this range of products, hooped rubber devices occupy an important place. They are made up an alternated stacking of elastomer sheets, in natural rubber or more generally in chloroprene (derived from natural polyisoprene, as we can see below) vulcanized at the end of the manufacture of the system, and stainless steel plates called hoops, which give the bearing a certain stiffness and which control its deformations.



Isoprene unit



Chloroprene unit

Manufacturing consists of the following:

– “mixing”, which consists of incorporating into the basic elastomer fillers and various necessary additives;

– calendaring, in order to obtain a sheet of constant thickness;

– confection, where cut elastomer blanks as well as hoops previously cut with shears to the sizes of the plan of the bearing twice less than the thickness of the coating and coated with a bonding agent are piled alternatively on the calendered sheets;

– molding: the above stacking is transferred to a mold and the mold is placed between the heating plates of a press adjusted to reach an internal pressure of 5 to 10 MPa and a temperature of 150 to 200°C, according to a precise program; vulcanization takes place here.

The durability of these products obviously depends on the formulation adopted and the manufacturing conditions. We can simply point out that elastomer is ozone sensitive and we must provide in its formulation the presence of specific antioxidant also called an anti-ozonant.

4.4.2. *Products for joints*

The construction of concrete pavements was hampered for a long time by an intrinsic property of this material – its shrinkage in young age – which compelled the project manager to saw the beautiful brand new road into slabs of sufficiently small length so that the internal stresses generated by this shrinkage did not result in large cracks with a random pattern. Thus, artificial cracks were created in order to limit the level of shrinkage stresses. The advent and the development of the continuous reinforced concrete technique (CRC) resolved this problem, but the maintenance of existing roads still requires the use of *products for joints of road slabs*, which we will discuss now.

These transverse joints were generally sawn with a depth equal to a fifth of the thickness of the slab, but the concrete in service is generally cracked down to the base, perpendicular to the sawing joint and this all the more quickly as the base course was of bad quality. This could lead in the long term to the penetration of water, then to the expulsion of fine elements (pumping), losses of load transfer and finally fluttering of the slabs culminating in their ruin.

To limit the risks of the development of this process, it has been necessary to waterproof these joints as quickly as possible after the sawing by means of a filling product capable of ensuring, at least partially, the sealing of the crack and load transfers by virtue of its good cohesion and its good adhesion to the concrete walls.

For a new pavement, the width of the joint is about 5 to 6 mm. It can reach 12 mm for the repair of an old structure. It is then necessary to start by sawing the joint again to obtain a clear interface, a clean concrete with good cohesion, particularly on the edges of the joint.

The products for joints are subjected as such to the usual climatic loads (variations in temperature, rains, solar radiation) or chemical loads (deicing salts, lubricating oils, various fuels). They undergo in addition particular stresses due to the structure and nature of the concrete pavements. These constraints are of two types:

– slow, under traction and compression, due to the horizontal movement of the slabs produced by daily and seasonal variation in temperature;

– rapid, under vertical shearing, due to the passage of wheels perpendicular to the joints themselves.

The products that have been used belong to either one of the following families:

– hot castable products based on polymer bitumens (PmB);

– cold castable products, either mono-components hardening with atmospheric moisture (silicone), or bi-components (acrylic, polyurethanes, polysulfides, etc.).

In the current state of the market, only those belonging to the first family are in practice used.

However, the old hydraulic concrete roads are not the only ones to require the presence of flexible joints: the coatings of civil engineering structures also contain joints between the spans to ensure the continuity of the road surface. This other category of joints is comparable with the first and must meet similar requirements.

4.4.3. *Warning devices for buried systems*

One of the specificities of urban engineering is to concentrate within a limited space distribution and drainage systems of all fluids (real or virtual) that are necessary for the life and comfort of today's society. The moment there is a need to intervene to add, repair or remove an element from these systems, the trouble starts. It was therefore thought necessary to accompany the course of each type of fluid with a ribbon colored according to an agreed code in order to find the element sought during excavation.

Thus, a *(visual) warning device* (NF EN 12613) has been defined as “a strip (type 1) or a grid (type 2) made of plastic for signaling the presence of cables or buried pipes during excavation operations”.

In practice, the basic polymer used is generally polypropylene.

The destination of the colors has been the object of a national consensus where the provisions laid down in the standard have been supplemented for the needs of the NF Mark in its particular regulation (Table 4.9). It may however be noted that the transition to the European standard might call this system into question.

Color	Destination	Reference
Blue	Drinking water (distribution, transport)	NF P 98-332
Yellow	Gas (combustible gases, distribution, transport, liquid or liquefied hydrocarbons)	
Red	Electricity (LV and HTA electric networks, public lighting, dynamic road equipments)	
Green	Low currents (telecommunication and video in open ground or in tubes)	
Brown	Drainage	
Orange	Gases, chemicals (pressurized fluids other than hydrocarbons and combustible gases)	
White	ELV Dynamic road equipments (< 50 V)	NF X 08-002

Table 4.9. *Warning systems. Color code used in France*

4.5. Industrial wood used in civil engineering

The oldest building material of organic nature is wood. It exists almost everywhere in the world, i.e. excepting deserts, is part of the planet’s ecosystem and at times exhibits remarkable durability. It is still little used in France in the field of civil engineering, despite the fact that French forests are particularly numerous and continue to grow. We can however note that for a few years, great efforts have been made to revive the development of wood industry, including in the field of civil engineering, and that notable technological advances herald a notable evolution in the situation in the coming years.

In this context, we will limit ourselves to a few basic concepts about the wood material, which is currently much more visible in the field of construction than in civil engineering.

4.5.1. *The wood material*

Schematically, wood can be regarded as a composite material with a tubular structure whose resistance is ensured by a semicrystalline polymer, *cellulose*, partially cross-linked by *hemicelluloses* and tangled in a *lignin* matrix coming from dead cells.

We can basically distinguish two classes of wood:

– *softwood* or gymnospermes which include firs, spruces, Douglas firs, pinasters, scotch pines, larches, etc.;

– *hardwood* or angiosperms, which include oaks, beeches, chestnuts, poplars, fruit-trees, etc. We can also add to this class *tropical wood*, which accounts for approximately 1% of world production.

Structural timber is extracted from the central part of the trunk, called the heartwood, which corresponds to the physiologically dead and therefore stabilized part of the tree. The active layers, i.e. the vessels supplied with sap, constitute the sapwood. They develop according to a tubular structure, with alternation of porous and light spring structure and tighter summer (or autumn) wood. This distinction is more marked in hardwood than in softwood. Gradually, the deeper layers of the sapwood lose their supply of sap, get plugged and absorb various substances (resins, tannins). This is called heartwood formation [CND 00].

The essential characteristics of wood can be summarized in three adjectives: wood is a heterogeneous, anisotropic and hygroscopic material, i.e. moisture sensitive.

The *heterogeneous* nature of the material is because the cells that compose it are of different nature and forms, its density is irregularly distributed and the singularities of growth make each part different.

This factor can be considered as both an asset and a drawback. This aspect, impossible to ignore and arising from its structure, must be integrated in its use and managed as such. The asset is cultural and sensorial: known since time immemorial, wood is familiar to man and perceived well by him when it is well treated. The drawback arises evidently when wood must be subject to a traditional industrial process. We must however note that great advances were made in this field during last years of the 20th century and that, as a result, the development of wood on an industrial scale can be viewed in a new light.

The *anisotropy* of wood is also an original character of the material. It also comes from the cellular structure which is oriented. It is this aspect that makes it a natural composite material. Its mechanical properties are actually different depending on the directions where a specific reference is used: axial co-ordinate according to the general direction of the trunk, radial, perpendicular to the previous direction and to the growth rings, tangential, tangential to these rings and orthogonal to the other two directions.

It may be noted here that, in the axial direction, wood exhibits interesting mechanical performances both under traction (90 to 150 MPa depending on the species) and under compression (35 to 80 MPa depending on the species). As a result, it is used for various structural members as well as for the manufacture of piles in foundations or posts for supporting transmission lines.

4.5.2. *Moisture sensitivity of wood*

It is the most important characteristic of this material insofar as it has to be controlled to consider any industrial use.

We call water content of a wood sample H% the relative difference in mass before (M_H) and after total desiccation (M_0), i.e. keeping it in a ventilated oven at 105°C until constant mass, which is expressed by:

$$H\% = \frac{M_H - M_0}{M_0} \times 100$$

At the time of felling, the total moisture ranges between 42% (hardwood) and 57% (softwood). The moisture then decreases to 30%, which corresponds to the saturation point of the fibers. This is the balance below which wood shrinks and above which it swells. It then reacts by always trying to place itself in equilibrium with the environment in which it is found. It thus reaches its “equilibrium moisture content” or “hygroscopic moisture”, which therefore depends on the relative humidity of the air and the ambient temperature.

The shrinkability of wood is not the same in the three directions. Although practically zero in the axial direction which corresponds to the direction of the fibers, it is not negligible in the other two directions. In practice, tangential shrinkage is always higher than radial shrinkage.

The density also depends on the degree of moisture of the wood. It may be noted however that it is generally given for a rate of 12%, which does not correspond to its normal conditions of use but to that of the instrumentation used to perform the measurement.

4.5.3. *Durability of the wood*

When preserved under dry conditions, wood can last for several centuries. Underwater, it can last 500 years. We can mention the story of the Tours bridge on the Loire, built in the 17th century with piers founded on wooden piles buried in the river bed and which collapsed suddenly in 1978 following large-scale dredging upstream, which led to a fall in the minimum low water level with the result that the head of the piles was subjected to a rise and fall. The contact with atmospheric oxygen cause a rapid rotting of the wood, which was no longer capable of fulfilling its bearing function and the piles fell down like a set of dominos [GRA 80].

However, raw wood has enemies, mainly xylophagous insects and fungus, which require treatments specific to the essence in question and the climatic conditions of service.

Xylophagous insects eat the cellulose and dig galleries that weaken the wood elements. The most common inspects are longhorn beetles, which can be eliminated by a surface treatment (drilling holes then injection) and termites, which can be stopped by anti-termite barriers.

4.5.4. *Fire behavior*

It is a fact that wood burns. However, in order to light it, certain time is needed as all old-fashioned campers or amateurs of countryside barbecues will corroborate. This “certain time” is invaluable and explains why well designed wooden structure holds out generally longer in the event of fire than light metal structures for example. We now have fire-resistant materials completely suitable for collective or industrial uses and which meet the current requirements.

Here again, we must be wary of preconceived ideas and admit that wood has good potentials which should be used to the full.

4.5.5. *Industrial wood*

To market a material free from the constraints of raw wood – dimensional sensitivity and brittleness due to environmental attacks – wood manufacturers have developed treatments to stabilize the material and to allow its use, just as steel is treated, for instance. This has resulted in the development of precision machines for cutting and assembling treated timber and in the spectacular growth of this material during the last few decades.

As regards the field of construction in general and civil engineering in particular, the technology of the use of wood is complex and would deserve a discussion that the limits of this book do not permit. We will only point out that the wooden parts used on building sites, boards, beams and various structural elements are produced according to controlled industrial processes, where the fundamental characteristics of the wood material are taken into account.

Thus, heterogeneity is used for its artistic qualities and minimized by all the assembling and mixing means necessary. Likewise, anisotropy can be developed or minimized as in plywood techniques where the direction of the boards is alternated. As for water content, this parameter is closely monitored and also controlled.

We can point out in this context that the assembly techniques and even the manufacturing techniques of certain products require large quantities of adhesives. We will see in the following chapter that it is these adhesives that have decisively transformed the bonding technique. In other words, current structural timber is in reality a wood-adhesive system. If we add the treatments that it has to undergo for its protection, we are far from the ideal of a natural material in its pure state. This does not in any way diminish the sensorial qualities of the material or its efficiency, but we must qualify the discourse on the ecological balance sheet.

Lastly, we must add that the assembling techniques specific to timber construction relate not only to adhesives but also to tightening, screwing and fitting devices, which are generally metallic. Besides, it is rare for a large-scale timber construction – we are interested in civil engineering – not to use concrete slabs or piles. All these materials thus come together and harmony can be found only in complementarity. Wood allows this.

4.6. Conclusion

Manufactured products of organic origin used in the various fields of civil engineering are very varied. Bringing them together in a general presentation is a rather perilous exercise, with some difficulties in its organization, the first two themes being particularly interdependent.

Waterproofing materials represent a world in themselves, although divided between geotechnics in general and road construction technology or civil engineering structures in particular. For the decks of civil engineering structures, there are four types of solutions: bituminous materials, thin films adhering to the support, prefabricated monolayer sheets and high production rate processes using roadworks equipments. In the other cases (tunnels, surface structures), geomembranes are used, generally associated with geotextiles. For surface structures, geosynthetic lining systems (GLS) are also installed.

Geosynthetics as a whole cover mainly two classes of products: geomembranes mentioned already, as they are highly used in waterproofing techniques, and geotextiles with more specific uses in geotechnics, among which we can find the reinforcement of geomembranes.

Products for light geotechnic structures include in particular the construction of embankments on compressible soils, tank structures in urban environment, and the use of recovered tires for the construction of embankments.

In addition, there is a whole range of products, namely: *bearings* of civil engineering structures, *products for joints* to ensure the continuity of the wearing course of pavements in various cases (motorway slabs, bridge with a flexible structure, repair of cracks), and *warning devices* for buried systems in urban engineering.

Industrial wood lastly is not always recognized as a material for civil engineering but has qualities that can enable it to occupy a more important place in the future, following the example of some European countries.

These materials, chemical in nature as, excepting industrial wood, they all are derived from the chemical industry, have become the concerns of physicochemists who had to use them for large projects so tardily that the literature concerning our approach, combining physiochemistry and civil engineering, is relatively poor. However, it seems that the current decade is preparing significant contributions that will invalidate the above statement.