The Manual of Below-Grade Waterproofing

The ever evolving technology of waterproofing presents challenges and risks for architects and engineers who do not specialize in the field. The revised edition of *The Manual of Below-Grade Waterproofing* provides the education and product information to enable designers to take a sound, fundamental approach to these contemporary challenges.

Building designers specify waterproofing systems and materials that are often based on limited and subjective manufacturers’ literature or past experience with systems that work under specific conditions, but will fail in other installations. Leakage usually leads to litigation. This book gives you the tools to prevent that.

This manual covers the history and science of waterproofing materials, the considerable distinctions between waterproofing roofs and plazas and below-grade surfaces, the critical procedures for protecting waterproofing materials during construction, diagnosing and remediating leaks, writing specifications, and detailing waterproofing components. The pros and cons of every waterproofing material and system are comprehensively covered. You will learn how to:

- weigh up positive- versus negative-side waterproofing systems;
- weigh up dampproofing versus waterproofing;
- coordinate with all the professionals in the waterproofing delivery chain; and
- follow environmental protection and government regulations.

This book is an essential resource for architects, civil engineers, contractors, designers, materials manufacturers, and all other professionals involved with the design and construction of underground spaces.

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The Manual of Below-Grade Waterproofing

Second edition

Justin Henshell
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Notes
1 Deceased.
2 Ibid.
3 Ibid.
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Among more than 100 below-grade waterproofing projects on which the firm has consulted are: Whitney Museum of American Art, New York; Wharton School of Business, University of Pennsylvania; Transbay Transit Center, San Francisco; Terminal C, Dubai Airport; Hudson Yards, New York; Glenstone Museum, Potomac, MD; Memorial Sloan Kettering, New York; and Museum for Westward Expansion, St. Louis.

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1 Introduction

A. What is waterproofing?

In this manual, in accordance with ASTM usage, *waterproofing* means a system designed to resist hydrostatic pressure exerted by moisture in a liquid state. It is differentiated from dampproofing, which is designed merely to resist the flow of moisture in a gaseous state (i.e., water vapor). See Chapter 3 “Dampproofing,” and Chapter 5 “Waterproofing,” for a detailed explanation of this distinction.

*Waterproofing* is often erroneously defined as a coating applied to above-grade masonry or concrete walls; a membrane cover on spandrel beams; a membrane in split-slab construction under a mechanical or shower room; a coating on a parking garage, in a tank, or pool; as well as four different treatments of below-grade foundation walls and slabs.

A subtler source of semantic confusion is distinguishing between a waterproofing system and a low-slope roof system when the roof system is a so-called Protected Membrane Roof (PMR) assembly. In a PMR, the membrane is placed directly on the deck below the insulation, instead of in its conventional, weather-exposed location atop the insulation. When a PMR is ballasted with concrete pavers, it resembles a waterproofed plaza. A roof plaza can, in fact, be identical to a waterproofed plaza at or below grade.

The distinguishing feature differentiating a PMR from a waterproofed plaza system is the accessibility of the membranes in the event of failure. This feature is the basic determinant of manufacturers’ willingness to issue guarantees. Manufacturers will generally guarantee a PMR if pavers are installed on pedestals, in which case the membrane is accessible. Most manufacturers will guarantee PMR systems in which pavers, serving as ballast or maintenance walkways, are loose-laid on the insulation. (In industry semantics, such a system is not considered to be plaza waterproofing.) If, on the other hand, the membrane is inaccessible – with wearing surface-units (such as brick, tile, or stone) installed in a mortar setting bed or in sand over a concrete protection slab – then the system is classified as waterproofing, and manufacturers will not guarantee it.
A guarantee should, however, be a secondary consideration. You should select a PMR system only if your primary goal is to provide a client with the dubious assurance of a manufacturer’s warranty. If a lower-risk system assuring long service life in a continuously moist environment over a moisture-sensitive space is your primary goal, then a waterproofing system is a more prudent selection.

Another source of semantic confusion is distinguishing between a below-grade waterproofing system and a plaza waterproofing system. Though both are used below grade, very few plaza waterproofing systems are designed to resist significant hydrostatic pressure.

B. Using this manual

You do not need to read this manual cover-to-cover to gain practical guidance. The table of contents and index (or keyword search, if you are reading an eBook edition) should direct you to the material that will help with your current need. Each chapter covers individual waterproofing topics in depth. Cross-references are provided within chapters to direct you to additional relevant material.

The objective of the manual is to help you avoid waterproofing system failures. Manufacturers of roof waterproofing systems provide considerably more selection, design, and installation support than manufacturers of below-grade waterproofing systems do. This manual is dedicated filling that gap as well as providing a sound, fundamental approach to waterproofing problems.

C. Manual’s scope and limitations

This manual focuses on waterproofing of below-grade, habitable building spaces subject to hydrostatic pressure, as well as dampproofing. It is therefore limited to covering waterproofing and dampproofing for the following underground building components:

- structural concrete slabs with a wearing surface or earth fill;
- concrete slabs-on-ground below-grade elevation; and
- foundation walls.

Waterproofing (and dampproofing) for the following structures are not covered:

- water-containment vessels;
- vehicular, pipe and similar tunnels not enclosing habitable space;
- above-grade mechanical room floors (not exposed to groundwater or soil chemicals);
- traffic toppings or traffic-bearing waterproofing systems for vehicles
and balconies offering short-term protection, but not resistance to hydrostatic pressure; and
• green vegetative roofs.

This manual is not a substitute for the professional expertise required to design a waterproofing system. It illustrates general design principles. As most waterproofing projects have unique aspects, you will not simply be able to copy details provided here. You will need to adapt them to your project. In some cases, details provided by manufacturers will be more relevant than the general details included in Chapter 17.

Because waterproofing technology is rapidly changing, some systems presented herein may be obsolete or superseded by others as you read this.

D. The importance of waterproofing

Urban planning critics, who discuss the purely architectural aspects of plaza design with informed expertise, normally ignore the functional aspect: The unseen waterproofing system required to sustain these aesthetic triumphs. Space under the street-level plaza, located on prime land sometimes priced at four digits per square foot, is inevitably dedicated to high-level occupancies in which the slightest leakage is intolerable.

A waterproofing system should ideally last the full service life of the building. Thus, durability is the first principle of waterproofing design. Most building systems can be designed for service lives far short of projected building service life. Air-conditioning equipment, lighting, office partitions, communications, even elevators, curtain walls, and roofs can be designed for anticipated replacement as they either become obsolete or wear out under constant weathering. A waterproofing system, however, is like a foundation and structural framework in its need for endurance.

The importance of durability is illustrated by industry practices. Few waterproofing manufacturers offer guarantees or useful warranties, yet manufacturers usually do support roofing materials. The few warranties available are for severely limited liability, for two major reasons:

1. Waterproofing for foundations and under slabs-on-ground is often inaccessible.
2. Replacement of waterproofing systems under plazas may require removal and replacement of tons of overburden or jackhammering removal of concrete protection slabs and concrete topping.

Such drastic remedial action sometimes costs more than 300 times the membrane’s cost. That risk motivates prudent designers to ignore first-cost economy when it entails any risk of failure. Prudent designers select systems and materials that will work, regardless of a few dimes per square foot cost increase. They also require:
approved applicators for installing waterproofing systems;
• rigorous quality assurance (QA) inspection programs during installation; and
• flood-testing, whenever practicable.

While the problems of modern waterproofing have multiplied, advances in waterproofing technology have multiplied at an even faster rate, giving you a vastly expanded selection of new systems and materials. Modern polymer chemistry expands your arsenal of weapons against leakage while complicating the problem of selecting the proper combination of systems or materials.

E. The boom in demand for waterproofing

The growing demand for a greater quantity and higher quality of waterproofing in building construction has a simple explanation. The rapid proliferation of air-conditioning following World War II made windowless underground spaces feasible for human occupancy. Before that, underground spaces were severely limited by the practical inability to control interior temperature, humidity, and circulating air quality for comfortable, healthy habitation. The advent of air-conditioning created a demand promoted by many interrelated factors:

• space needs for expanded mechanical plants
• space needs for windowless functions
• trend toward water-shedding curtain walls
• sites with poor drainage
• incentive zoning for open, street-level plazas
• rise in HVAC energy costs
• rising cost of waterproofing failures

Space needs for expanded mechanical plants grew with the demand for sophisticated HVAC systems, electronic data processing centers, and other new technologies in the postwar building boom. The rudimentary building mechanical equipment preceding the 1950s seldom required deep basements. Huge chillers and other mechanical equipment for office skyscrapers created a demand for more underground space. Basements, sub-basements, and even sub-sub-basements were excavated to accommodate this equipment (see Figure 1.1).

Space needs for windowless functions include many functions best conducted in an environment usually isolated from the outside world. As underground locations are necessarily windowless, they are prime locations for a broad spectrum of occupancies: theaters and similar audio-visual uses, archives, mainframe computers, electronic switch gear, parking, retailing, and bowling alleys.
The trend toward water-shedding curtain walls aggravated building waterproofing problems. The traditional masonry walls of pre-World War II construction absorbed substantial quantities of rainwater and shed it by evaporation in a cyclical wetting-drying process. Glass and metal wall panels shed this water rapidly via vertical flow directly to the foundation soil. Accumulation of storm water at the foundation thus magnifies drainage and waterproofing problems at the building basement.

Sites with poor drainage became more common during the 1950s when the accelerated tempo of postwar building made prime land scarcer. Foundation soil at previously occupied sites was sometimes contaminated, particularly in reclaimed swamps. Contaminants included acid and alkaline water, insecticides, soil poisoners, and fertilizers and petroleum products discharged from vessels, refineries, and underground tanks.

Zoning regulations promulgated to induce developers to provide more open space in city centers, magnified waterproofing problems. Incentive zoning offered developers greater building heights and floor area in return for street-level plazas. To maximize the economic potential of high-priced urban land, underground commercial space and parking garages were built.
below these plazas. Waterproofing of these city-center plazas requires much
greater dependability and durability than traditional membrane water-
proofing of sidewalk vaults over cellar utility spaces.

The energy crises of the 1970s indirectly complicated waterproofing
design. Prior to the sudden increases in energy costs, when heating oil cost
less than 10 cents per gallon, thermal insulation was invariably omitted
from waterproofing systems. Earth-covered buildings, which enjoyed a brief
vogue in the early 1970s, are more energy-efficient than conventional,
above-ground buildings. Increasing the underground space in a conven-
tional building increases the overall energy efficiency of the building, but
presents a tougher waterproofing problem.

Rising costs of waterproofing failures have accompanied modern build-
ing trends. Failure may occur even without leakage of liquid moisture into
the occupied space. Environmentally sensitive occupancies are routinely
located underground in contemporary buildings. Electronic equipment in
underground computer rooms and public assembly spaces containing
audio-visual equipment require rigorous humidity control as well as
leakproof waterproofing. Auditoriums with wood floors are nearly as
demanding as computer rooms. Such uses create unprecedented water-
proofing problems.

F. Historical background

Paradoxically, the archetypal waterproofing project, the Hanging Gardens
of Babylon, anticipated modern waterproofing problems nearly 26
centuries ago, six centuries before the Christian era. One of the seven
wonders of the ancient world, the Hanging Gardens featured terraces rising
75 feet from a colonnade superstructure. Waterproofing consisted of bitu-
men and lead. Along with other plants, trees were planted in the overburden
over the earth-covered deck and watered by slave-powered irrigation
machines lifting water from the nearby Euphrates (see Figure 1.2).

By the beginning of the twentieth century, waterproofing projects
involved more mundane uses, primarily tunnels, dams, pools, and other
water-containment structures. Cellar vaults under sidewalks were also
protected, normally with built-up coal tar pitch membranes. These early
built-up bituminous waterproofing membranes comprised alternate layers
of cotton or burlap, organic felts, and coal tar pitch. Membranes were then
covered with bricks dipped in hot pitch. Before World War I, built-up water-
proofing was applied to building foundations, vertically to brick and tile
walls, horizontally to mud slabs in hot coal tar pitch or asphalt. Standard
specifications for these early built-up membranes comprised four to six plies
for waterproofing and three to four plies for dampproofing. Concrete foun-
dations and floor slabs were cast over these hot-applied membranes. For
shallow cellars, a sub-slab drainage system was specified in conjunction
with membranes.
Because waterproofing membranes were expensive to install and difficult to repair, cementitious waterproofing was introduced a century ago as a less expensive, more convenient alternative. Cementitious waterproofing coats interior (dry) faces of walls and slabs. The most popular of several proprietary compounds was a hydrolithic metallic system containing iron fillings. Oxidation of the filings surfaces, in the presence of mixing water hydrating the cement, expanded the iron fillings’ volume to several multiples of its unoxidized volume, and this expanded volume filled interstices in the concrete matrix and formed a tight, water-resistant solid.

Two systems and two materials dominated traditional waterproofing: wet-face (positive-side) waterproofing featuring built-up membranes and dry-side (negative-side) waterproofing featuring cementitious coatings. Use of these traditional materials has declined to minor status, buried under an avalanche of newer and better materials.

Built-up coal tar pitch membranes survive because almost all contemporary waterproofing materials are incompatible with coal tar pitch. This makes repair of pitch membranes a nightmare unless the same bitumen is used. VOC restrictions and air pollution regulations that ban hot kettles add further complications.
G. Modern waterproofing materials

The development of new materials to replace traditional built-up membranes and cementitious coatings accompanied an accelerated evolution of waterproofing that has also largely replaced drainage media and waterstops with new, superior plastics. A host of modern membrane materials have supplanted hot-mopped bituminous membrane materials in use since the mid-nineteenth century: rubberized-asphalt membranes, single-ply sheets of butyl and Polyvinyl chloride (PVC), one- and two-component liquid-applied membranes (LAMs) and bentonite sheets. The old cementitious coatings with iron or aluminum filings are being replaced by crystalline/chemical conversion coatings capable of sealing tiny shrinkage cracks. Bentonite clay is the basis of many prefabricated composite components. Bentonite-based laminates may contain one or more combinations of high-density polyethylene, geotextiles, and butyl sheets, plus several different versions of kraft paper containers.

By the 1990s, environmental constraints became a significant factor shaping the evolution of waterproofing systems and materials. With the advent of EPA and VOC (volatile organic content) regulations setting TLV (threshold level values promulgated by OSHA), systems releasing volatile solvents and potentially carcinogenic fumes were severely restricted or banned in densely populated center cities. This trend has severely reduced the use of hot-mopped built-up bituminous membranes and promoted their replacement with environmentally harmless systems: liquid-applied membranes, cold-applied systems, and water-based (instead of solvent-based) primers. Prefabricated modified bitumens (i.e., rubberized asphalt) membranes, supported on HDPE (high-density polyethylene) sheets, are prominent among the replacements for traditional hot-mopped built-up membranes. In addition to reducing (or even eliminating) the polluting fumes emanating from traditional hot-mopped application, modified bitumen membranes represent a leap forward in the goal of building construction: to shift as much work as practicable from field to factory. This process facilitates quality control, labor productivity, and safety. One waterproofing manufacturer, W.R. Grace, introduced a proprietary, self-adhering modified-bitumen membrane, which Grace called “rubberized asphalt,” back in the 1960s. Grace’s Bituthene had monopolized this market until its patents expired in the early 1990s when several manufacturers began marketing similar products (see Figure 1.3). All modified-bitumen waterproofing membranes marketed today contain an SBS (styrene butadiene styrene) plasticizer. Because it is unreinforced (but laminated to HDPE), SBS-modified bitumen provides superior waterproofing. The alternative roofing products, APP (atactic polypropylene) and SBS-modified bitumen sheets, are reinforced with glass or polyester felts. They have not achieved a significant market share in the waterproofing field because, at exposed edges, the reinforcement can wick water into the sheet, delaminating it and shortening its service life.
Single-ply sheets, both thermosetting (i.e., vulcanized rubber) and thermoplastic, have been vastly improved. Butyl is favored over EPDM and neoprene, which is no longer manufactured in large sheets. Butyl has much lower water absorptivity than either EPDM or neoprene, a tremendous advantage for continuously wet waterproofing membranes.

Among the thermoplastic waterproofing sheets, glass fiber-reinforced PVC, in gauges up to 120 mils, has emerged as the material of choice, replacing CPE and unreinforced PVC, whose thinner cross sections often resulted in plasticizer loss and consequent embrittlement as the material aged.

Long used under slabs and for foundations, especially as blindside waterproofing, bentonite clay has become one of the most widely used positive-side waterproofing materials. It comes in a wide variety of laminates, including geotextiles filled with bentonite granules and high-density polyethylene sheets with adhered bentonite granules. (See Chapter 12 for discussion of bentonite-based waterproofing products.)
Negative-side, cementitious coatings with iron or aluminum filings are fading in popularity. Crystalline/chemical coatings offer greater dependability, longer service life, and a self-healing property that enhances their long term waterproofing quality. Also called chemical conversion or capillary coatings, these solutions of organic and inorganic compounds react chemically with Portland cement and free lime in the presence of moisture. They fill capillaries and shrinkage cracks with long chain molecules crystallized within concrete. When shrinkage cracks occur after the concrete has cured, the reactivated crystallization process tends to fill the crack openings.

Synthetic materials are now used in place of natural materials even in ancillary components of waterproofing systems. Plastic drainage panels are now almost always used instead of pea gravel and granular backfill on plazas and against foundations. Geotextiles serve as filters for plastic drainage panels and granular backfill, and also as wrapping filters for footing drains. These synthetic materials offer greater filtration design control than bulkier natural materials. With their thinner cross sections, they also reduce excavation volume and costs.

Like improved filtering materials, waterstops have undergone several stages of improvement. Brittle bent metal strips were replaced by plastic and rubber-derivative dumbbells and bulb cross sections. Those were subsequently superseded by butyl and bentonite/butyl bars (see Appendix C). Along with greater durability, butyl and bentonite/butyl bars offer these advantages:

- simple installation (featuring lap joints);
- elimination of onsite welding;
- easy visual inspection of installation;
- stability during concrete casting operations; and
- complete encapsulation in concrete.

H. New standards for improved design

Waterproofing design has improved along with materials with an influx of industry standards. Plaza waterproofing design took a giant forward step with the Charles Parisie article on waterproofing plazas that lead to the 1978 and 1983 publications of ASTM Standards C898 (for LAMs) and C981 (for built-up bituminous membranes).

These ASTM standards have revolutionized plaza design, through establishment of three vitally important design principles:

1. sloping decks for dependable drainage
2. use of thermal insulation
3. use of drainage courses above membranes
These standards prevented defects resulting from traditional practices that are unsuitable for modern waterproofing projects. For nearly a century, traditional waterproofing assemblies over setback terraces and sidewalk vaults consisted of four- or five-ply built-up membranes, without protection boards or thermal insulation. Membranes were covered with concrete or quarry tile in mortar setting beds. On terraces, membranes were installed on a one- or two-inch-thick concrete topping, underlain by cinder fill and sloped to drain. As an alternative design, decks were level with setting beds sloped to drain.

The omission of insulation from these traditional assemblies kept coal tar pitch membranes warmed by heat loss from the interior space, within a relatively narrow temperature range and thus reduced thermal contraction stresses experienced by membranes with insulation located on the warm side of the membrane.

The specific defect corrected by ASTM Standard C898 was the practice of sandwiching a waterproofing membrane between a structural concrete deck and a wearing slab. This defective detail propagated shrinkage cracks from the substrate below or movement from the topping above into the membrane (Figure 1.4). Traditional built-up bituminous membranes are especially vulnerable to splitting. (Their breaking strains are less than two percent at low temperature, compared with 200 percent or more for vulcanized rubber sheets and breaking strains ranging up to 100 percent for modified bitumens.)

The solution to this problem was isolation of the membrane from the paving with an intervening layer of insulation. Extruded polystyrene board has the properties required for waterproofing insulation. It has high compressive strength, required to resist traffic loads. It also has extremely low water absorptivity, required to prevent water buildup within the waterproofing assembly. Placed above a plaza waterproofing membrane, extruded polystyrene board reduces the membrane’s temperature range.

![Diagram](image.png)

*Figure 1.4* Traditional split-slab construction bonded the wearing course (1), to the membrane (2), as indicated on the left. Contemporary design divorces it with a layer (3) of gravel (left), or drainage composite (right).
thereby reducing the splitting risk from thermal contraction at low temperature. Drainage fills and composite panels normally used in conjunction with this foamed insulation, also help to isolate the membrane from the paving.

Membrane splitting from concrete cracking propagated upward from the deck is a less severe problem than movement propagated downward from the paving. The use of alternative adhered membrane materials – modified bitumens, EPDM, and PVC – with their much higher breaking strains, virtually eliminates the risk of membrane splitting from deck cracking. Even traditional built-up membranes are fairly safe from splitting at the narrow temperature ranges assured by locating insulation between cold winter air and the membrane.

Another design error corrected by the modern standards involved an increasing number of wearing-surface failures caused by improper drain location or improper drain installation. Drain elevation was set to carry water from a quarry tile wearing surface, with no drain for the membrane below. When drains with weep holes at the membrane elevation were installed to correct this latter defect, the weep holes were often clogged either with bitumen mopping or cement leached from the mortar setting bed. As a consequence, water was dammed in ever-widening circles around drains, causing efflorescence, popping tiles, disintegrating grout, and organic growth. These factors then combined to accelerate failure. Vegetation growth, for example, can ultimately result in roots penetrating a membrane.

Note

2 Principles of water management

Water management is essential to keeping a building dry. As with many aspects of building design, a gram of prevention is worth a kilogram of cure. Managing water flow to alleviate or eliminate leakage problems is better than just relying on waterproofing.

Good water management is analogous to good thermal design. Thermal design was inadequately managed in the ubiquitous glass walled-office towers built in the 1960s and early 1970s (right before the energy crisis and big increase in costs commanded designers’ attention). Many architects ignored these buildings’ tremendous solar heat loads, which ranged up to 10 times more through single-layered glass than with opaque insulated curtain walls. Previously, they just had their mechanical engineers design the air-conditioning system to handle these heavy loads. They ignored the additional capital and operating costs as well as the greater difficulty in assuring comfortable conditions in these heat-absorbing structures.

Just as wall-shading and heat-reflective glass reduce thermal loads, sloping below-grade structural slabs to drain can reduce hydrostatic loading of subsurface building components. Drainage panels or pervious granular backfills alleviate lateral pressure against walls. Granular fills under slabs-on-grade reduce capillary movement of moisture upward through voids in the subsoil, reducing or eliminating hydrostatic pressure.

These subsurface building components must also be designed to resist corrosive chemicals present in soil. Most products are usually resistant to chemicals with pH values of 3 to 12.

A. Hydrostatic pressure

Though structural design of waterproofed building components is beyond this manual’s scope, a waterproofing designer needs to have at least an elementary understanding of hydrostatics. Below-grade structures must resist a combination of hydrostatic and soil pressures. These pressures generally range from 30 to 62.4 psf per foot of depth. They are obviously lower for dry, granular soils, which facilitate vertical subsurface water flow, and higher for wet soils, which approach purely liquid properties. Some
soils – e.g. saturated clays and silts – exert lateral pressure (psf) equal to their densities (pcf), which can exceed that of purely hydrostatic pressure. This added earth pressure, however, affects only the structural design of a wall or slab. Despite the additional lateral compressive stress on a waterproofing membrane, the leakage threat to the waterproofing component comes from liquid water pressure alone.

Hydrostatic pressure increases linearly with depth, producing a triangular horizontal loading pattern (see Figure 2.1 and Table 2.1). At a depth of 10 feet, hydrostatic pressure is $62.4 \times 10 = 624$ psf, in all directions. The extreme pressures shown in Figure 2.1 assume a groundwater level at grade elevation, a conservative assumption that nonetheless indicates the scope of a waterproofing designer’s problem.

![Diagram](image-url)

**Figure 2.1** If groundwater extends to grade level (a possible temporary state in areas struck with torrential rain), hydrostatic pressure under the worst conditions can be as follows: $p = wd$ on top slab; $p = w(d+h)$ lateral pressure at the base of the wall, and $p = w(d+h)$ upward pressure on the slab-on-ground. If $d = 2$ ft. and $h = 10$ ft., the lateral pressure at the base of the wall could equal $62.4 \times (2 + 10) = 749$ psf
Hydrostatic pressure on a building component occurs when the water table rises above it at any point. The water table (also known as the groundwater level), free-water elevation, and the phreatic surface, is defined by labs as the underground elevation where water is at atmospheric pressure. It may be at grade or hundreds of feet below grade. Hydrostatic pressure occurs on slabs-on-grade and foundation walls when they are below the groundwater line when surface water runoff temporarily raises the groundwater level, or when there is a perched water table. This is a condition where localized bodies of water are separated from the normal free-water elevation by impervious, unsaturated soils. Hydrostatic pressure occurs on structural slabs below grade when they are below the groundwater level, when flash floods occur, from heavy runoff from rising walls, and from clogged drains or undersized drainage systems.

Groundwater level, and consequent hydrostatic pressure can vary seasonally (generally highest in spring), daily, or even hourly. The resulting hydrostatic pressure may be intermittent, with groundwater level periodically rising above and falling below the waterproofed components' elevation; or it can be continuous when groundwater level remains constantly above waterproofed components. Spectacularly rapid changes in groundwater level can occur in semi-tropical locations like Florida, which sometimes experiences rainfalls of 10 inches or more in a day. Even in arid Arizona, flooding rains can suddenly raise water-table elevations in the clay desert soil. Under such conditions, the ground is swiftly saturated. Full

Table 2.1 Hydrostatic pressure increases with depth

<table>
<thead>
<tr>
<th>Hydrostatic head feet</th>
<th>Pressure per square inch pounds</th>
<th>Lifting pressure per square foot (under floor) pounds</th>
<th>Average pressure per square foot on wall surface affected pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.21</td>
<td>31.0</td>
<td>15.6</td>
</tr>
<tr>
<td>1.0</td>
<td>0.43</td>
<td>62.0</td>
<td>31.2</td>
</tr>
<tr>
<td>2.0</td>
<td>0.87</td>
<td>125.3</td>
<td>62.5</td>
</tr>
<tr>
<td>3.0</td>
<td>1.30</td>
<td>187.2</td>
<td>93.7</td>
</tr>
<tr>
<td>4.0</td>
<td>1.73</td>
<td>249.1</td>
<td>125.0</td>
</tr>
<tr>
<td>5.0</td>
<td>2.17</td>
<td>312.3</td>
<td>156.0</td>
</tr>
<tr>
<td>6.0</td>
<td>2.60</td>
<td>374.4</td>
<td>187.2</td>
</tr>
<tr>
<td>8.0</td>
<td>3.47</td>
<td>500.0</td>
<td>250.0</td>
</tr>
<tr>
<td>10.0</td>
<td>4.34</td>
<td>625.0</td>
<td>312.5</td>
</tr>
<tr>
<td>12.0</td>
<td>5.20</td>
<td>749.0</td>
<td>374.5</td>
</tr>
<tr>
<td>15.0</td>
<td>6.50</td>
<td>937.0</td>
<td>468.0</td>
</tr>
<tr>
<td>20.0</td>
<td>8.67</td>
<td>1248.4</td>
<td>624.2</td>
</tr>
<tr>
<td>25.0</td>
<td>10.84</td>
<td>1561.0</td>
<td>780.5</td>
</tr>
<tr>
<td>30.0</td>
<td>13.01</td>
<td>1873.4</td>
<td>937.0</td>
</tr>
<tr>
<td>40.0</td>
<td>17.34</td>
<td>2497.0</td>
<td>1248.5</td>
</tr>
</tbody>
</table>

hydrostatic pressure can be temporarily exerted against foundation walls, slabs-on-ground, and structural slabs until the surplus water drains away through the foundation soil.

Groundwater level is only the basic determinant of hydrostatic pressure. It also depends on the nature of the soil. Water rises by capillary action in most soils. This capillary rise varies from 11.5 feet in soils comprising microscopic particles (i.e., clay and silt) to zero in granular soils, where the large spaces between particles nullify capillarity. The top plane of the saturation zone – i.e., the space between groundwater level and the limit of capillary rise – lies between those extremes. Even in coarse sand, this saturation zone can extend hydrostatic pressure more than two feet above groundwater elevation (see Table 2.2).

Slabs-on-ground subjected to hydrostatic pressure must be designed to resist uplift, via one or more of the following methods:

- increasing slab weight (to counterbalance upward hydrostatic pressure)
- reinforcing the slab for flexural resistance and anchoring it to foundations or grade beams
- tying the slab to rock anchors

---

### Table 2.2 Capillary rise

<table>
<thead>
<tr>
<th>Capillary rise</th>
<th>Soil type</th>
<th>Saturation zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.5’</td>
<td>clay</td>
<td>5.7’</td>
</tr>
<tr>
<td>11.5’</td>
<td>silt</td>
<td>5.7’</td>
</tr>
<tr>
<td>7.5’</td>
<td>fine sand</td>
<td>4.5’</td>
</tr>
<tr>
<td>2.6’</td>
<td>course sand</td>
<td>2.2’</td>
</tr>
<tr>
<td>0.0’</td>
<td>gravel</td>
<td>0.0’</td>
</tr>
</tbody>
</table>

Note: Water rises in all soils except gravel via capillary action, with the results tabulated above. In clay and silt, the saturation zone extends nearly six feet above the groundwater table. Liquid moisture in the saturation zone exerts hydrostatic pressure that must be resisted by the waterproofed components.

Passive resistance (prevention of hydrostatic pressure) can be accomplished by installing under-slab drains and footing drains directed to the storm-water system.

In addition to designing the system for the most severe hydrostatic pressures likely to occur, one must also consider other hazards when selecting a system. Swiftly flowing underground water can wash away bentonite, leaving the foundation wall defenseless. High hydrostatic pressure can force a waterproofing membrane into voids in its concrete substrate, causing shearing and flexural rupture. Hydrostatic pressure can also increase a membrane’s water absorption, with consequent swelling. Membrane swelling can break a membrane’s bond with its substrate, forming wrinkles vulnerable to flexural cracking and eventual leakage through local weak spots.

On negative-side waterproofing systems (see Chapter 7) hydrostatic pressure promotes water penetration into concrete walls and slabs through tie-rod holes, cold joints, and rock pockets. Other potential leak sources occur at buried conduit; tieback block-outs; and where soda cans, beer bottles, and other debris thrown into the formwork prior to casting operations create cavities in the concrete.

B. Site planning and landscaping

The most rudimentary solution to relieving water pressure in open areas with high water tables is to raise the building above it and use the excavated earth to grade away from it. Passive water and moisture control can be achieved via several methods, including:

- proper grading to control surface runoff. Grading should be sloped away from the foundation by at least five percent for the first 10 feet. The ICC code is more conservative, requiring a 1-in-12 (8.7 percent) slope.
- foundation planting, which reduces hydrostatic pressure by absorbing groundwater through plant roots.
- providing a layer of impervious soil or paving adjacent to foundations that diverts water flowing down the exterior wall to prevent it from creating hydrostatic pressure against the foundation.
- extending downspouts to discharge drain-water well away from foundations, which reduces the quantity of water that can percolate downward through the soil adjacent to foundation walls and slabs, where it can exert hydrostatic pressure.
- connecting downspouts to storm-water sewers. This is even more effective than extending downspouts away from the building as a means of relieving subsurface hydrostatic pressure. Unless the drainage system fails, this strategy removes all or nearly all surface water from the building perimeter.
• backfilling with pervious material and installing footing drains, which reduces hydrostatic pressure. In conjunction with previously listed remedies, porous backfill allows subsurface water to flow vertically to footing drains, which preferably discharge at some lower surface elevation. (See Figures 2.2 and 2.3.) Footing and under-slab drains draw down surrounding groundwater to relieve walls and floors from hydrostatic pressure. They also collect rainwater and snow-melt that percolates through the backfill.
• providing under-slab drainage blankets and drains.
• providing intercepting drains (uphill on hilly sites).
• draining impermeable surfaces around a hill-sided building (which can dam water).

C. Drain pipe materials

Drain pipe is manufactured in two basic types: rigid and flexible. Rigid pipe is either porous concrete or clay tile. Flexible pipe is made of corrugated polyethylene, PVC (corrugated and smooth-bore), bituminized fibers, or styrene rubber. Flexible pipe offers a major advantage over rigid pipe with its ability to accommodate (1) differential settlement without cracking under flexural stress and (2) silting up from soil penetration through the cracks.

Clay tile illustrates the liabilities of rigid pipe. It was the most prevalent drainage pipe material until the 1960s when its defects then became manifest.

Figure 2.2  Detail of footing drain shows minimum aggregate blanket and minimum dimension from bottom of slab-on-ground to top of pipe. Pipe is usually four or six inches diameter and may be level, but a 0.4% to 1% slope is preferred.