An Analysis of Waterproofing Systems and Materials

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Project and Report submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Department of Building Construction

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March 17, 2008
Blacksburg, Virginia

Keywords: Waterproofing, Capillary Blocking, Dampproofing, Membrane, Coarse Aggregate, Drain Mat, Drain Pipe, Filter Fabric

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EXECUTIVE SUMMARY

Water is the life blood of the human body. It makes up 70% of who we are (Oliver 1997) yet in excess water will kill us. Water promotes a variety of positive and adverse effects not only on humans but also on buildings. Not to be underestimated, Brand (1994) sums up the destructiveness of water below.

> The root of all evil is water. It dissolves buildings. Water is the elixir to unwelcome life such as rot and insects. Water, the universal solvent, makes chemical reactions happen every place you don't want them. It consumes wood, erodes masonry, corrodes metals, peels paint, expands destructively when it freezes, and permeates everywhere when it evaporates. It warps, swells, discolours, rusts, loosens, mildews and stinks…

With the destructive traits described above, it is vital for contractors to construct buildings that can withstand the forces and effects of moisture. This paper focuses on keeping buildings interiors dry by analyzing foundation waterproofing.

This project and report provides building owners and contractors with an improved understanding of waterproofing systems and materials. More specifically, this paper provides a comprehensive inventory of waterproofing materials and a guideline, complete with possible combination strategies based on a building's moisture tolerance and soil types.

The first stage of this paper is to analyze how water and soils react. An understanding of these reactions, the type of foundations used and the tolerance of moisture penetration within a building will determine the ideal foundation waterproofing system. Specifically, this paper will focus on Piedmont soils, the predominant soil type for southwest Virginia, and three different types of foundations: slab on grade, crawl spaces and subterranean basements. Additionally, this paper will describe in detail, three basic waterproofing techniques: capillary blocking, damp proofing and the use of membranes. By analyzing the uses and installation practices of these waterproofing systems, this paper will investigate the materials used for each practice. Lastly, this paper presents a "best practices" chart which outlines the ideal application environment for the three waterproofing techniques.

The primary research technique for this paper is data collection through literature review. Textbooks, health and safety publications, journal articles and case studies are the primary sources of information. The collection and specifications of materials will rely heavily on manufacture web pages and other internet sources. More detail of the project methodology is available in Appendix 2.

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Introduction

On average, water-related damages cost the construction and insurance industries roughly $900 billion a year (Insurance Journal 2004). The majority of these costs can be greatly reduced not by the creation of better products but through the proper installation of current products. From a previous pictorial study (see Appendix C) capturing water and moisture related damages, human error, ignorance or apathy are among the major factors that lead to water damage in the built environment. With this in mind, it is imperative to educate future construction leaders to minimize the damages caused by water-related issues. By stressing proper material installation, knowing what right and wrong applications look like and understanding the relationships between moisture, soils and waterproofing techniques, construction leaders and managers can mitigate water damage.

Along with educating construction industry leaders, it is vital for the layperson or individual homeowner to understand what type of soil surrounds their structure and how that soil behaves in the presence of moisture. By understanding basic soil properties, a building owner can ensure the proper implementation of waterproofing techniques. A constantly saturated foundation eventually degrades and compromises the structural integrity of a building. Areas such as foundations, crawl spaces and basements are highly susceptible to moisture. A 1992 study of 100 office buildings in the United States revealed that 43% suffered from current water damage while 85% reported past water damage (Mendell and Cozen 2002). Additionally, a 1989 questionnaire sent to homeowners in six cities across the United States revealed that 46% to 58% of residences suffered from water related damages (Brunekreef et al. 1989). Though these statistics include water damage originating from both inside and outside the building, the majority of water leakages originate from exterior sources (U.S. Census Bureau 2007).

The U.S. Census Bureau reported in 2001 that 11.8% of houses suffered water damage from external sources. Of those, 3,934,000 reported water in basements or crawlspaces under occupant living space (U.S. Census Bureau 2007). Figure 1 represents the number of houses reporting water in basements from 1993 to 2005. The trend shows a steady decline of incidents. This downward trend may be explained by several factors such as advancements in materials, implementation of new waterproofing techniques or a lack of homeowner's reporting damages. However, despite a declining trend, homes and buildings must be properly waterproofed in order to prevent water penetration and damage associated with dampness.

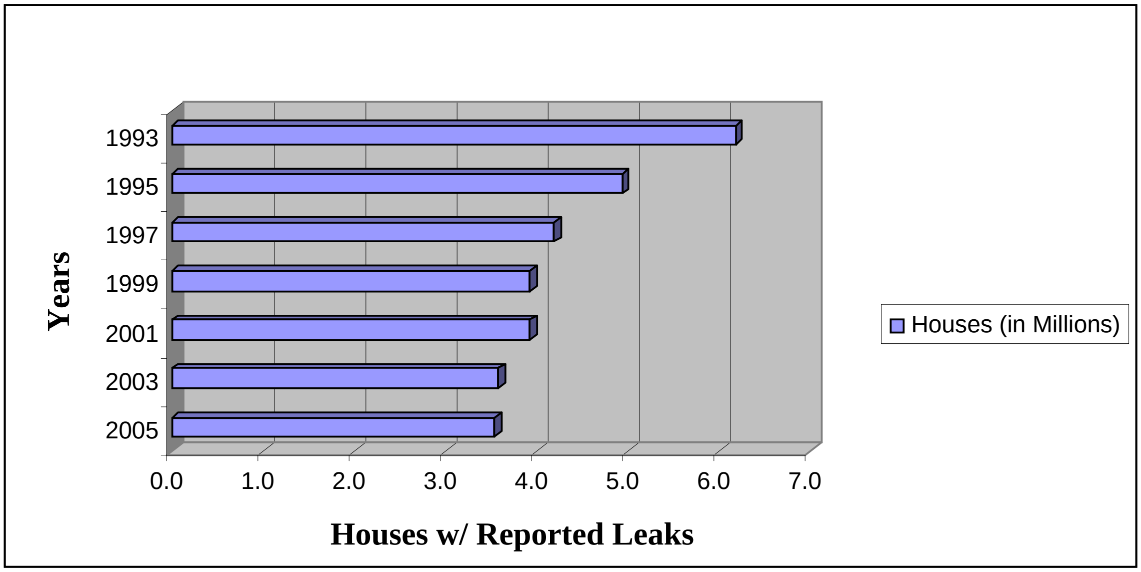


Figure 1: Number of Reported Basement Leaks

Figures gathered from: U.S. Census Bureau "American Housing Survey (AHS): National Data" www.census.gov/hhes/housing/ahs/nationaldata.html. Graph created by Brandon Shell.

Damage associated with dampness goes beyond the physical and monetary value of replacing building materials. Excess moisture and dampness can easily manifest into chemical and biological damage by causing the growth of microorganisms and release of volatile chemicals. Microorganisms and their spores are present on every surface within a building; however, they only grow when primary basic needs are met which includes the presence of moisture. Figure 2 depicts the components required to foster the growth of mildew: spores, moisture, temperature and a food source. The rate of growth of microorganisms is dependent on the availability of resources and site conditions. For example, instances such as flooding or acute water damage combined with adequate temperatures can foster the growth of mold and mildew on certain surfaces in a matter of days (Institute of Medicine 2004). Additionally, mold produces large quantities of spores

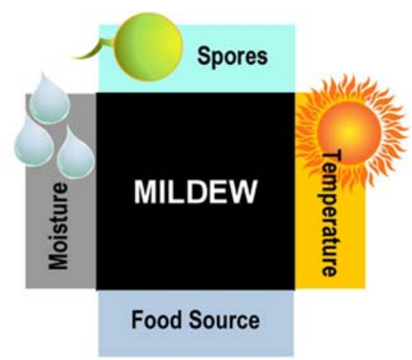


Figure 2: Necessary Components for Mildew Growth

Picture is from a moisture protection slide show presented by Patrik Lazzari from Yates Construction on 17 May 2007.

within very short periods of time. Murtoniemi et al. (2001) reported that gypsum board saturated and left to dry at room temperature with a relative humidity (RH) above 95% showed visible signs of fungal growth within 1 to 2 weeks while ceiling tile showed a latent period of 3 days before growth. Along with moisture, the average temperature of indoor spaces between, 33-130° F, further fosters microorganisms' growth. This range is just above freezing and less than the temperature required for the denaturalization of proteins on which microorganisms feed, therefore providing an ideal growth environment for microorganisms to flourish (Institute of Medicine 2004). Figure 3 represents an extreme example of mold damage in an apartment building in Biloxi, MS following Hurricane Katrina.

Figure 3: Mold Damaged Apartment

Picture is from a moisture protection slide show presented by Patrik Lazzari from Yates Construction on 17 May 2007.

The growth of microorganisms within a building degrades indoor air quality creating an unhealthy living and working environment for humans. Common molds, bacteria, and other microbial particles produce spores that are regularly found in indoor air and on indoor surfaces. These spores are transported through indoor environments by such forces as gravitational settling, fans, vents, and even cleaning (Institute of Medicine 2004). The primary means of human exposure to spores is through inhalation and dermal contact. With an increased presence of microorganism colonies due to excess dampness and prolonged moisture, spore counts within an indoor environment increase exponentially, amplifying the likelihood of human exposure. This poor indoor air quality directly relates to increased reporting of health related issues such as respiratory conditions, skin ailments and headaches. More specifically, symptoms include coughing, asthma, wheezing, eczema, and fatigue. Additionally, there is a correlation between these symptoms and the diagnosis of sick building syndrome (SBS), which is often attributed to prolonged exposure to chemical contaminants, molds, bacteria and inadequate ventilation (Institute of Medicine 2004). Such environments and related ailments directly affect worker productivity as well as building and occupant satisfaction.

Preservation of human health, positive worker productivity, occupant satisfaction and the preservation of construction materials depend on many aspects of a building. One major aspect is the ability of an indoor environment to remain dry. Proper foundation waterproofing to prevent moisture penetration into a building envelope is vital in the preservation and health of the structure and its occupants. The next section of this paper will discuss previously documented issues with craftsmanship and site planning for foundation waterproofing.

Background

One single performance factor determines the success of foundation waterproofing: the ability to keep water out of a structure. This paper identifies four primary areas that owners and contractors must understand and implement correctly in order to ensure success. Figure 4 displays these areas in the large circles: Field Practice, Soil Analysis and Site Planning, Waterproofing Techniques, and Waterproofing Materials.

Domain Map Analysis

Figure 4 represents a modified gap analysis. This paper refers to this modified chart as a Domain Map Analysis which not only identifies four key areas of waterproofing but also those areas requiring further research and exploration. Areas which may benefit the construction industry but require further research are the possible combination or modularization of waterproofing materials and the use of sustainable materials in the waterproofing process. In order to assist in future research, this paper will provide a compilation of previously studied topics in order to create a comprehensive overview and link existing materials with ideal waterproofing techniques and soils. Due to scope and time constraints, this paper will not address in detail the complete modularization of materials. However, with future research and development modularization of materials is noted as one area that could benefit the construction industry. The following sections will provide background information and relative importance on the circled areas identified in the domain map: Field Practices, Soil Analysis and Site Planning, Waterproofing Techniques, and Waterproofing Materials.

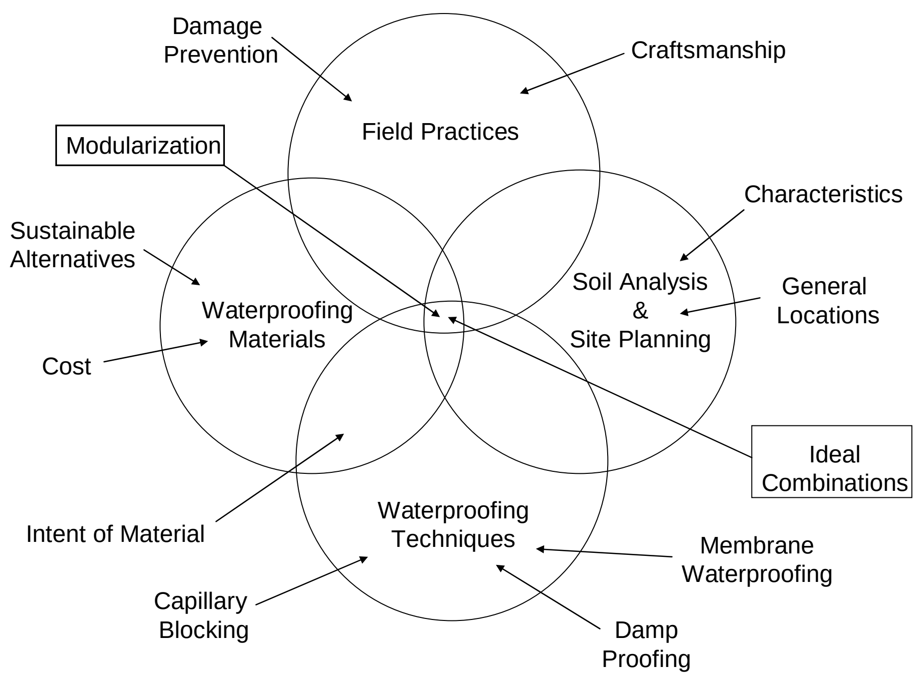


Figure 4: Domain Map

Field Practices

The key aspects of field practices are the ability to implement a waterproofing system properly in order to meet design and manufacturer specifications and the ability to preserve the waterproofing system throughout the remaining duration of construction. Construction drawings provide specific instructions and details as to how a contractor should implement and install the system. Craftsmanship is the ability of the contractor to install the system to meet both the design requirements as well as the product installation instructions. Figure 5 is an example of waterproofing details for a commercial building foundation. Day (1994) discusses the failure of a contractor to properly read and follow construction drawings and the inability of the developer to notice the discrepancy between the height of the membrane compared to the finished ground surface. This paper explores the causes and effects of leaking basement walls at a 222 unit condominium. An exploratory dig around the foundation determined a gap of .5 meters between the top of the waterproofing membrane and the finished grade. This gap provided enough surface area and capillary action, the upward movement of water through soils, between the soil and the concrete foundation to cause severe leaks within the basement walls. Day's journal exemplifies the necessity for not only contractors but also developers to follow drawings and ensure proper installations and inspections in order to prevent costly and litigious situations.

From a personal perspective, assisting in the waterproofing of a 7-story, commercial building during the summer of 2007 provided invaluable lessons on correct and incorrect waterproofing installation techniques. For example, Figure 6 shows electrical conduit running through the foundation wall.

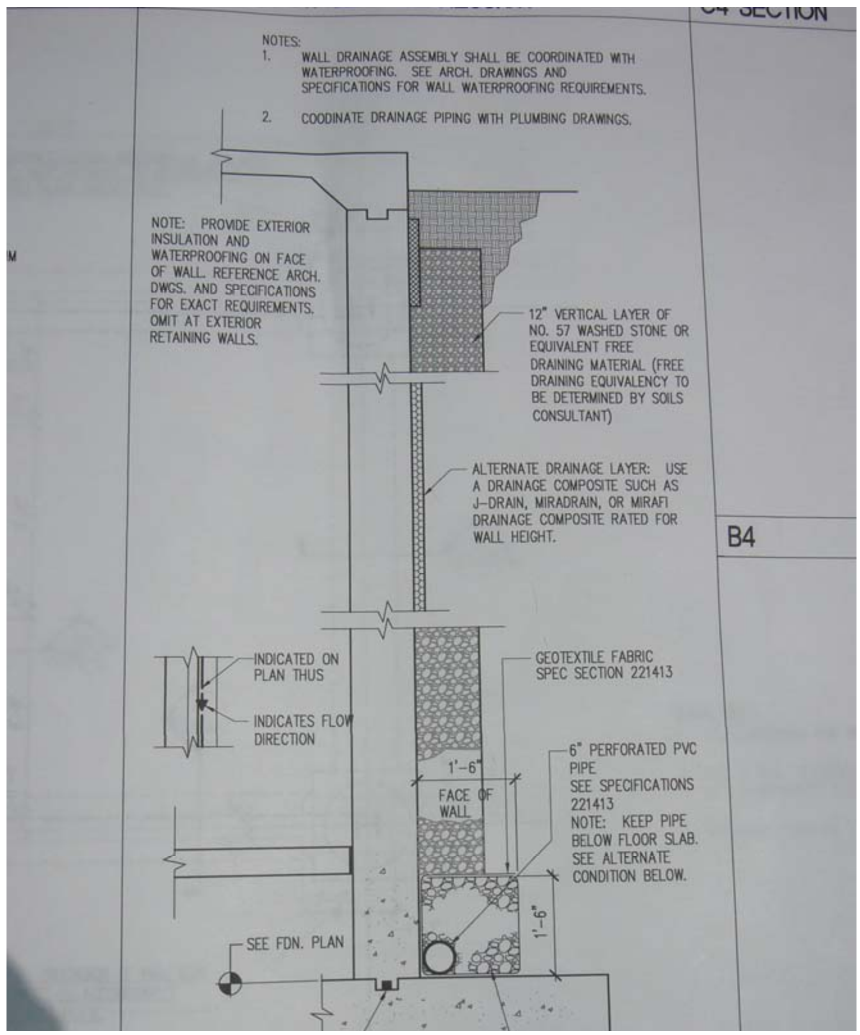


Figure 5:
Sample Waterproofing Drawing
ODELL. Construction Drawings for Reynolds Office Building. Richmond: ODELL Associates Inc., 2007

The initial mastic applied to seal the conduit/foundation interface had voids and gaps, which easily allowed water penetration into the interior of the building. The waterproofing subcontractor eventually filled the voids with additional mastic in order to properly seal the conduit. The initial application of mastic is an example of poor craftsmanship which could have caused severe water damage.

The following three pictures show improper sealing around electrical conduit into an external wall. Mastic was not properly seated and sealed upon initial installation leaving holes for water penetration.

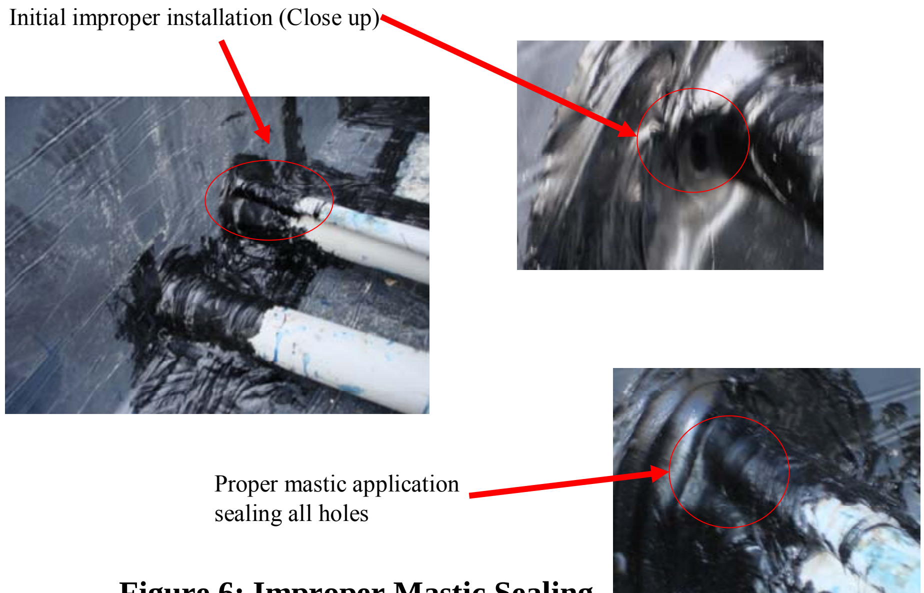


Figure 6: Improper Mastic Sealing

Along with the importance of craftsmanship is the preservation of installed materials. Typically, waterproofing systems are installed early in the construction process in order to preserve the building interior as the core and shell is sealed. With ongoing construction taking place, it is vital to protect the installed waterproofing materials. Once the building is dried in, foundation waterproofing materials damaged during the construction process pose a great risk to the indoor environment by allowing water penetration within the building. Figure 7 shows two examples of damaged membranes after installation. The best method to protect installed membranes and waterproofing systems is to backfill the foundation wall as soon as possible. Backfill will provide protection not only from construction accidents but also UV damage from the sun.

Another challenge associated with waterproofing is maintaining the intergrity of the membrane after installation while other construction tasks continue. Below are two examples of compromised membranes after installation. These holes must now be fixed before backfilling can begin.

Figure 7: Compromised Membranes

Soil Analysis and Site Planning

Soils play an integral part of successful building waterproofing. Understanding soil composition and characteristics allows key stakeholders such as owners, contractors and developers to make informed decisions about waterproofing techniques and materials. Specifically, understanding how the soil around a stakeholders building performs in the presence of water is of paramount importance. Water travels through soil by gravitational flow and capillary action. For example, different soils force the upward movement of water at different rates. This force, known as capillary action, depends on the particle size and distribution of the soil. A discussion of capillary action for specific soils is presented in later sections.   The end state of this water movement is the exertion of hydrostatic pressure against a building's below-grade walls and slabs (Beall 1998). The walls, slab floors and waterproofing materials must be able to withstand this pressure in order to keep the building dry. Incorporating subsurface drainage systems and active water diversion techniques reduces the forces of hydrostatic pressure against the foundation.

Though beyond the scope of this paper, proper site planning is a key factor in reducing the force of hydrostatic pressure against foundations. Key stakeholders can reduce this force by taking simple steps to facilitate the flow of water away from building exteriors. Two methods are positive sloping backfill and proper above ground water diversions. Positive slope backfill consists of sloping soil adjacent to a building away from the structure. A minimum guideline is to slope for roughly ½ in/ft away from the building (Kubal 1999). This will allow above ground water from sources such as rain and sprinklers to flow away from the foundation.

Much like positive slope backfill, above ground water diversions aim to keep water away from building foundations. This includes directing downspouts, roof drains and sprinklers away from building walls. Edwards (2006) conducted a study to analyze the causes, financial ramifications and possible mitigation techniques for leaking basements. The author concludes that a vast number of older houses suffer from systemic failures involving downspout drains and poor design decisions. These failures result in unstable lateral loads causing high hydrostatic pressure developments. Figure 8 depicts the saturation process of soil adjacent to foundation walls. Edwards specifically noted a two-story brick home for sale with an asking price of $790,000. An inspection by a prospective buyer revealed that the basement walls not only leaked but were seriously cracked. Hydrostatic pressure from saturated backfill against the walls ultimately caused the cracks and leaks. The saturated soil resulted from blocked and overflowing downspouts during inclement weather. The combination of these factors eventually forced the owners to spend $24,000 to repair the gutters, downspouts, cracks, waterproofing and landscaping. Additionally, the equity of the house dropped with an eventual sale price of $555,000.

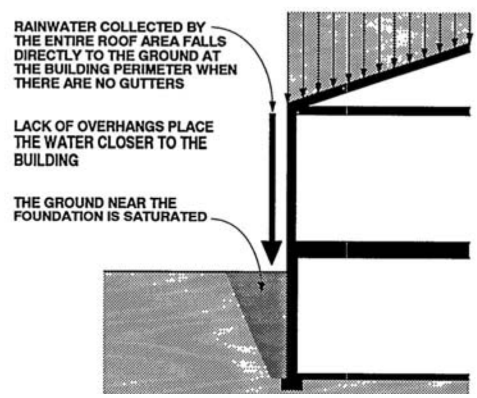


Figure 8: Soil Saturation

Picture was taken from Lstiburek and Carmody's "Moisture Control Handbook

From Edward's study, a major culprit of leaking basements is soil. Constantly saturated soil against foundation walls acts as a moisture sink. In order to create equilibrium, moisture must dissipate from sinks before buildings are adversely affected (Oliver 1997). If moisture is not dissipated, sinks will continue to act as sources of moisture. A major means of dissipation is through waterproofing systems. In Figure 9, waterproofing systems are considered moisture reservoirs, temporary or semi-permanent receptors for moisture (Oliver 1997). Waterproofing systems not only block the penetration of water vapor into indoor environments through foundation walls but also allow underground water to flow away from the building. This is depicted as a balance path that allows the dissipation of dampness.

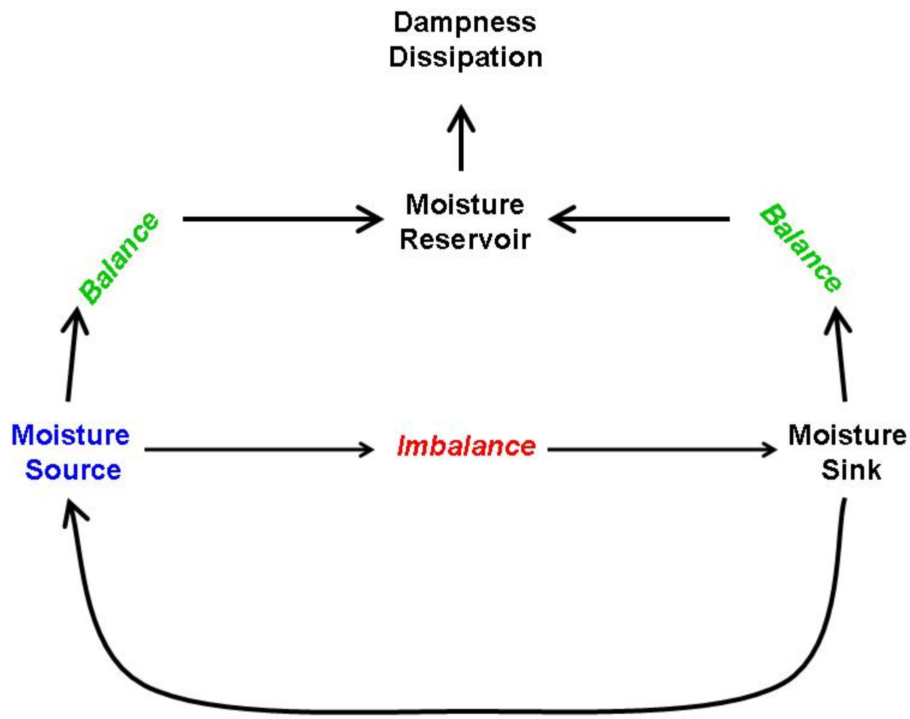


Figure 9: Moisture Transfer Cycle

The original idea of the moisture transfer cycle below was presented by Oliver. Brandon Shell added slight modifications in order to better understand the cycle and for readability.

Waterproofing Techniques

The building type and depth below grade as well as local soil compositions are significant factors when determining which type of waterproofing system to implement. Prior to World War II, the demand for waterproofing was relatively low. Underground spaces were typically deemed as uninhabitable due to the inability to control temperature, humidity and air circulation (Henshell 2000). However, with the advent of air-conditioning, owners viewed underground spaces as ideal for expanding usable building space. Post war construction began to utilize underground space for not only storage but also mechanical rooms, computer rooms, offices and even plazas.

With the ability to control subterranean indoor environments, needs turned to preventing moisture penetration. The two primary forms of waterproofing are negative side and positive side waterproofing. Negative side is the practice of waterproofing the dry side or interior of the building while positive side applies materials to the wet side or exterior of the building (Henshell 2000). Negative side waterproofing is seen more as a remedial practice for previous failing systems. One advantage to negative side is the fact that the waterproofed surface is easily accessible compared to positive side. One downfall to negative side is the vulnerability for leaks at joints such as wall and floor intersections. Positive side on the other hand is the most common practice for new construction and provides designers with many opportunities for subsystems and materials (Henshell 2000). The three most common means of positive side waterproofing will be discussed in detail.

Capillary blocking, damp proofing, and membrane waterproofing are the three most common means of waterproofing. Capillary blocking is the process of sealing concrete with a cementitious material in order to prevent moisture from penetrating concrete pores. Damp proofing is the process of applying materials to a wall in order to block the movement of water vapor. Damp proofing is ineffective in the presence of hydrostatic pressure. Membrane waterproofing is the application of a membrane to foundation walls in order to resist vapor migration and hydrostatic pressure from liquid moisture (Henshell 2000). The materials and application processes of these three waterproofing practices will be discussed in detail in the Waterproofing Techniques section of this paper.

Waterproofing Materials

The earliest form of waterproofing traces back 26 centuries to the Hanging Gardens of Babylon (Henshell 2000). Terraced roof gardens filled with building's overburden and planted with trees and plants were contained with bitumen and lead. Though the materials from 600 B.C. to today have drastically changed, the concept is the same: stop the flow of water into buildings. Each of the three waterproofing techniques mentioned above have extremely different materials that each serve unique functions. This paper gathers a comprehensive list of the materials currently used in cementitious, damp proofing and membrane waterproofing techniques. Additionally, it will explore the possibility of not only using sustainable or reusable materials but also combinations or the modularization of materials.

Water Movement and Soils

Before analyzing Piedmont soils, it is vital to understand how water moves through soils. Previously discussed in the Background section under Soil Analysis and Site Planning, water moves through soil by gravitational flow and capillary action. From basic laws of physics, gravity is the force that moves objects together. More specifically for this paper, gravity is the force that moves water laterally from higher elevations to lower elevations until emerging in a larger body such as a spring, stream, river, lake or ocean (Beall 1998). Capillary action is the upward movement of water through soils. This upward movement depends on the particle size, distribution and pore size of the soil. Though both gravitational flow and capillary suction are vital factors in the exertion of hydrostatic pressure on building foundations, capillary action is most relevant when discussing water movement through soils surrounding buildings.

The four basic types of soils are sand, silt, clay and loam. Despite different make-ups, basic components of these soils remain the same: minerals, air, water and organic matter. Figure 10 represents the basic components and their respective percentages. These components will vary slightly depending on soil location. Major fluctuations in component percentages will differ primarily between air and water depending on the percent of saturation. Figure 11 indicates the height of capillary moisture rise for the four basic types of soils. It is important to note that capillary moisture cannot be drained out of soils due to the surface tension created by the pore structure of the soil particles (Cook and Ellis 1987). However, this moisture can be evaporated through ventilation and exposure to dry air.

As mentioned earlier, particles size, distribution and pore size are key elements in soil classification. Most samples of soil contains particles of all sizes (Cook and Ellis 1987). The size of particles is attributed to the degradation of rocks and minerals from weathering. The rate of disintegration of particles directly relates to a classification of being a sand or clay. Easily weathered materials, which form smaller particles, are classified as clays while larger un-weathered rock and mineral fragments are likely to be classified as sand.

Sandy soils have a gritty texture and are formed from weathered rock such as limestone, quartz, granite and shale. These soils drain excess moisture relatively well and have the smallest capillary rise among the major soil types. Silt soils are composed of minerals such as quartz and fine organic particles, which create a dark smooth texture. Unfortunately, these soils tend to hold moisture thus creating a large capillary rise of eight feet or more. Much like silt soils, clays also have a very large capillary rise of eight feet or more above the water table. Clays have very fine pore structures thus create high surface tensions among particles. This surface tension coupled with a net-negative surface charges, causes clays to retain water and drain very poorly. Loamy soils tend to be the middle of the road for capillary rise and retaining water. Loams are a combination of the other three types of soil. Consisting of roughly 40% sand, 40% silt and 20% clay (but not more than 27%), loams drain relatively well yet retain moisture with a capillary rise of roughly 6 feet or more (Cook and Ellis 1987).

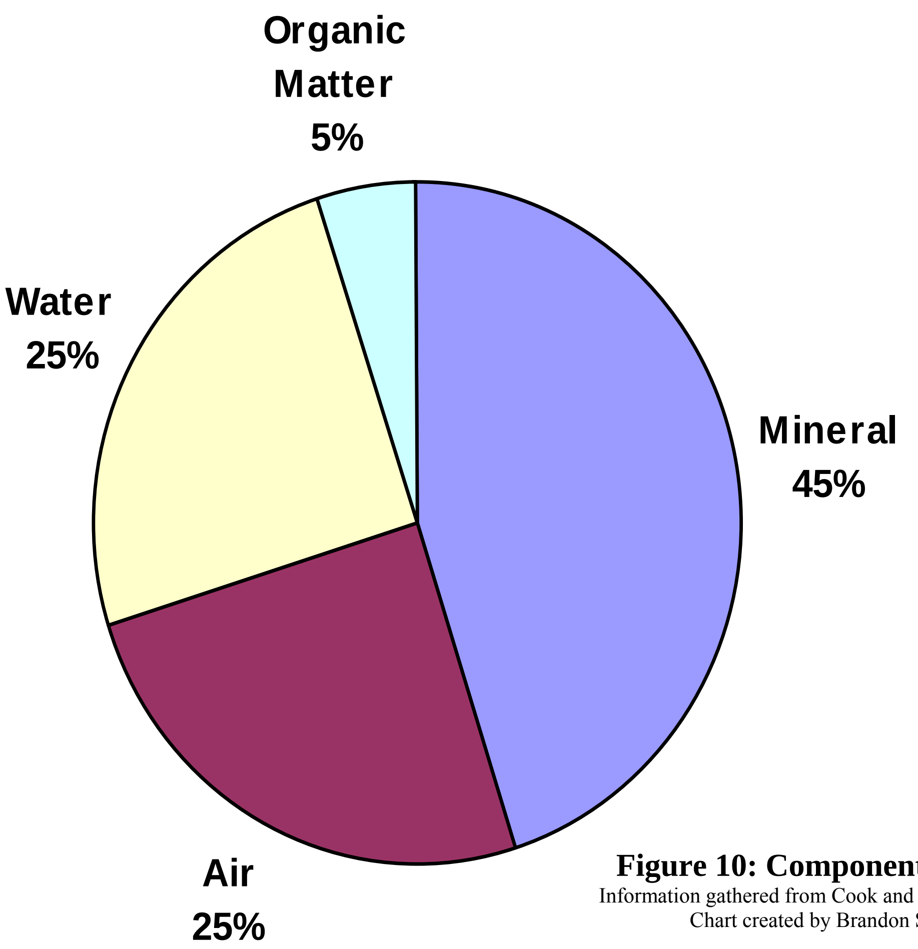


Figure 10: Components of Soil
Information gathered from Cook and Ellis 1987. Pie Chart created by Brandon Shell

Figure 11: Height of capillary moisture rise above water table for various soils		
Soil Type	**Saturation Zone (ft)**	**Capillary Rise (ft)**
Sand	**1-5**	**3-8**
Silt	**5+**	**8+**
Clay	**5+**	**8+**
Loam	**3+**	**6+**
Gravel	**0**	**0**
Table from Beall 1998 adapted by Brandon Shell		

Piedmont Soils

This paper focuses on Piedmont soils due to Virginia Tech's location in the Mid Atlantic Region of the Piedmont Province. Figure 12 highlights in brown the location of Piedmont soils in the Mid Atlantic Region. Despite the appearance of an abrupt stop along the southern boarder of Virginia in Figure 12, the Piedmont soil region continues to stretch south into Alabama. The Piedmont Region is a broad strip approximately 161 km wide and 1290 km long. Situated between the Blue Ridge Mountains and the eastern Coastal Planes, this region's predominant rock structure consists primarily of metamorphic rocks with small patches of granite and silica (Kelley and Lutenegger 1999). The presence of these rocks has created soils ranging from silt to medium sandy silt with average depths of 20 to 80 inches (1999). However, the formation of the Blue Ridge Mountains created an extreme situation where soils exhibit characteristics of both fine grained (un-drained) and coarse grained (drained) soils in random fashion, creating high variability over short distances (Fink et al. 1999). With this variation, it is important to keep in mind that soil compositions and characteristics can vary greatly despite being in the same region. From the sand/silt composition of the soil in the mid-Atlantic Piedmont Region and data from Figure 11, the estimated capillary action ranges from three to eight plus feet. These soil compositions and expected capillary actions force designers and builders to understand and implement some form of waterproofing when designing and constructing facilities in the mid-Atlantic Piedmont Region.

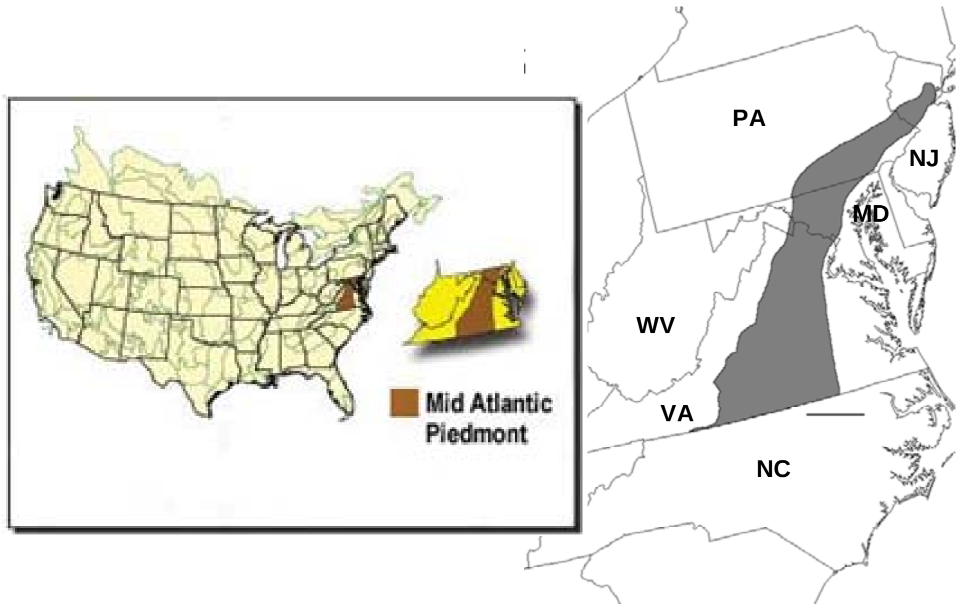


Figure 12: Regional Map

Original maps are from the Bureau of Land Management (http://www.blm.gov/wildlife/pl_10sum.htm); altered by Brandon Shell

Building Types

During the design and construction phase of a building, the designer and the client should agree upon the limits, expectations and applications for all below grade areas such as basements. All buildings should have some form of moisture protection; however, the level of protection depends on the desired usage of below grade facilities. As a rule of thumb, there are four levels of protection ranging from categories 1 through 4. Category 4 requires an indoor space to remain completely dry while category 1 allows visible damp patches and minor seepage (Oliver 1997). Depending upon the type of building or structure and the desired waterproofing category, three primary techniques are used: capillary blocking, damp proofing and membranes. Before discussing in detail the three waterproofing techniques, it is important to understand basic building or structure types.

For the purpose of this paper, buildings can be broken down into two basic categories: those above grade and those below grade. Granted all buildings will have foundation and support components below grade, above grade buildings are typically slab on grade or slightly below grade. Slab on grade refers to a building with a bottom floor supported by the ground. These bottom floors are constructed of cast in place concrete. Another above ground structure would be either concrete or wood foundation buildings with crawl spaces slightly below grade. This paper refers to below grade buildings as those with basements or other useable facilities lower in elevation than a finished grade. Additionally, other structures, which are greatly affected by water penetration, are tunnels, water reservoirs and elevator or escalator pits (Kubal 1999). Though this paper will not specifically analyze these special needs structures, they require mentioning because capillary blocking is their primary waterproofing technique.

Figure 13 presents graphical representations of both above and below grade structures. Exhibit A) in Figure 13 represents construction of a facility with a crawl space. Crawl space construction can consist of either concrete or wood foundation walls and can be either vented or non vented. Regardless of construction materials or air flow, waterproofing steps must be taken in order to preserve the interior materials and air quality of the structure. Exhibit B) represents slab on grade construction while exhibit C) represents a basement. Much like crawl space construction, basement foundation walls can be constructed of either wood or concrete. Again, regardless of construction materials used, waterproofing steps must be implemented.

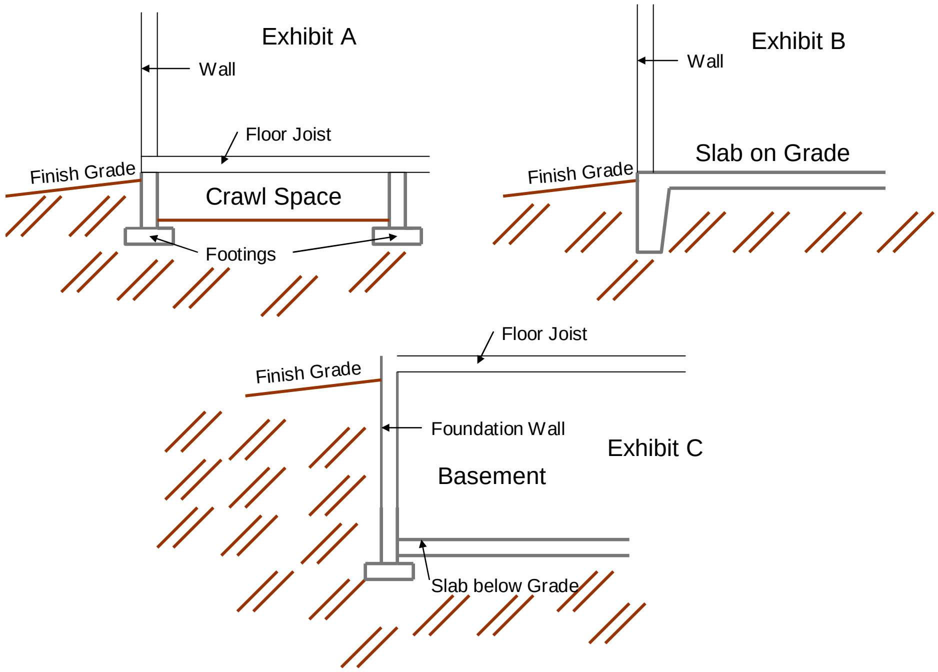
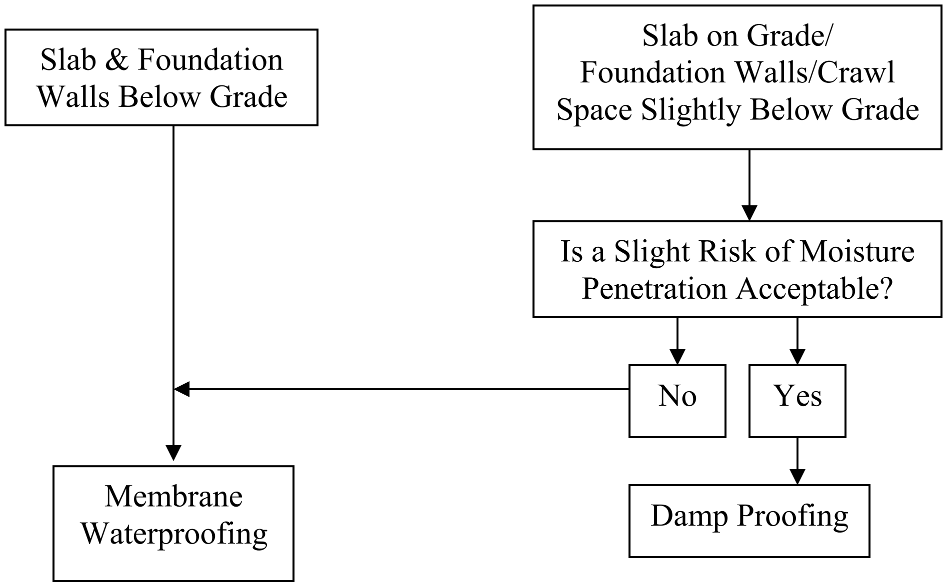


Figure 13: Building Types

Detailed drawing ideas are from Lstiburek and Carmody 1991; drawings were created by Brandon Shell

Below is a simplified flow chart created by Henshell (2000) to help designers and builders determine whether waterproofing with a membrane or damp proofing is acceptable for specified buildings and walls. As a rule of thumb, especially for the Mid-Atlantic Piedmont Region, below grade floor slabs and foundation walls should always be waterproofed with membranes due to the possibility of hydrostatic pressure. Slabs on grade and foundations slightly below grade may only require damp proofing depending on local water tables and the acceptance of a slight risk of moisture penetration.



Brandon Shell modified Henshell's original chart in order to match the foundations discussed in this paper.

Universal Waterproofing Materials

The first step in waterproofing any foundation wall is external water management. As mentioned earlier in this paper, directing above ground water runoff away from foundations is vital. Additionally, the direction and containment of subsurface water greatly reduces the force of hydrostatic pressure exerted on foundation walls. The presence of hydrostatic pressure will often determine which type of waterproofing system to use. However, regardless of the selected waterproofing system, materials common to all three techniques are coarse aggregates or drainage mats, drainage pipes and filter fabrics (Mehta et al. 2008).

Coarse Aggregate

The function of a coarse aggregate in waterproofing is to act as a capillary break between soils and foundation walls. From figure 11, the capillary action and saturation zone for gravel, the most commonly used coarse aggregate, is zero.

Figure 14: Installation of Coarse Aggregate Backfill

Other common aggregates are coarse sand, pea-gravel, blast furnace slag and crushed stone (Beall 1999). Typically, aggregates should be of a single grade and no larger than ¾ inches. Aggregates are used as a capillary break under slab on grade or slab below grade because their pore structure is large enough to prevent capillary action (Beall 1999). At a minimum, aggregates should create a 6-inch bed, which surround perforated drainage pipes and should continue up the side of the foundation to within a few inches of the finished grade. As shown in the picture above, the installation of coarse aggregates usually incorporates the use of both heavy equipment and human labor.

Drainage Mats

Drainage mats are a complement or secondary form of the coarse aggregate layer. Also referred to as a drain board, these three dimensional plastic boards are installed to not only protect the applied waterproofing coatings on foundation walls but also to prevent capillary action. Drainage mats perform the same function as coarse aggregates in that they collect and convey water away from the foundation. Mats are constructed of highly durable plastics ranging in width from .4 inches to .6 inches (Henshell 2000) and withstanding pressures of 10,000 psf (Kubal 1999). Mats are designed and deformed to create embedded conical imprints, which provide multi-directional water flow at a rate of 3 to 5 times faster than traditional coarse aggregates (1999). Additionally, sheets are lined with filter fabrics, which will be discussed later in this paper. Drainage mats are generally supplied in rolls and are lightweight enough to be installed by one person. Mats typically adhere to foundations initially with a light coat of adhesive but are secured by the weight of backfill.

Below is the instillation of the drainage board.

The following is a close-up of a drainage board.
This side view reveals conical imprints which allow
water to more easily drain away from foundations.

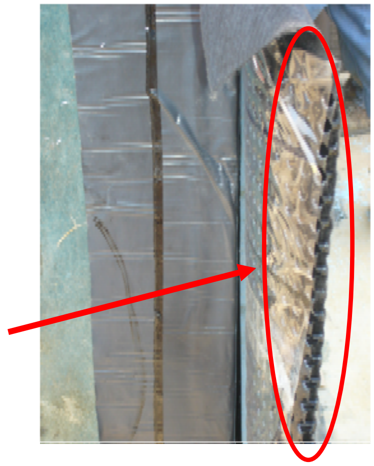


Figure 15: Drainage Mats

Drainage Pipes

Drainage pipes collect and discharge ground water away from foundations. As water percolates through the coarse aggregate, it flows down to the base of the foundation. In order to collect this water, drainage pipes are installed along the base of foundation walls on a slope of at least 1% towards the lowest elevation. Additionally, pipes are placed under slabs in order to prevent upward exertion of hydrostatic pressure on the slab (Henshell 2000). These under slab pipes must be above the bottom of the footings and drain through the footings via weep tubes, which lead to perimeter drains as depicted in Figure 17 (2000). Pipes should be between 4 inches to 6 inches in diameter, perforated in order to allow water inflow and are wrapped in filter fabric to prevent soil penetration and clogging. Pipes are either rigid or flexible. Typical rigid pipes are constructed of either clay tiles or porous concrete. As foundations are backfilled, rigid tiles are more likely than flexible tiles to crack, break and become dislodged and ineffective. Flexible pipes on the other hand conform more easily to unique bends or corners and are more resistant under the stresses of backfilling. Additionally, flexible pipes are less likely to clog from soil penetration. Common flexible piping is manufactured from polyvinyl chloride (PVC), bituminized fibers and styrene plastic (Henshell 2000).

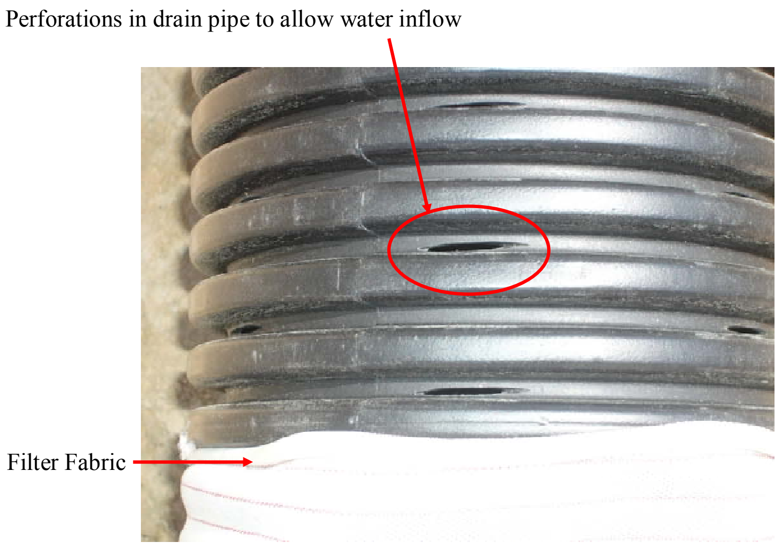


Figure 16: Drain Pipe

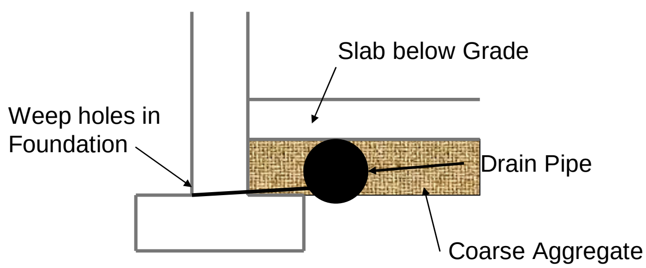


Figure 17: Drain Pipe Under Slab with Weep Holes

Filter Fabric

Filter fabrics play a vital role in the segregation of backfilled soils and waterproofing systems. Filter fabrics are geotextiles with extremely high resistance to subterranean deterioration. Made from chemically inert plastics, fabrics are either woven or spun to different rates of permeability in order to separate fine aggregates and soils from the coarse aggregate layer and drainpipes. This filtration and separation prevents the lateral movement of backfilled soil through the coarse aggregate layer decreasing the exertion of hydrostatic pressure and capillary action on foundation walls. Additionally, filter fabrics keep drainpipes from clogging and impeding the flow of ground water away from foundations. The rate of filter fabric permeability depends on the type of soil surrounding a foundation. For example, soils with high clay content should consist of a nonwoven (spun) needle punched geotextile. This type of fabric allows minimal passage of water due to the characteristic of clay's pore structure to retain water. Sandy soils on the other hand require woven materials with high permeability. This allows a high flow of water while holding back the individual grains of sand and rock. Due to the presence of a sand/silt soil base in the mid-Atlantic Piedmont Region, small opening woven geotextiles are recommended. This mid range fabric type allows for an acceptable flow of water while maintaining the integrity between backfill and coarse aggregates or drainpipes (Kubal 1999).

Waterproofing Techniques

Surface Preparation

The first step in any waterproofing situation is the preparation of foundation walls. Whether concrete or wood, walls must be free of dust, debris and any other objects which may penetrate or cause uneven application of waterproof coatings. Metal ties or nails used to stabilize formwork during concrete wall construction must be removed and any remaining holes within the concrete must be patched. Areas of honeycomb or exposed rebar must be patched and filled. Wood surfaces must be free of knotholes, gouges and irregularities. Having smooth, dry walls that are free of dirt and debris allows membranes, coatings or slurries to properly and evenly adhere to foundations.

Prior to the application of any waterproofing material, the outside wall surface must be properly prepared. First, the concrete must cure for at least 7 days. Next preparations include breaking all snap ties used to secure the form work, patching any honeycomb areas on the wall and ensuring there are no jagged or rough edges that could potentially puncture the waterproofing membrane. Below are pictures of the concrete form work and the snap ties which must be removed.

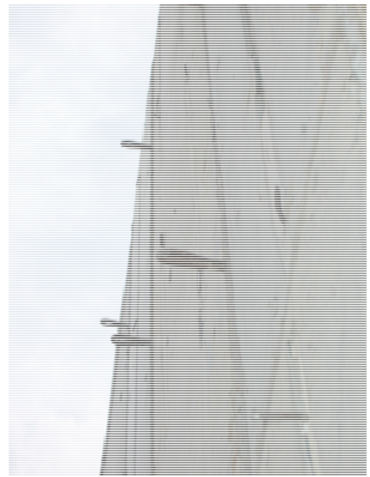


Figure 18: Formwork and Foundation Wall Preparation

Capillary Blocking

Capillary blocking is the process of applying slurries or renders to external or internal block or concrete surfaces in order to waterproof. Also known as cementitious or crystalline, these systems combine both organic and inorganic compounds. When mixed these compounds react to block concrete pores. Common mixes include Portland cement, lime, water and chemicals which create a catalytic reaction promoting a crystalline formation within the pores and capillaries of concrete (Henshell 2000). These cementitious coatings impede the infiltration of water. Mixes are proprietary and often only require the addition of water prior to application.

Prior to the application process of capillary blocking systems, many manufacturers require that concrete walls be sand blasted or bush-hammered to a depth of roughly 1/16 inch. This enables the cementitious solutions to adequately bond to the foundation walls (Kubal 1999). Additionally, surfaces should be either uncured or saturated with water just prior to application. Cementitious coatings are applied with a minimum of two coats by either spray, trowel or brush. The first coat applied consists of a manufacturer's proprietary chemical mixture while the second coat consists of both chemical mixtures and cement and sand mixtures. If additional protection is necessary, anywhere between three and five coats of primarily cement and sand can be applied. Total coat thickness ranges from 1/8 inch to 1/4 inch.

The major downfall to using a capillary blocking system for below grade waterproofing is its inability to withstand hydrostatic pressure, foundation cracking or joint movement. Cementitious systems used for below grade purposes should be applied on the positive side of foundations and utilize three to five coats of cement and sand for additional protection. Other shortcomings of using capillary blocking systems are a curing period anywhere from 24 to 48 hours and the required use of a cant, an angled transition between change in plane details, along the footing/foundation wall interface. As mentioned earlier, the ideal use of cementitious systems are in below grade civil projects such as tunnels, wastewater treatment facilities, swimming pools and elevator and escalator pits.

Damp Proofing

Much like capillary blocking, damp proofing is most effective in the absence of hydrostatic pressure. Defined by the American Society for Testing and Materials, damp proofing is the treatment of a surface or structure to block the flow of water in the absence of hydrostatic pressure. More specifically, damp proofing resists vapor migration from soils to the interior of buildings. Water vapor naturally diffuses from areas of higher pressure to lower pressure. Diffusion typically occurs from soils and coarse aggregates which are areas of higher pressure, towards foundation crawl spaces or basements which are areas of lower pressure. This vapor migration leaves buildings susceptible to condensation not only within building materials but also within interior spaces.

The proper application of damp proofing materials reduces the transfer of water vapor to the interior of buildings and materials. As mentioned earlier, damp proofing is acceptable for slab on grade and foundation walls with crawl spaces slightly below grade. Damp proofing is not recommended in areas where soil moisture is constantly high or water tables fluctuate to within less than six inches below the bottom of a slab. Designers and builders only eliminate damp proofing when sites are exceedingly dry or when the bottom of a slab on grade is higher than any surrounding grade (Henshell 2000).

However, when damp proofing materials are eliminated contractors must install subsurface drainage systems such as drainpipes and layers of coarse aggregate or drain board as a precaution to unforeseen events.

Damp proofing materials are used in both positive and negative sides of buildings. Typically, the application of a damp proofing material on the negative side is often a remediation technique for an already installed and failing positive side system. When applied to the positive side of a building, damp proofing can be applied directly to cured and prepared concrete surfaces. When applying damp proofing coats to older structures or foundations, contractors should ensure all cracks, holes or voids are patched because damp proofing materials are not effective over compromised surfaces. When applied to masonry block or brick foundations damp proofing must adhere to a parge coat between 3/8 to 1/2 inch thickness (Beall 1998). A parge coat consists of Portland cement and acts as a smooth continuous surface.

The most common type of damp proofing material is a bituminous coating that is brushed, sprayed, rolled or troweled into place. As a liquid form, emulsions are water based which prevent application in freezing temperatures. Additionally, they must be fully set before backfilling in order to allow the water base to evaporate and the solvent to seal properly. A common residential damp proofing material consists of a polyethylene sheet wrap. These wraps are typically 6-mil and are extremely susceptible to damage during backfill.

Much like the wraps used for foundation walls, slabs are damp proofed with vapor retarders. These under slab retarders are installed between the coarse aggregate layer and the concrete slab in overlapping sheets and sealed with either tape or a sealant. Sheets are typically between 6 and 10 mils of polyethylene, asphalt/polyethylene composites, coated granular-surfaced felts or polymer-modified bitumen sheets (Henshell 2000). Sheets should be durable enough to handle the pressure of the concrete slab installation and a resistance of less than 1 perm, the rate of water vapor transmission for one grain per hour per square foot per inch. The purpose of the under slab vapor retarders is to stop upward movement of water vapor due to capillary action.

Membranes

Unlike damp proofing, waterproofing with membranes creates a system that is capable of preventing leakage of water into building foundations under the force of hydrostatic pressure. Damp proofing resists the transition of water vapor, while membrane waterproofing resists both water vapor and liquid water. Buildings exposed to subsurface hydrostatic pressure or have below grade space with no interior moisture or condensation tolerance, require membrane waterproofing.

Much like damp proofing, membranes can be applied on either the positive or negative side of buildings. One major advantage of positive side waterproofing is the protection the membrane provides against contaminated or corrosive soils. Such soils can corrode and degrade masonry, concrete and even reinforcing bars (Henshell 2000). The positive application of a membrane not only prevents the flow of water but also blocks contact between corrosive soils and foundation walls. Similar to damp proofing, the negative application of membranes is typically a remediation effort of previously failing systems. One advantage of negative side application on concrete walls is the sandwiching effect of moisture. As moisture moves from soils through concrete walls and is blocked by an interior membrane, the concrete is subject to solidifying hydration which promotes continued strength gain (Henshell 2000). However, this type of application does not protect from corrosive soils and the membrane is more vulnerable to subsurface foundation cracking. Additionally, membranes should never be applied simultaneously to both the positive and negative side of a building. Doing so will trap moisture within the wall and cause one if not both of the membranes to blister and lose adhesion.

Membranes come in both fluid and sheet forms and are applied by spray, brush or adhesive sheets. Fluid systems are comprised of urethanes, rubbers, plastics, vinyls or polymeric asphalts. One major advantage of using fluid applied systems is the absence of seams. Seamless application eliminates the need for flashing and transition accessories between other building envelope components. However, one difficulty in fluid application is controlling the thickness. A membrane applied too thin will not have the elastomeric properties to bridge and withstand cracking and thermal movement. Much like damp proofing, concrete foundations must cure for a minimum of seven days and must be clean, smooth and dry. Any moisture on foundation walls prior to fluid application will prevent the membrane from adhering. Properly applied liquid membrane systems are between 50 to 60 mil and have elongation properties of 500%, allowing them to bridge cracks up to 1/16 inch wide (Kubal 1999). Supplied in 5 gallon or 55 gallon containers, fluid membranes are toxic; therefore, all materials and packaging must be disposed of properly.

Sheet membranes are typically manufactured out of thermoplastics, vulcanized rubbers or rubberized asphalts. Unlike spray applications, sheet thickness is regulated during manufacturing and ranges from 20 mil to 120 mil and is packaged in rolls varying in width between 3 and 10 feet. Membranes are manufactured with an adhesive back that is exposed once installers remove a protective paper layer. However, prior to application, installers must prime foundation walls and apply additional adhesive material. Figure 19 depicts the application of a sheet membrane to a concrete foundation walls.

Figure 19: Membrane Application

In Figure 19, the blue/green colored material on the foundation wall is a primer/adhesive. The black sheets are the actual membrane.

One major downfall of sheet membranes is the presence of seams. By the nature of the product, sheets must be overlapped much like roof shingles in order to prevent water penetration. Unlike spray membranes, sheets must be lapped at changes of planes, termination points and at transitions with other building envelopes. Figure 20 highlights in red circles three corners along the grade beam/foundation wall that have plane changes and require overlaps in order to ensure a proper seal. Seam overlaps should be a minimum of 2 inches and membranes application should begin at the lowest point and work upward towards the highest elevation (1999). Once membranes are overlapped, seams and termination points must be sealed with a mastic to ensure proper bonding. Figure 21 depicts overlapped membranes at plane changes that have been sealed with mastic. Once applied, installers roll the membrane with hand-propelled devices that ensure proper adhesion.

Points of overlap along the first layer of membrane application.

Figure 20: Membrane Overlap at Plane Changes

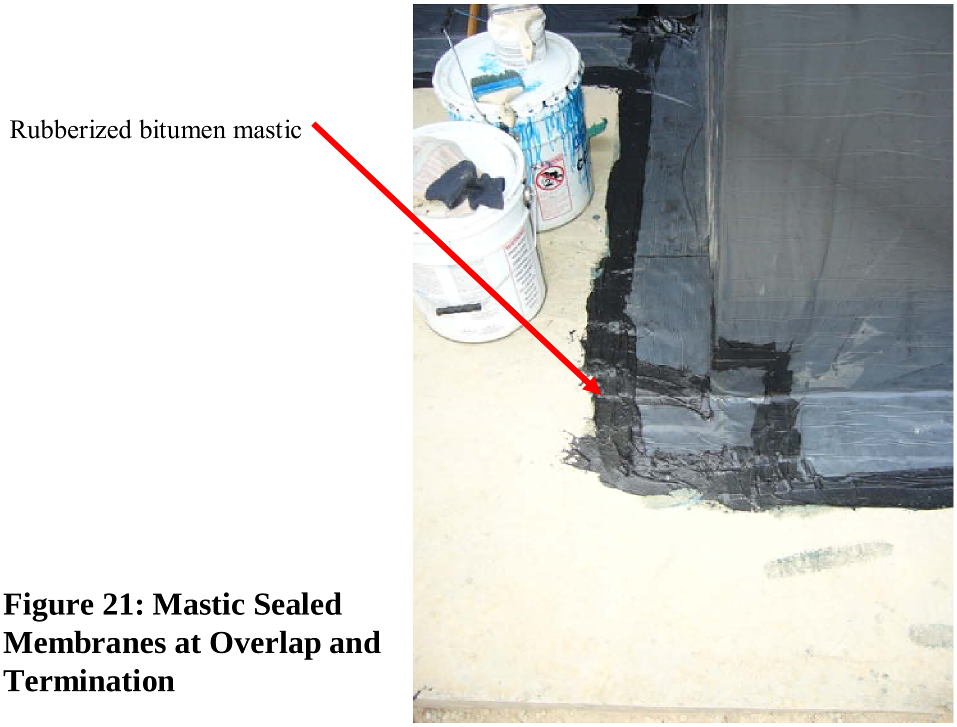


Figure 21: Mastic Sealed Membranes at Overlap and Termination

An extremely vital aspect of waterproofing especially membrane installation is craftsmanship. Designers, contractors and building owners should specify a well defined and implemented quality assurance and inspection program. Improperly installed membranes that allow water penetration can be extremely costly to repair and may render interior subterranean spaces unusable. Flaws in installation must be identified and corrected prior to back filling. Henshell (2000) recommends that installers be certified or approved by manufacturers and that first day's work be inspected by a technically qualified manufacturer's representative. Granted such extremes are not likely to occur for residential construction projects; however, it is important for homeowners and contractors to know what right and wrong looks like in order to hold installers responsible for work and preserve indoor building quality. Appendix C is a pictorial slide show providing examples of correct and incorrect waterproofing techniques.

The final step in ensuring membrane integrity is the installation of a protective layer prior to backfilling. Membranes both spray and sheet are extremely vulnerable to punctures from back filled aggregate or ongoing site construction mishaps. In order to preserve membrane integrity, polystyrene boards, usually ½ inch thick, are installed with adhesives directly over the membranes. Figure 22 depicts the installation of polystyrene over a membrane.

Figure 22: Installation of Protective Polystyrene Boards Over Sheet Membranes

Combination of Materials

Alfred North Whitehead, a prominent English mathematician, once said "Every really new idea looks crazy at first." Such a quote eerily resembles the construction industry. Change in the construction industry comes very slow. The following section will explore combinations of materials in order to maximize installation effectiveness and hopefully eliminate some of the possible craftsmanship errors during waterproofing.

The combination of two or more materials during a waterproofing process may eliminate labor force demands as well as reduce packaging waste and overall energy demands. For example, the combination of drain mats and polystyrene boards will eliminate the redundancy of installing both materials separately. Rather than providing drain mats in pre-packaged rolls, manufacturers could adhere drain mats to polystyrene in a factory environment. Typically, polystyrene is installed before the drain mats. However, if manufacturers combine the two elements in a factory environment, the polystyrene and drain mats could be installed at the same time thus eliminating the labor hours required to install both materials separately. Additionally, a combination of materials would eliminate the packaging required for both the drain mats and polystyrene as well as the possible energy costs of delivery for two different materials.

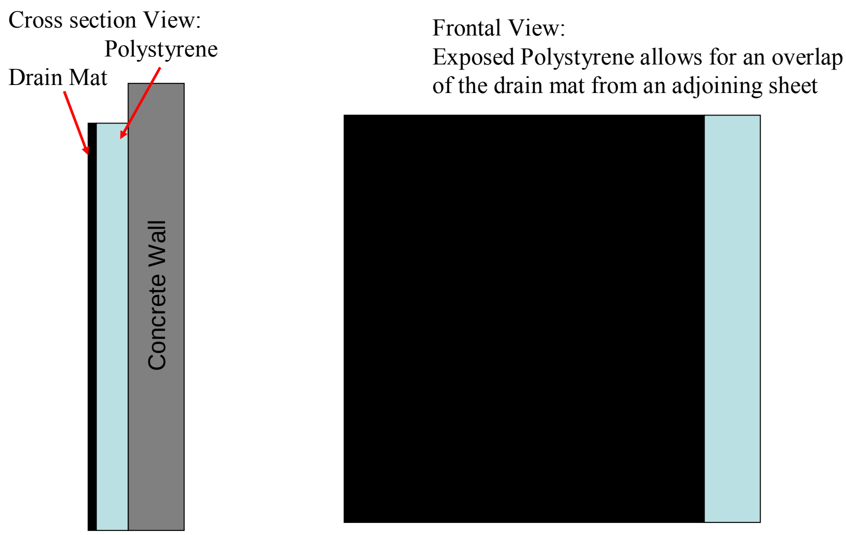


Figure 23: Design of Polystyrene/ Drain Mat Combination

Figure 23 above, depicts a possible combination of polystyrene and a drain mat. Manufacturers may adhere the drain mats with one side extending over the polystyrene by 4 to 6 inches. The other side of the polystyrene will be exposed with no drain mat. This will allow for an overlapping or shingling effect along the distance of the foundation wall. The same principle can apply with an excess of drain mat on the bottom of the polystyrene to allow for overlap as the sheets are placed farther up a foundation wall.

One step beyond the combination of materials is the modularization of a waterproofing system. Such a system will incorporate the drain pipe, filter fabric, coarse aggregate around the drain pipe, drain mat and polystyrene. All of these materials will be enclosed into one compartment. Such a system will be place against a foundation wall once a waterproofing membrane has been installed. Like the polystyrene/drain mat combination, the system will come in standard sizes and will be placed along foundation walls and link together through clips and male and female ends of drain pipes. Figure 24 shows a frontal view of the system with male and female drainpipe ends. The challenges associated with such a system are reducing weight and creating a retaining system to hold all of the components together.

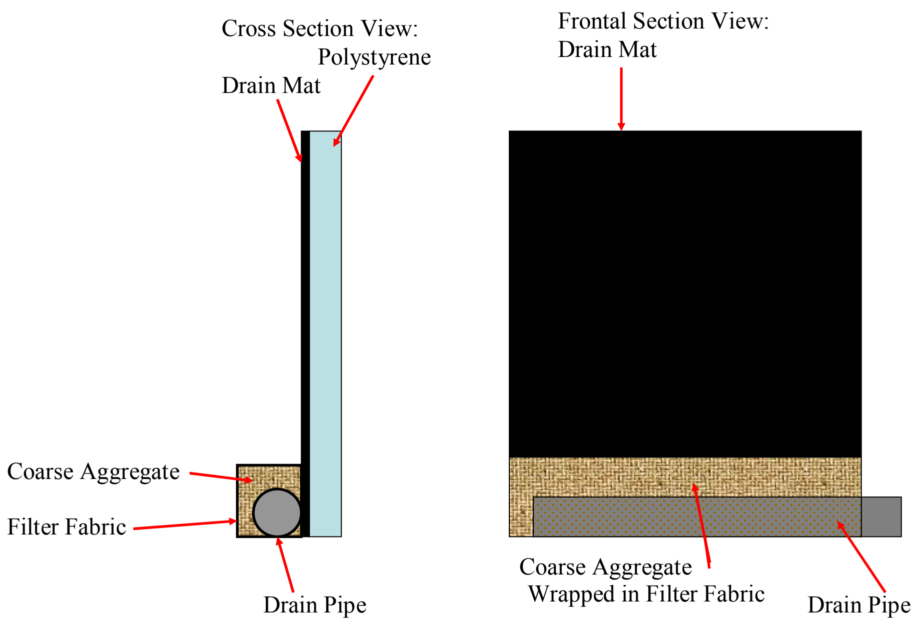


Figure 24: View of Modularized Waterproofing System

A major factor in the weight of the system is the type of coarse aggregate used. A system incorporating typical #57 stone would be too heavy to be placed by human labor. The true challenge is designing a system that utilizes a light weight, durable and crush resistant coarse aggregate. Possible alternatives for lightweight aggregates would be some form of a plastic or polyethylene. An additional challenge is the mechanism used to retain the entire system. Possible alternatives would be again a durable plastic with voids, like a milk crate, that could contain the interior components while allowing the inflow of water. Additionally some form of thin gauge wire or mesh could be used such as gabion baskets. The idea of modularizing or combining components needs further development both by manufacturing companies and on site installers.

Conclusion

Waterproofing is an integral part of preserving not only the components of a building and interior spaces but also human health. The intent of this paper's analysis and comparisons of soil types, building foundations and waterproofing techniques is to help building owners, contractors and manufacturers properly safeguard the built environment. Simplifying this process is the table below, which summarizes the three waterproofing techniques and their ideal installation situations.

Waterproofing Method			
	Capillary Blocking/ Cementitious	Damp Proofing	Membrane Waterproofing
Ideal Foundation Type/Usage	Civil Projects (swimming pools, tunnels, waste water treatment facilities, elevator/escalator pits)	Slab on Grade Foundations; Buildings with Crawl Spaces or Slightly Below Grade Foundations	All Subterranean Spaces; Basements; Plazas
Moisture Tolerance Within a Building	Recommended if Moisture Risk is Unacceptable	Not Recommended if Moisture Risk is Unacceptable	Recommended if Moisture Risk is Unacceptable
Soil Type	All	Sand, Silt, Sand/Silt	All
Hydrostatic Pressure Tolerance	No (Capillary Blocking) Yes (Cementitious)	No	Yes
Application Skill Level	High	Low	High
Overall Strength	High Durability	Ease of Application	Ability to Span Foundation Cracks up to 1/16 inch; Effective Against Hydrostatic Pressure
Overall Weakness	System is Compromised if Foundation Cracks	Ineffective Against Hydrostatic Pressure; Compromised if Foundation Cracks	Application Requires a High Skill Level; Once Installed Extremely Vulnerable to Damage
Comments	System Requires a Cant along Prepared Surfaces; 3 to 5 Coats and a 24 to 48 hour Curing Period	Application Options Include Spray, Roller, Trowel or Sheet Wrap	Proper Protection and Backfilling is Recommended as soon as Possible

The following example, explains how to use the above chart. An individual wants to construct a two story, two-car garage with living space on the second floor. The landowner does not know the specific type of the soil on their property. The proposed site is located on one of the lowest points relative to the surrounding land and is very close to a natural drainage path, which is seasonally active. The foundation of the garage will consist of a slab slightly below grade. From the first row in the chart (Ideal Foundation Type/Usage) for a foundation slightly below grade, damp proofing and membrane waterproofing are the ideal choices. Capillary/cementitious waterproofing is more suited for heavy civil engineering projects. Figure 25 explains the decision criteria from the information provided in the chart above.

Hypothetical Facts:
-Foundation: Slightly below grade
-Soil Type: Unknown
-Site Location: Low point based of surrounding land
-Other Issues: Site location is near a seasonal natural drainage area

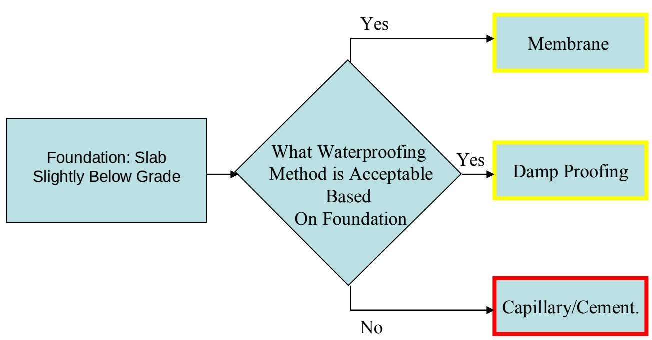


Figure 25: Flow Chart for Foundation Type

The next major decision centers around the tolerance of moisture within the structure (Moisture Tolerance Within a Building). Due to the desire to have livable space above the garage, the tolerance for moisture is zero. In an ordinary garage, some moisture would be acceptable; however, in this situation, in order to preserve human health the building must be as free as possible from excess moisture. Figure 26 outlines the decision, which recommends membrane waterproofing. In the Waterproofing

Method Chart, cementitious waterproofing is also recommended if moisture risk is unacceptable; however, this method is not viable due to the project scope.

Hypothetical Facts:
-Foundation: Slightly below grade
-Soil Type: Unknown
-Site Location: Low point based of surrounding land
-Other Issues: Site location is near a seasonal natural drainage area

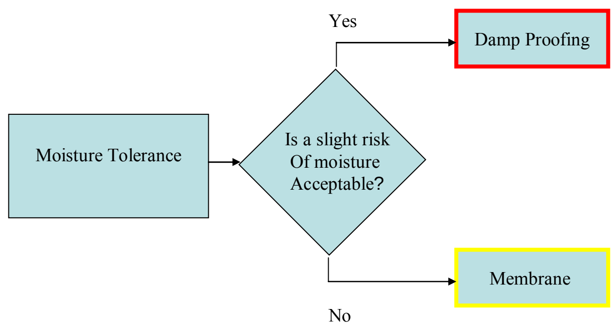


Figure 26: Flow Chart for Moisture Tolerance

The final major decision point is the presence of hydrostatic pressure (Hydrostatic Pressure Tolerance). Because the garage is very near and during extreme cases in the path of a seasonal natural drainage path, the possibility of hydrostatic pressure against the foundations is extremely likely. Figure 27 displays the decision to select again either cementitious or membrane waterproofing due to their abilities to withstand hydrostatic pressure. Again, due to project scope, cementitious waterproofing is eliminated from selection.

Hypothetical Facts:
-Foundation: Slightly below grade
-Soil Type: Unknown
-Site Location: Low point based of surrounding land
-Other Issues: Site location is near a seasonal natural drainage area

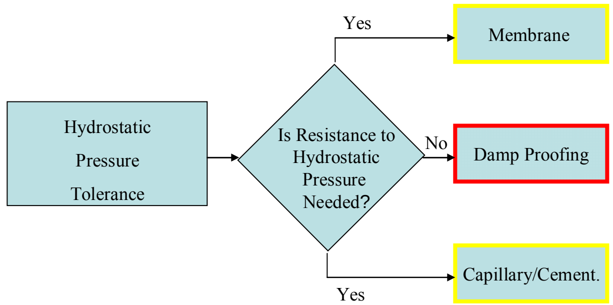


Figure 27: Hydrostatic Pressure Tolerance

From the project scope, foundation type, moisture tolerance and the possibility of hydrostatic pressure, membrane waterproofing is the best type of waterproofing system. The final analysis focuses on the instillation of the membrane Application Skill Level). If the homeowner is experience and comfortable with self-installation of membrane waterproofing then self-performance is recommended. However, due to the high level of skill required to properly and successfully apply a membrane system, if the homeowner is not skilled in application, a professional waterproofing company should be called for membrane installation.

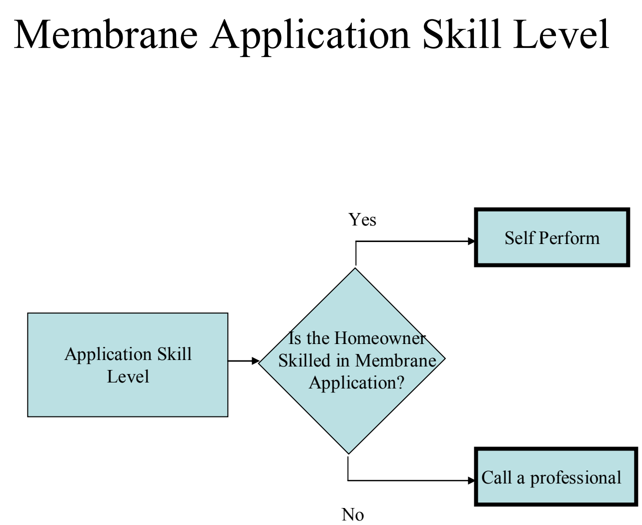


Figure 28: Application Skill Level

Along with the importance of understanding the proper uses and situations of the different waterproofing systems is the exploration of combining or modularizing waterproofing materials. Combination and modularization of materials has the potential to revolutionize the waterproofing industry. Further research is needed in order to create a system that not only proves to be less labor intensive but more importantly will be accepted universally across the construction industry. Finally, Appendix 1 provides a product list for common waterproofing materials. Though this list is not inclusive, it represents significant number of manufacturers and proprietary products.

Figure 29 illustrates a map of the playing field for this study as well as the key players who may possibly benefit from this report. The three circles represent the primary players. Building owners will ultimately benefit from having materials installed properly and in the correct context. By having successful waterproofing systems implemented in the proper situations, buildings interiors will remain dry. Contractors and developers will primarily benefit from understanding the dynamics of soils, site preparation, craftsmanship issues and material options. Product manufacturers may develop new system components or modularized materials that will not only assist contractor installations but also streamline manufacturing processes. These three stakeholders revolve around waterproofing products which they rely on, install and produce. By increasing the effectiveness of waterproofing products, systems and installation techniques, the likelihood that building interiors will remain dry increases. Additionally, efficiency of material production and installation will reduce other costs associated with waterproofing such as labor. Lastly, affordable products and product delivery will benefit all stakeholders involved.

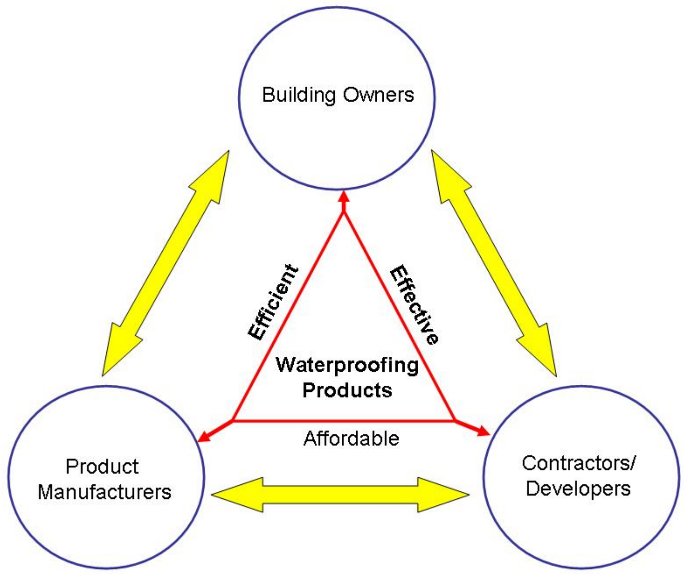


Figure 29: Key Players and Benefits

The completion of this study has yielded several topics, which require further research in order to benefit and safeguard the construction industry. Future research studying the following topics will provide the key players with more knowledge, better products and more sound installation practices.

- the modularization of waterproofing materials
- the remediation of existing structures suffering from water damage
- the blockage of water and water vapor movement through joints and other material interfaces around building envelopes
- the blockage of water and water vapor movement from under slabs and foundation/slab joints

Two possible challenges that should be considered prior to the study of the aforementioned topics are laboratory experiments and funding for material purchases.

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The purpose of this study is to describe a case history of moisture migration through basement walls at a condominium project. The major issues studied was a sub surface exploration at the condominium that revealed the upper .4-.5 m of basement wall did not have a waterproofing membrane. The author concludes that common deficiencies that contribute to moisture migration through basement walls can be mitigated. For example, noticing the height of the waterproofing membrane in relation to the final finish ground surface during construction should have alerted the developer to the problem.

Day, R. (1996). Moisture Penetration of Concrete Floor Slabs, Basement Walls and Flat Slab Ceilings. Practice Periodical on Structural Design and Construction, 1 (4).

The purpose of this study is to describe structural design and construction details to mitigate the effects of moisture migration through concrete floor slabs, basement walls, and flat slab ceilings. The major issues studied are the mechanisms of moisture mitigation, damages, ways to test moisture and vapor flow rates, and design and construction techniques that may mitigate damages. The author concludes that the main structural feature to prevent both water vapor and capillary rise through floor slabs are a moisture barrier and open graded gravel layer. Additionally, flat slab ceilings should have drainage, sealed joints and contractors should prevent cutting holes through flat slab ceilings.

Edwards, S. (2006). The Leaking Basement Epidemic-Causes, Cures and Consequences. Forensic Engineering, ASCE.

The purpose of this study is to look at the causes, financial ramifications, and ideas on mitigation of leaking basements. The author concludes that a vast number of older houses suffer from systemic failures involving downspout drains, poor design decisions resulting in unstable lateral loads causing high hydrostatic pressure developments. These factors combine to cause leaky basements and loss of property value. The major issues studied: overall drainage system of the house; attempted and failed remediation techniques for leaking basement walls over the years; water action around the house; soil/hydrostatic pressure against the basement walls.

Henshell, J. (2000). The Manual of Below-Grade Waterproofing Systems. John-Wiley, New York.

Henshell's book goes into detail describing the different materials and components associated with below-grade waterproofing. He specifically compares the different material options and their strengths and weaknesses in certain situations. Overall, this is a very comprehensive and technically written book.

Institute of Medicine of the National Academies.(2004). Damp Indoor Spaces and Health. The National Academies Press, Washington, D.C.

As the title suggests, this book provides in depth and thorough analysis of the affects of moisture on the human body. Specifically, this piece provides fantastic statistics and studies of damp environments. This book provides several key figures regarding water damage in U.S. houses.

Kubal, M. (1999). Construction Waterproofing Handbook. McGraw-Hill, New York.

This handbook discusses the overall waterproofing of the entire building envelope. The author provides in-depth and detailed pictures to accompany the easy to follow text descriptions. This book is very useful in describing the need for specific waterproofing materials and proper installation techniques. I specifically used this book to better understand the characteristics and proper uses of backer rod and the techniques of waterproofing parapet walls.

Mailvaganam, N. and Collins, P. (2004). "Workmanship Factors Influencing Quality of Installed parking Garage Waterproofing Membranes." Journal of Performance of Constructed Facilities, 18 (3).

The purpose of this study is to investigate the influence of workmanship factors and surface preparation on the performance of five elastomeric membranes. The major issues studied were the tensile properties of applied membranes, allowed water vapor transmission, and the adhesion of membranes to concrete under different application conditions. The author concludes that low temperature effects are routinely encountered, delayed application coupled with cold hinders the development of the tensile strength, poor on-site quality control effects membrane thickness which results in questionable ability to prevent ingress of water and chloride ions.

The National Roofing Contractors Association Waterproofing and Dampproofing Manual. (1989). National Roofing Contractors Association, Illinois.

This manual provides a brief description of the overall above and below grade waterproofing procedures, material options and instillation procedures. Despite being slightly dated, this manual has 14 easily understandable drawings showing various waterproofing situations and the required layering of materials.

Oliver, A. (1997). Dampness in Buildings. 2nd ed. Blackwell Science, London.

Oliver takes a very scientific approach in describing the characteristics of water and moisture movements and how they effect building materials and penetrate building envelopes. I specifically used this book to better understand the techniques of waterproofing roofs and parapet walls.

ODELL. (2007). Construction Drawings for Reynolds Office Building. ODELL Associates Inc., Richmond.

Constructions drawings provided the intended plan and materials for one technique of foundation waterproofing.

Perkins, P. (1997). Repair, Protection and Waterproofing of Concrete Structures. 3rd ed. E & FN Spon, New York.

This book focuses on the characteristics, maintenance, preservation and repair of concrete. This very technical and in-depth book is slightly difficult to understand if the reader is not familiar with concrete structures. I used this book to better understand the effects of harsh environments, specifically saltwater, on concrete structures.

Rose, W. (2005). Water in Buildings. Wiley, New Jersey.

Rose focuses on the causes and effects of water penetration into buildings. This book specifically focuses on mold and decay caused by moisture and condensation. At times, the scientific formulas of water and moisture movement through building materials are confusing; however, the historical background of building design is very helpful. I specifically used this book for understanding moisture issues in attics and roof ventilation.

Appendix 2:

Methodology

This project and report focuses on data collection through literature review, published materials, manufacturer web pages and product specifications. Primary areas of focus and research include but are not limited to Piedmont soils in Virginia, basic waterproofing techniques and practices, and materials for waterproofing. In narrowing and describing focus areas, this paper attempts to cover work believed to be influential in shaping a common understanding and of relative importance to understanding the importance of moisture free indoor environments.

Information on the effects of human health from damp indoor environments was collected from journals and text from the Institute of Medicine, the Center for Disease Control and other medical sources. Information on soils and waterproofing techniques were gathered from textbooks and web pages. From extensive research, relatively few papers or peer reviewed literature were identified that addressed building construction or maintenance issues directly relating to foundation waterproofing. Text, studies and journals were identified through extensive searches of library, internet and relevant databases. In order to expand the literature review, references and citations of books were researched for relevant sources.

When reviewing all publications but more importantly manufacturer's web sites and product specifications it is paramount to remain unbiased. This paper does not produce or provide product comparisons or recommendations based on cost, manufacturer or any other criteria. Products are listed in like categories based on waterproofing techniques. For example, if a product is advertised or described as a drain board by the manufacturer, the product will be listed as such. Additionally, this paper is mindful of products, procedures or studies that show a positive association that is over represented in literature.

An Analysis of Waterproofing Systems and Materials

Brandon Shell

Agenda

- **Introduction**
- **Background**
- **Water Movement and Soils**
- **Building Types**
- **Waterproofing Techniques**
- **Universal Waterproofing Materials**
- **Combination of Materials/Modularization**
- **Conclusion**
- **Questions**

Introduction: Why Study Waterproofing

What: Water damage in shaft assembly during construction

Cost: Clean, demo, and rebuild - **$500,000**

Impact: **2 month** delay on scheduling

Picture and statistics received from Patrik Lazzari from Yates Construction

Introduction: Why Study Waterproofing

What: Water infiltration through slab during construction

Cost: Clean, demo and rebuild **$80,000**

Impact: **1 month** delay on scheduling

Picture and statistics received from Patrik Lazzari from Yates Construction

Introduction: Why Study Waterproofing

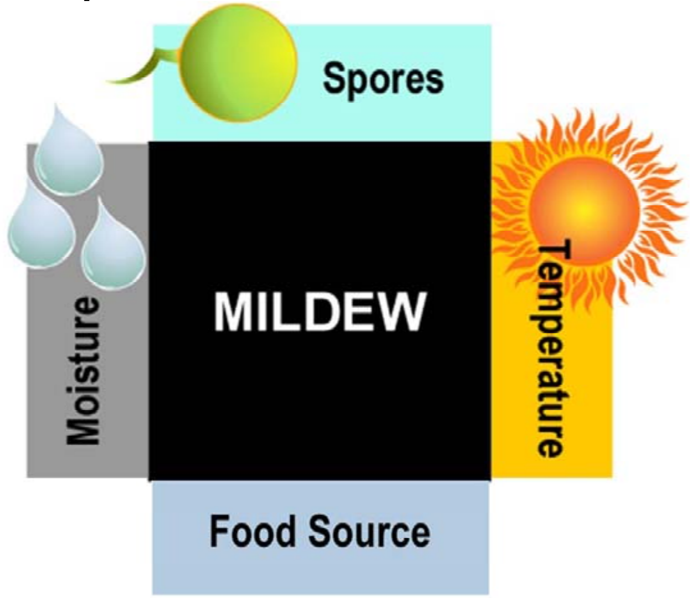
What: Wide spread mold growth in a stair well

Cost: Demo and site rework **$200,000**

Impact: Building occupant inconvenience due to construction, loss of builder reputation-incalculable

Picture and statistics received from Patrik Lazzari from Yates Construction

Components of Mold/Mildew



Effects of Mold/Mildew

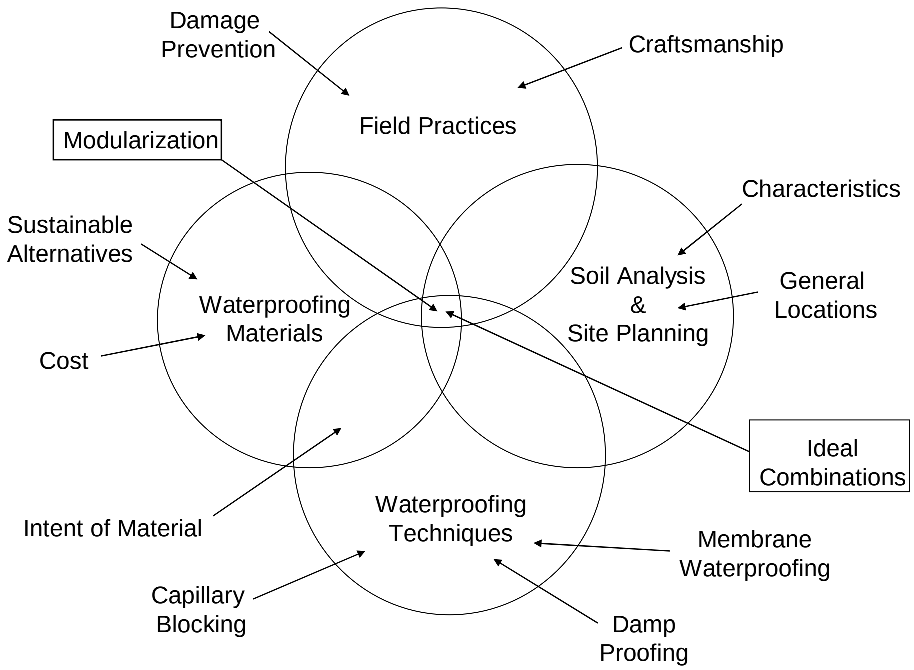
Effects on Human Health

Poor Indoor Air Quality = Poor Human Health

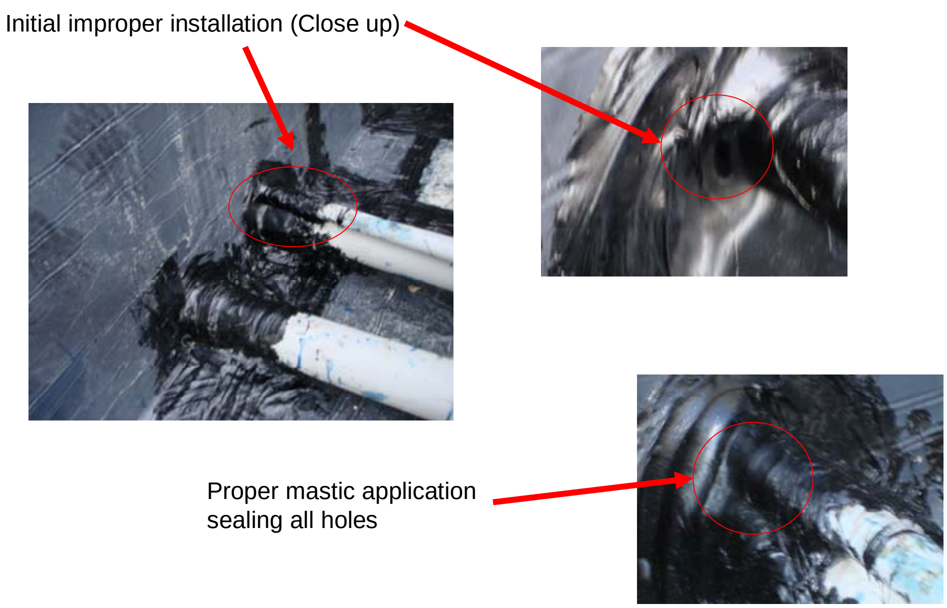
- Respiratory Conditions
  - Coughing
  - Asthma
  - Wheezing
- Skin Ailments
  - Eczema
- Headaches
- Fatigue
- Sick Building Syndrome (SBS)

Background

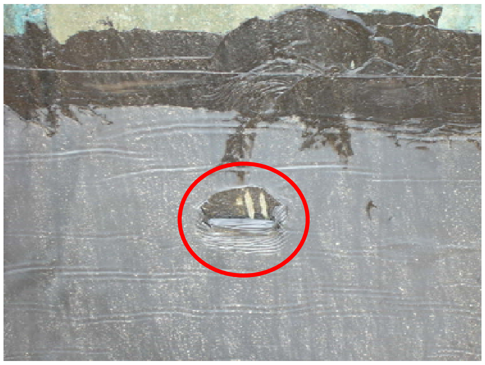
- Domain Map
  - Field Practice
  - Soil Analysis and Site Planning
  - Waterproofing Techniques
  - Waterproofing Materials
  - Areas Needing Further Research
    - Modularization
    - Ideal Combinations



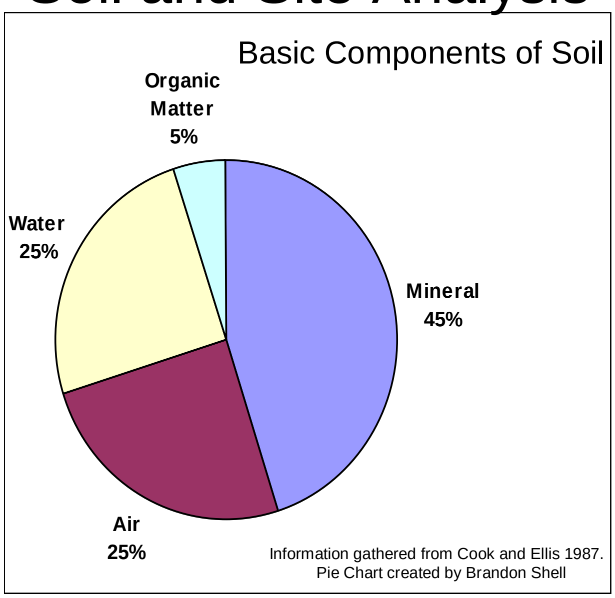
Field Practice



Field Practice



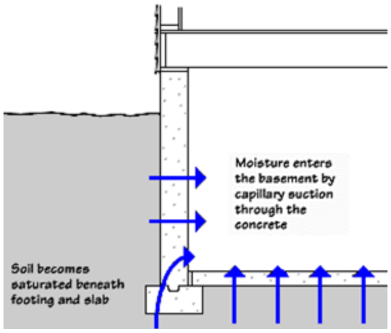
Soil and Site Analysis

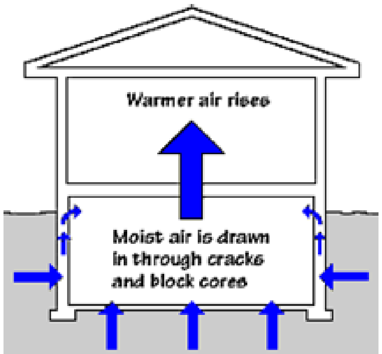


Soil and Site Analysis

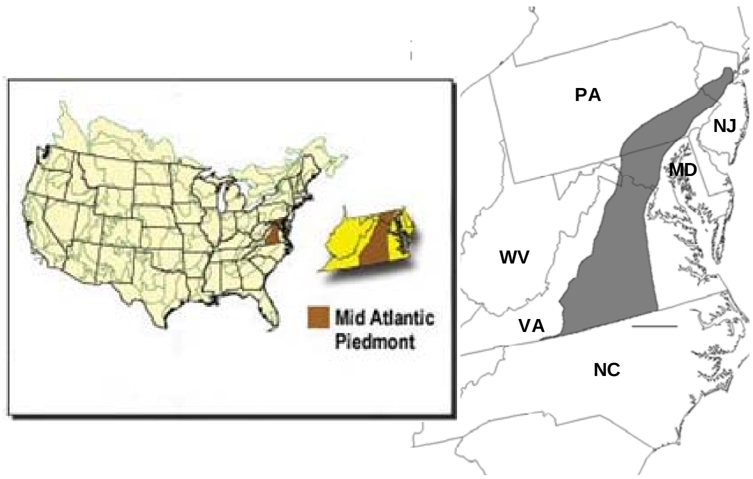
Height of Capillary Moisture Rise		
Soil Type	**Saturation Zone (ft)**	**Capillary Rise (ft)**
Sand	**1-5**	**3-8**
Silt	**5+**	**8+**
Clay	**5+**	**8+**
Loam	**3+**	**6+**
Gravel	**0**	**0**
Table from Beall 1998 adapted by Brandon Shell		

Soil and Site Analysis





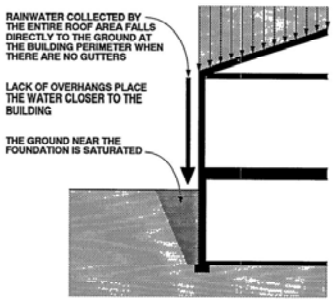
Soil and Site Analysis



Soil and Site Analysis

- Piedmont Region
  - Approximately 161 km wide and 1290 km long
  - Between the Blue Ridge Mountains and the eastern Coastal Planes
  - Predominant rock structure: metamorphic rock; patches of granite and silica
  - Soils: silt to medium sandy silt
  - Average depth: 20 to 80 inches
- Blue Ridge Mountains: created a situation where soils exhibit characteristics of both fine grained (un-drained) and coarse grained (drained)
  - Random fashion, high variability over short distances

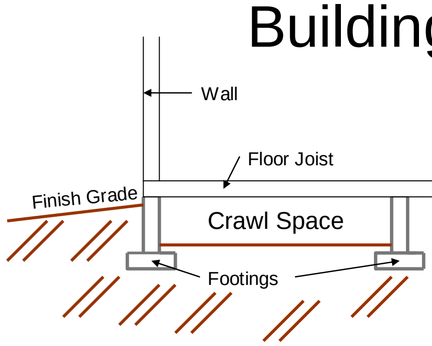
Soil and Site Analysis

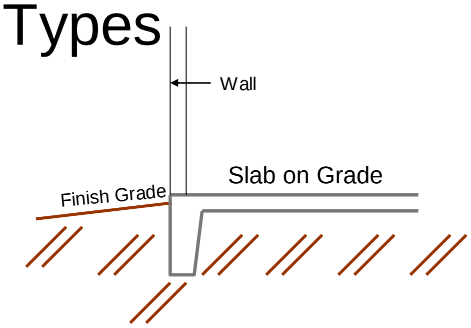


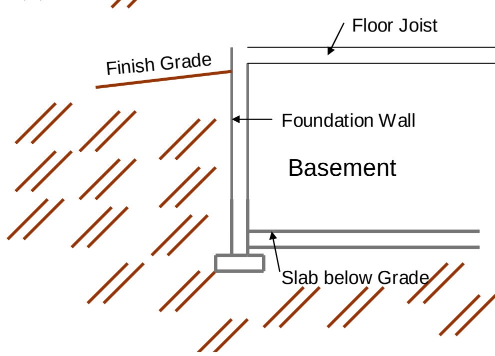
Picture was taken from Lstiburek and Carmody's "Moisture Control Handbook

Case Study by Edwards
Situation: Home for sale for $790,000
Problem: Leaking Basement Walls
Reason for Leaks: Constantly Saturated Soil
Solution: $24,000 to repair
Final Home Sale: $555,000

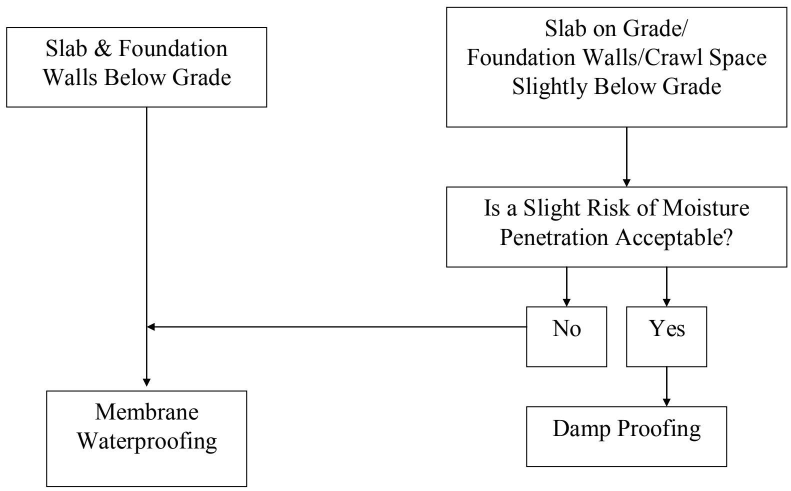
Building Types







Tolerance to Moisture



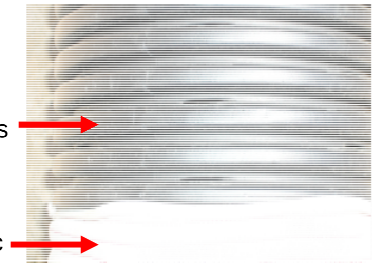
Waterproofing Techniques

- Cementitious/Capillary blocking

- Damp proofing

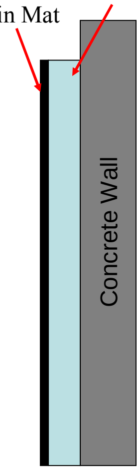
- Membrane waterproofing

Universal Waterproofing Materials

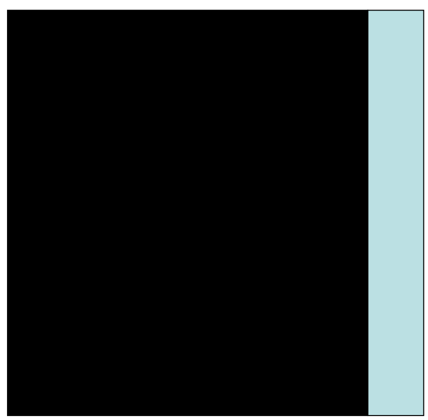


Combination of Materials

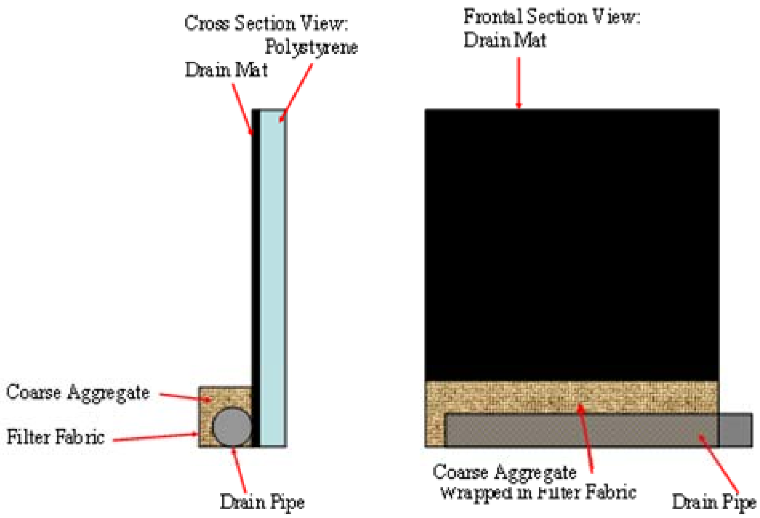
Cross section View:



Frontal View:
Exposed Polystyrene allows for an overlap of the drain mat from an adjoining sheet



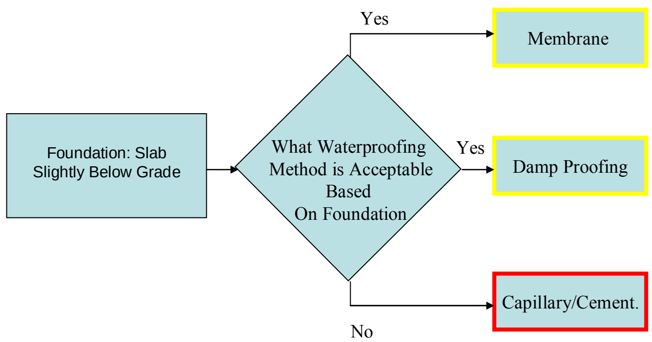
Modularization



Waterproofing Method			
	Capillary Blocking/ Cementitious	Damp Proofing	Membrane Waterproofing
Ideal Foundation Type/Usage	Civil Projects (swimming pools, tunnels, waste water treatment facilities, elevator/escalator pits)	Slab on Grade Foundations; Buildings with Crawl Spaces or Slightly Below Grade Foundations	All Subterranean Spaces; Basements; Plazas
Moisture Tolerance Within a Building	Recommended if Moisture Risk is Unacceptable	Not Recommended if Moisture Risk is Unacceptable	Recommended if Moisture Risk is Unacceptable
Soil Type	All	Sand, Silt, Sand/Silt	All
Hydrostatic Pressure Tolerance	No (Capillary Blocking) Yes (Cementitious)	No	Yes
Application Skill Level	High	Low	High
Overall Strength	High Durability	Ease of Application	Ability to Span Foundation Cracks up to 1/16 inch; Effective Against Hydrostatic Pressure
Overall Weakness	System is Compromised if Foundation Cracks	Ineffective Against Hydrostatic Pressure; Compromised if Foundation Cracks	Application Requires a High Skill Level; Once Installed Extremely Vulnerable to Damage
Comments	System Requires a Cant along Prepared Surfaces; 3 to 5 Coats and a 24 to 48 hour Curing Period	Application Options Include Spray, Roller, Trowel or Sheet Wrap	Proper Protection and Backfilling is Recommended as soon as Possible

Example: Garage with Living Space

Hypothetical Facts:
-Foundation: Slightly below grade
-Soil Type: Unknown
-Site Location: Low point based of surrounding land
-Other Issues: Site location is near a seasonal natural drainage area



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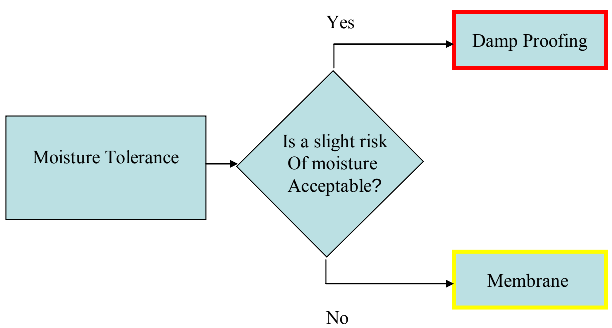

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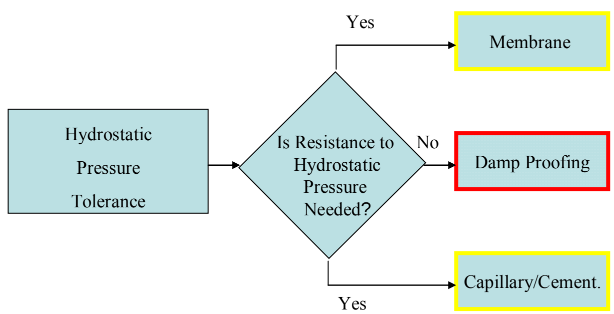
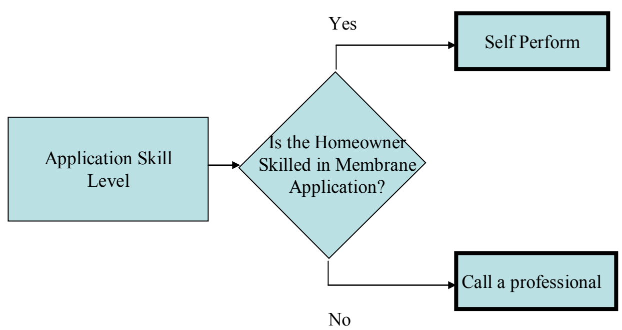


Example: Garage with Living Space

- Results
  - Foundation Criteria
    - Membrane
    - Damp Proofing
  - Moisture Tolerance
    - Membrane
  - Hydrostatic Pressure Tolerance
    - Membrane
    - Capillary/Cementitious
- Selection = Membrane

Example: Garage with Living Space

Membrane Application Skill Level



Questions?