Housing Foundations and Geotechnical Challenges

BEST PRACTICES FOR RESIDENTIAL BUILDERS IN BRITISH COLUMBIA

BRITISH COLUMBIA

Homeowner Protection Office
Branch of BC Housing

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Professional Engineers and Geoscientists of BC

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1.0 Introduction

This guide has been prepared to promote best practices for builders with respect to geotechnical issues, both when selecting a site and when constructing single and multi-family residences.

Based on the wide variety of soil types, landforms, topographic features, and climates found throughout British Columbia, there are a range of potential geotechnical challenges that can affect building sites. The recommendations presented herein may not be suitable for every project or building site; therefore, every site must be considered on an individual basis.

The British Columbia Building Code (BCBC) outlines minimum standards regarding life safety, health, and structural sufficiency of buildings. The information provided in this document is intended as current best practice guidelines, according to industry professionals, which exceed the BCBC's minimum requirements.

2.0 Physiography, Geology and Soil Conditions of BC

The potential geotechnical challenges faced by builders, developers, and property owners in BC are typically a function of the geographical location, geomorphological landforms, and geology (both bedrock geology and surficial geology) that influence each site.

2.1 Geographical Location

In general, the geographical location of a site (i.e., latitude and longitude) determines the climate and relative seismic hazard of the area, both of which can result in significant geotechnical challenges that include ground settlement, flooding, erosion, permafrost, liquefaction, and slope instability. The geographical location of a site also determines the site elevation, which is a function of the geomorphological landforms that created and continue to influence the surrounding landscape.

2.2 Geomorphological Landforms

The landforms that comprise a landscape are a result of geomorphological processes such as tectonic uplift, glaciation, erosion, and sedimentation, which have interacted with climatic factors and regional geology over millions of years to result in the landforms we see today. Climate controls weathering, erosion, and deposition, as well as the rates at which they occur, while the interaction between various types of bedrock and weathering and erosional forces influences the character of resulting landforms and surficial soils.

2.3 Bedrock Geology

Bedrock geology is determined by the tectonic and depositional processes that have taken place throughout a region's history. There are three main types of rocks, all of which occur in BC:

2.3.1 Igneous Rocks

Formed by the cooling of molten rock (magma), either below the Earth's surface (plutonic rocks) or above (volcanic rocks). Examples: basalt plateaus in the Central Interior, dormant volcanoes with young columnar basalt flows near Whistler, and the Stawamus Chief granodiorite monolith at Squamish.

2.3.2 Sedimentary Rocks

Formed by deposition of material via water, wind, ice, or mass movement on the Earth's surface, on ocean floors, or precipitated from a solution. Examples: sandstone on the Southern Gulf Islands, oil and coal-bearing shale in northeastern BC, and limestone within the Rocky Mountains.

2.3.3 Metamorphic Rocks

Formed by transforming existing rocks (either igneous, sedimentary, or older metamorphic rocks) into new rocks when physical and/or chemical changes result from high pressures and temperatures. Examples: marble near Pavillion in the Southern Interior, gneisses near Penticton, and quartzites and schists of the Rocky Mountains.

2.3.4 Bedrock Structure

As bedrock is exposed to the affects of pressure, temperature, and tectonic forces beneath the Earth's surface, structural weakness planes such as joints, foliations, and faults may develop within the rock. These weakness planes, as well as bedding planes that develop during the formation of sedimentary rocks, can affect the shape, strength, and overall rockmass quality of a bedrock exposure when it is exposed at the Earth's surface.

2.3.5 Bedrock Chemical Composition

It is noteworthy that some rocks, when exposed to air and water (and particularly, when crushed into aggregate), may undergo an oxidation process that can lead to acid rock drainage and metals leaching, which can be very harmful to the environment. In some rock types, the rock itself can swell, leading to heaving of overlying structures.

Some areas of BC commonly involve building directly on bedrock where surficial soil is minimal (such as near Whistler, West Vancouver, and Victoria). Such conditions typically occur at higher elevations and/or on sloping terrain, where surficial soil has not accumulated and/or has been eroded. However, for access reasons, most building sites are located in valley bottoms, on alluvial terraces, on debris fans, on plateaus in the Central Interior, and on soil plains in northeastern BC that are underlain by a significant thickness of soil; therefore, most building sites are affected by the potential geotechnical challenges imposed by surficial geology rather than bedrock geology.

2.4 Surficial Geology

The soil types that obscure bedrock in BC can range in thickness from several centimetres to more than 300 metres (1,000 feet) and in strength from negligible to nearly as strong as rock. The characteristics of soil are mainly a function of their depositional history and their grain size; however, chemical composition can also be a significant factor. The following discussion summarizes the main soil types encountered in BC.

2.4.1 Glacial Soils

During the most recent Ice Age, vast thicknesses of ice covered most of BC, scouring the terrain and the underlying soil and rock as it slowly flowed. As the ice melted and retreated, a variety of glacial deposits were left behind, deposited in direct contact with the ice (glacial till), into glacial lakes (glaciolacustrine soil), within glacial outwash streams (glaciofluvial soil), and into the ocean (glaciomarine soil). Glacial till blankets a considerable portion of modern-day BC, and these soil types, some of which have been densified by previous overlying ice (i.e., basal tills), are generally a favourable foundation subgrade material as a result. Other glacial sediments, which have been deposited by water into lakes, rivers, and the ocean, as well as ablation tills (i.e., which have not been densified by overlying ice) behave in ways similar to alluvial sediments and may be susceptible to settlement.

2.4.2 Alluvial Soils

The grain size of an alluvial soil deposit is a function of the water energy that deposited it; for example, larger particles like gravel and sand deposit first as flow energy decreases, with finer particles like silt and clay staying suspended until flow energy is low enough to allow particles to drop from suspension. Depending on the variability of the grain sizes that comprise various soil deposits, some may be susceptible to compression and settlement (i.e., fine grained lake deposits), liquefaction during seismic events (i.e., saturated sands in river and marine deposits such as those near the Fraser River delta and Okanagan Lake), and slope stability problems (i.e., old river and lake deposits that have formed modern terraces and are being eroded by present day rivers and lakes, such as those near Maple Ridge and Summerland).

2.4.3 Aeolian Soils

Soil can also be deposited by wind (aeolian soils), which can be susceptible to collapse due to the weak (delicate) soil structure, such as localized deposits of volcanic ash and sand dunes located near the Okanagan Valley.

2.4.4 *Organic Soils*

Organic soil occurs where plants have been buried, and this soil is generally an unsuitable foundation material due to both the ongoing ground settlement that occurs as the materials decompose, as well as settlement that can occur as the soil structure is compressed during the placement of surcharge loads (i.e., peat deposits in Prince Rupert and the Lower Mainland).

2.4.5 *Colluvial Soils*

Gravity-deposited soil, or colluvium, occurs on and at the base of sloping terrain where processes such as landslides, rockfalls, debris flows, and avalanches carry material to lower elevations. Colluvial deposits are often fan shaped when viewed from above and are often considered to be desirable building locations in some areas, as valley bottoms are becoming increasingly developed.

2.4.6 *Anthropogenic Soils*

Finally, where humans have moved and deposited soil, these materials are referred to as fill or anthropogenic deposits. Commonly, unless suitable quality control is implemented, fill materials are unsorted, uncompacted, and unsuitable for supporting foundation loads. Fill may comprise mixed mineral, organic, and other unknown material. Even fill that appears to be mineral may have been placed on buried organic deposits, which can decompose and settle. Fill that has been locally derived can appear to be a natural deposit.

On sloping sites developed before about 1975, it is common for original site clearing debris to have been pushed downhill and then covered by subsequently excavated mineral soil; this practice is known to be ongoing in some areas. Fill placed on slopes can be a stability concern, especially if placed at the crest of a slope. Fill may be contaminated and require review and testing from an environmental engineer.

Hogfuel was previously commonly used in some areas of BC to raise building grades, particularly above potentially compressible soils. This organic material experiences high rates of decomposition, associated with significant settlement, as well as significant compressibility and methane gas generation during decomposition.

A significant portion of the province's development occurred within the Lower Mainland (from the United States border to West and North Vancouver and as far east as Chilliwack). For this area, the Geological Survey of Canada has produced a series of surficial geology maps (see the Links section) that provide information that is useful for builders and developers. The eight most prevalent natural soil types present in the Lower Mainland each have typical characteristics and associated potential geotechnical challenges, and are described in Appendix B. It should be noted that many areas within this region have been developed for more than a century. The natural soil may have been partially removed and/or covered with fill. There are often challenges associated with finding a demolition and construction sequence that is practical and safe.

KEY TOPICS COVERED

- potential geotechnical challenges depend on location, landforms, geology
- rock types: igneous, sedimentary, metamorphic
- soil types: glacial, alluvial, aeolian, organic, colluvial, anthropogenic (fill)
- fill materials typically problematic

3.0 Potential Geotechnical Challenges

Some common geotechnical challenges encountered in BC are described below, and each hazard is identified with a letter that is used in the following map (Figure 1) to indicate potential geotechnical challenges that commonly affect the most populated areas of the province (population centres with greater than approximately 15,000 people based on the 2011 census). It should be reiterated that each building site should be considered individually; this figure is merely a generic summary of the most common regional hazards.

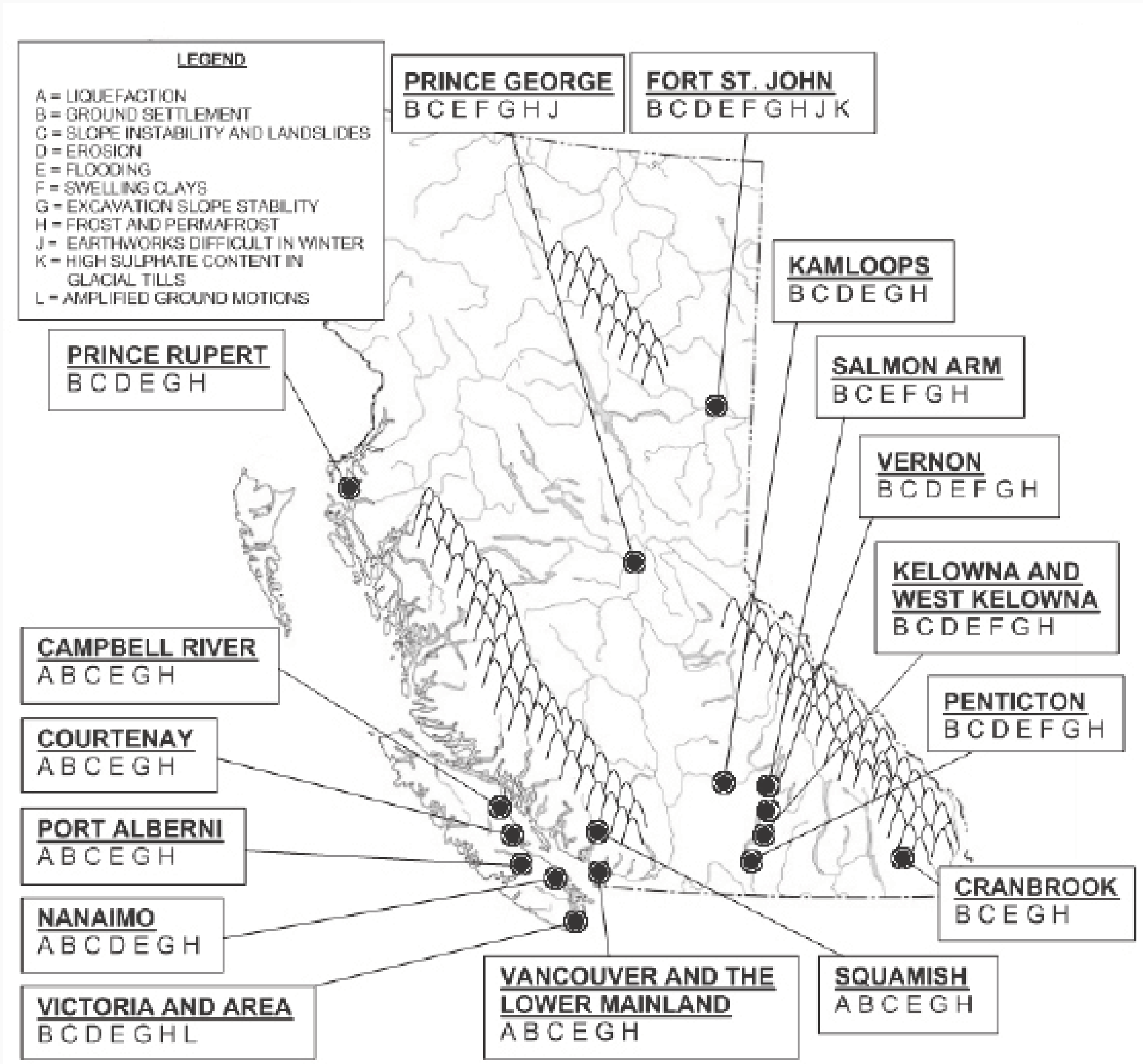

Figure 1: **Potential geotechnical challenges in high population areas of BC.**

3.1 **Liquefaction (A)**

Soil liquefaction occurs when a saturated soil loses its strength in response to an applied stress such as earthquake shaking, causing it to behave like a liquid. Structures underlain by liquefiable soil can experience significant magnitudes of settlement and lateral displacement during an earthquake. It occurs in granular soil such as alluvial, glaciofluvial, colluvial, or granular fill materials that are very loose to compact in density. In BC, the most susceptible areas are on the West Coast, where seismic accelerations are moderate or higher.

Photo 1: **Debris flow at Lions Bay, BC.** (www.geog.ubc.ca)

3.2 **Ground Settlement (B)**

Ground settlement can result from several causes, some of which are natural and some of which occur in response to an applied load. Natural decomposition of organic matter within soils (such as peat and buried topsoil and wood fragments) can result in ground settlement above. Consolidation of fine grained soil (such as glaciolacustrine, lacustrine, and glaciomarine sediments), densification of loose materials such as fills and ablation tills, compression of peat, and collapse of aeolian soil can occur in response to an applied load. Ground settlement can affect overlying and adjacent structures and foundations, particularly if the magnitude of settlement is large or if differential settlement occurs.

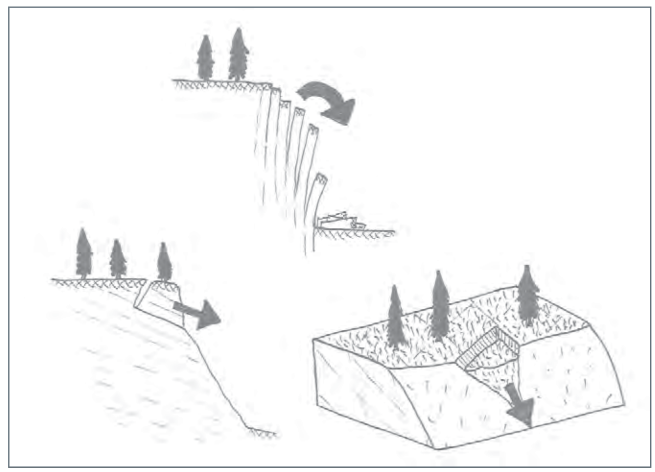

Figure 2: **Rock slope failure mechanisms.**
(clockwise from top: toppling, wedge, and planar failures)

3.3 **Slope Instability and Landslides (C)**

Slope failures occur when the strength or resistance of the materials comprising a slope is insufficient to support the gravitational and other destabilizing forces acting on a slope. Most slope failures occur as a result of geometric factors (i.e., the slope being steep and/or unfavourably oriented), groundwater and surface water effects, surcharge loading effects, and/or seismic effects. Changes to slope geometry, such as excavating at the toe or filling at the crest, can trigger slope failures, as can the imposition of other loads (such as building weight) near the crest. Slope failures can also occur in saturated soils and are common after heavy rain events or rain-on-snow events.

Loose or weak materials such as fill, near-surface weathered soils or weathered, fragmented bedrock are particularly vulnerable to slope failure, as are slopes that have lost apparent cohesion from root mass reinforcement as a result of wildfire or deforestation. Susceptible slopes are typically steeper than approximately 30 degrees; however, slope failures are possible in some areas (such as those underlain by clay soils) where slopes are as shallow as 10 degrees. Earthquakes can trigger slope failures where slopes are otherwise stable under static conditions.

There are several main types of slope failures, including landslides, earth slumps, debris flows (see Photo 1), and rockfalls. Landslides can occur in soil or rock, can be rapidly moving, and can be large in scale. Earth slumps typically occur in soil, are relatively shallow, and can be slow moving. Debris flows typically occur in steep ravines, behave like a liquid, can be very fast moving, and typically comprise water, soil, rock fragments (to several metres in diameter), and vegetation, including logs, stumps, and other entrained materials. Rockfalls typically occur on steep slopes with minimal soil cover and where bedrock is weathered, highly fractured, or where joints within the rock are unfavourably oriented.

As indicated in Figure 2, rock slope failures can be described as planar failures (sliding on one discontinuity surface that dips, or angles down, out of the slope), wedge failures (sliding on the intersection line of two discontinuity surfaces that dips out of the slope), or toppling failures (overturning of steeply dipping discontinuities [>65° inclination] oriented subparallel to the slope). Excavation slopes in rock commonly create rockfall hazards, and scaling and/or rock slope stabilization is often required.

Previous slope failures can often be identified by the presence of landslide deposits at the base of slopes, landslide or debris flow headscarps or scars, hummocky or lumpy ground at the lower portion of a slope, scoured creek channels, or fresh exposed bedrock or soil on an otherwise weathered or vegetated slope. Previous slope instabilities may be susceptible to further failures; therefore, development in the vicinity of such areas is generally not recommended. Potential slope stability problems can be identified by observation of ground or foundation settlement near the slope crest, tension cracks near the slope crest (particularly concentric in plan view), seepage near the toe of a slope, pistol-butted or jack-strawed trees on a slope (see Photo 2), bulging ground at the toe of a slope, or ravelling of rock slopes.

Debris flows and rockfalls can be difficult to accurately predict, as they occur rapidly and often initiate upslope of a site that might lie in its path. New upslope conditions, including new development, can contribute to increased stormwater runoff and therefore new hazards in an area previously demonstrating stable behaviour. Future climate scenarios may also be associated with increased debris flood / flow and landslide risk.

APEGBC has published a document, *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC*, which provides criteria for the assessment of terrain with respect to slope stability and landslide hazards. Some jurisdictions require Professional Geotechnical Engineers to submit an *Appendix D: Landslide Assessment Assurance Statement* prior to granting a development or building permit for a property to ensure that such hazards have been suitably addressed prior to development.

3.4 **Erosion (D)**

Erosion is degradation by means of natural agents, including water, wind, and ice. Although typically a natural process, it can be caused by anthropogenic factors such as uncontrolled water discharge. It is common in arid regions and on steep slopes where vegetation is minimal, such as the alluvial and glaciofluvial terraces of the Okanagan Valley and South Thompson region. Significant or ongoing erosion can lead to slope instability at the crest of the slope, or even the formation of sinkholes, as has occurred on the Kamloops benchlands. Increased erosion can be expected following logging or wildfire; this would be expected to lead to increased stormwater runoff and possibly increased downstream erosion.

3.5 **Flooding (E)**

Flood hazards in BC are generally limited to properties in the vicinity of rivers, creeks, lakes, and the ocean. Seasonal flooding occurs on some rivers, creeks, and lakes, and some of the larger municipalities have established criteria with respect to developing in floodplain areas. Further discussion is provided in Section 12.0: Surface Water Management in this guide. For properties adjacent to the ocean, sea level rise is a topic of concern, which may affect waterfront development in the future. The western and southern portions of Vancouver Island are also subjected to a tsunami hazard, which could occur as a result of a large earthquake west of Vancouver Island or farther west, south, or north in the Pacific Ocean.

Photo 2: **Example of pistol-butted trees.**

Photo 3: **Installing temporary excavation shoring (shotcrete and anchors).**

3.6 **Swelling Clays (F)**

In arid regions, alluvial, glaciomarine, and glaciolacustrine clays may be susceptible to swelling when water is introduced. This can also be a seasonal affect linked to cycles of swelling (which can be exacerbated by irrigation) and dessication. The phenomenon of swelling clays often results in significant displacement of, and repair or replacement costs for, foundations, roads, utilities, and other structures supported by the swelling clays as well as for the subgrades underlying these structures, which can be difficult to access.

3.7 **Excavation Slope Stability (G)**

Where below-grade foundations or excavation on sloping sites are proposed, excavation design requires consideration of excavation slope stability for safety, structural, and logistical reasons. All soil types require that excavation slope stabilization measures are implemented, which include sloping excavation cutslopes or installing temporary excavation support (see Photo 3) where there is insufficient space for sloping. Excavation slopes are particularly susceptible to failure where soil is loose (such as fill, topsoil, or colluvium), where bedrock is highly fractured or has unfavourable discontinuity orientations, or where the slope gradient is too steep.

3.8 **Frost and Permafrost (H)**

Frost affects most areas of BC seasonally, though to varying degrees. In northern latitudes, permafrost can occur, where subsurface soil is frozen year round. Frost heave occurs when previously unfrozen soils expand as ice crystals form, which typically affects soil types finer grained than gravel.

Frost heave can displace existing structures. For proposed structures, frozen soil or soil that has been loosened via freeze-thaw effects can affect foundation subgrade preparation, as described in Section 6.5: Foundation Subgrade Preparation. Frozen ground can also create logistical problems, as it is more difficult to excavate and should be thawed prior to pouring concrete. For sites underlain by permafrost, conventional shallow foundation systems are generally inappropriate. Geotechnical design considerations in permafrost areas include avoiding differential frost heave, maintaining frozen soil to preserve its bearing capacity, and minimizing heat transfer between the structure and the frozen soil.

3.9 **Earthworks Difficult in Winter (J)**

In northern and interior regions, frozen ground can make earthworks difficult in winter due to the significant difficulty and cost involved with excavating frozen soil, controlling soil moisture, and/or the high cost of keeping the ground thawed.

3.10 High Sulphate Content in Glacial Tills (K)

Some soils in BC, such as glacial till materials near Fort St. John, can have a high sulphate content, which degrades concrete and causes an overall loss of concrete strength. As a result, a higher concrete exposure class is required in these areas to improve the durability of concrete. This is a design consideration that could result in higher construction costs.

3.11 Amplified Seismic Ground Motions (L)

Some soil deposits can amplify seismic waves and result in increased ground motion at the surface. For example, marine silty clays in the Victoria area have been reported to have this effect where the deposits are sufficiently thick.

KEY TOPICS COVERED

- liquefaction (West Coast)
- ground settlement
- slope instability and landslides
- erosion
- flooding (including tsunami hazard)
- swelling clays (arid regions)
- excavation slope stability
- frost (most of BC) and permafrost (Northern regions)

4.0 Hiring Professionals

Builders are professionally regulated as Licensed Residential Builders and liable for homes under policies of home warranty insurance. The *Homeowner Protection Act* requires that all new residential construction have home warranty insurance. Warranty insurance includes one year on strata lots, 15 months on common property, two years on certain major systems, five years on the building envelope and 10 years on the structural. Details can be found on the HPO website (www.hpo.bc.ca).

Whether or not a project requires the services of a Professional Geotechnical Engineer may be determined by the permitting department of the Authority Having Jurisdiction (i.e., city, town, district, etc.), the warranty insurance provider, and/or as local conditions merit. Whether required or not, including a Professional Geotechnical Engineer on the project team may reduce the risk of problems. The flow chart in Appendix A illustrates the typical stages of a residential development project and where inclusion of a Professional Geotechnical Engineer should be considered.

Some examples of issues that have resulted from projects that would have benefited from a professional assessment include the following:

- Water damage from seepage into basements and other below grade structures resulting from compromised or inadequate foundation or underslab drainage systems or cracked foundations.
- Water damage resulting from flooding hazards not considered when determining building elevations.
- Structural damage or failure of an unsupported foundation or retaining wall resulting from use of heavy compaction equipment against the wall.
- Settlement and/or cracking of foundations, retaining walls, or hard landscaping features supported on poorly compacted fill materials or poor subgrade materials (such as compressible, swelling, or organic materials).
- Settlement and/or cracking of foundations, retaining walls, or hard landscaping features located adjacent to non-engineered excavation slopes.
- Movement, cracking, and/or failure of non-engineered retaining walls.
- Damage to or loss of structures, yard space, and/or people resulting from slope failures, landslides, rockfalls, and/or erosion.

Recommendations may encompass the following topics, which are schematically illustrated in Figure 3:

- foundation subgrades (and deep foundations) for new homes or additions
- permanent and temporary excavation safety and shoring (and underpinning)
- use of Engineered Fill materials, compatibility of filter fabric with adjacent fill or natural soil

- foundation backfill
- foundation drainage (also referred to as perimeter drainage) and underslab drainage, drainage remediation
- Flood Construction Levels (FCLs)
- surface and groundwater management
- sediment and erosion control
- roads and pavements
- retaining walls
- septic systems
- slope stability
- natural hazard assessments

For information on what the investigation and report should conform to, refer to the Association of Professional Engineers and Geoscientists of British Columbia's (APEGBC) document: *Guidelines for Geotechnical Engineering Services for Building Projects*, which is referenced in the Links section at the end of this document. APEGBC also publishes an online list of region-specific engineering consultants provided in their Links section under Discrete Scope Projects Directory.

KEY TOPICS COVERED

- promote best practices
- field reviews by professionals per BCBC Letters of Assurance
- Professional Geotechnical Engineer benefits the project team
- builders can be found legally liable for problems later
- consultant selection process is important

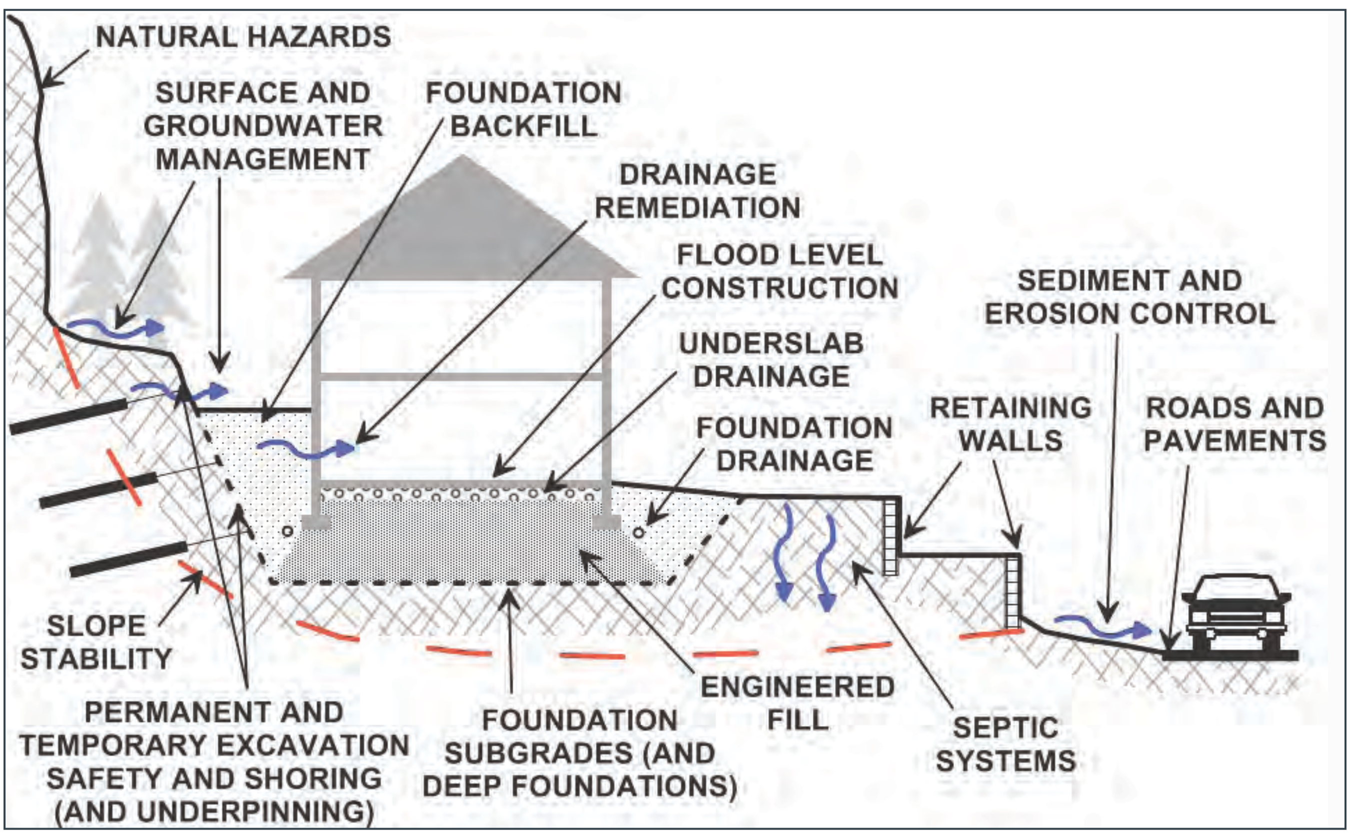

Figure 3: **Project components that may benefit from the input of a Professional Geotechnical Engineer.**

■ 5.0 Site Selection

There are many sources that can inform prudent site selection. These can include local engineers with local geotechnical knowledge, available documentation (including maps), and historical aerial photographs.

Google Earth has an application that allows the viewer to see previous aerial photographs, but these are typically limited to 2000 and after. Historical aerial photographs can be rented from the University of British Columbia's Department of Geography and these typically date back to the 1940s.

Within the Lower Mainland, information regarding surficial geology as presented on the maps by Armstrong, et al, available from the Geological Society of Canada, has been found to be very accurate. Fire Insurance Maps often document past uses of land parcels. In New Westminster in particular, the library has maps that show the locations of buried ravines. Similar information can be found for Vancouver within the *Vancouver's Old Streams* map, which is referenced in the Links section of this document.

Topographic maps can provide an insight as to potential geotechnical challenges that could affect a site. Topographic contour lines indicate lines of equal elevation therefore, contour lines that curve into a slope indicate a ridge or "nose" on a slope (see Figure 4).

Where contour lines are spaced close together, slope gradients are steeper than where lines are spaced farther apart. The scale and contour interval of a topographic map should be considered in its interpretation. Selecting building sites away from steep slopes (both above and below) and away from gullies (including near the base of a slope in the vicinity of a gully) is generally good practice in order to minimize the site's exposure to slope stability and landslide hazards.

The presence of archaeological sites on private property can lead to significant costs, delays, and/or development restrictions that the owner and builder would have to contend with if encountered. Known archaeological sites are documented by the provincial government, while unknown sites may be discovered during ground-altering construction activities.

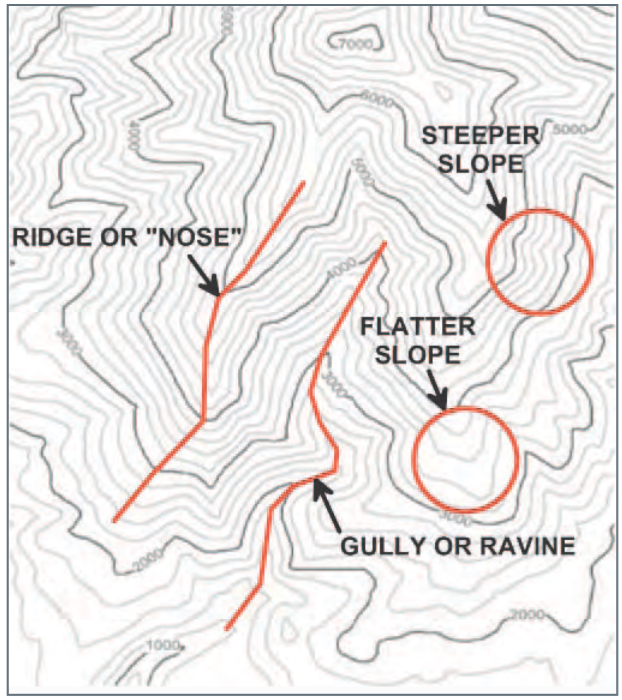

Figure 4: **Example topographic map features.**
(reynolds.asu.edu/topo_gallery/topo_gallery.htm)

Development activities must comply with the *BC Heritage Conservation Act* (see the Links section for *Archaeologist Impact Assessment Guidelines*, developed by the provincial government). A consulting archaeologist may provide recommendations in this regard.

Other useful documentation about the potential problems associated with a particular piece of land, including past uses, can often be found in local newspapers, the Land Titles Office, and the library. For example, a recent, large (1349 acres) real estate transaction occurred in Vernon, with the buyer being unaware that the lakeside property had been impacted by former military training initiatives and that it contained buried explosives, which were widely known to have killed eight people over the years.

Finally, a canvass of the existing developments in an area can also be a good indication of the feasibility of a particular feature or structure. For example, if there are no basements or in-ground swimming pools in a particular neighbourhood, then there is a good chance that it may be excessively problematic and costly to proceed with these types of developments in that area.

Note that the geotechnical requirements of a project will generally be more comprehensive if the property is being subdivided or if it is located in an area requiring a development permit as compared with those for a typical building lot. Often, geotechnical reports prepared for a proposed subdivision do not address the detailed design requirements of individual developments within the subdivision.

Once a site is selected, it is important to develop a positive relationship with neighbours as it can help facilitate:

- Approval of rezoning, development permits, and variances.
- Temporary use of power and water.
- After hours security of the site, including a watchful eye on construction equipment and stockpiled construction materials.
- Permission to trespass, including encroachment of excavation shoring elements.

KEY TOPICS COVERED

- engineers with local experience
- historical aerial photos
- maps (topographic, geological, streams, fire insurance)
- archaeological sites
- local newspapers
- Land Titles Office
- canvass existing developments

6.0 Foundations

The British Columbia Building Code (BCBC) 2012 provides minimum foundation requirements for houses constructed using conventional strip and pad footings and foundation walls. In some areas, (i.e., those underlain by compressible soil), other foundation types may be more suitable. These could include deep foundations (i.e., piles) or raft foundations, which would require subsurface investigation for design purposes. It is considered best practice to allow a Professional Geotechnical Engineer to determine what type of subsurface investigation is required based on the expected subsurface conditions at the site, including on his or her previous experience in the vicinity of the site.

Differential settlement across a building footprint should be expected if foundation types or subgrade conditions (including loading history of compressible soils) are variable. Differential settlement can result in cracked foundation walls (that can subsequently leak), cracked wall and floor finishes, sloping or uneven floors, sloping window sills, bath tubs that don't drain, etc. (see Photo 4). Potential problems can be mitigated if geotechnical and structural engineers are effectively integrated into the project team.

6.1 Conventional Footings and Foundation Walls

Although the BCBC 2012 does not require reinforcing steel in foundation walls that meet certain conditions, as described in the BCBC 2012, concrete shrinkage and unexpected surcharge loads on foundation wall back-fill during construction as well as during the design life of the structure cannot be fully predicted and it is therefore considered best practice to include reinforcing.

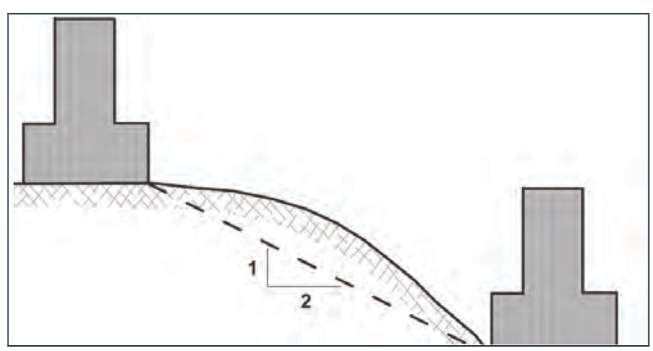

Figure 5: **Footings should step at no more than 1 vertical to 2 horizontal**

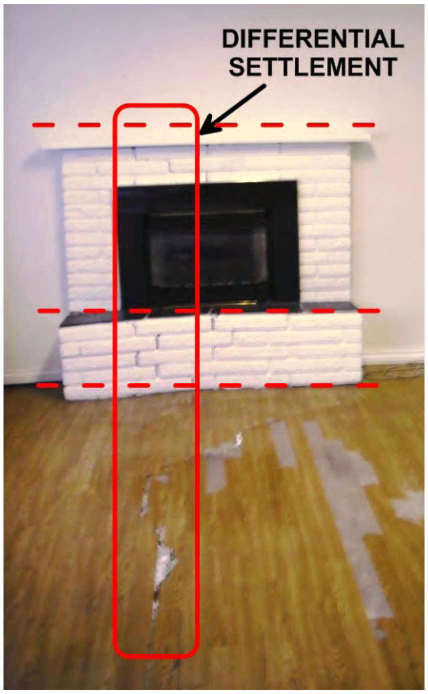

Photo 4: **Example of differential settlement manifested in a brick fireplace and wood flooring.**

Notwithstanding the minimum footing width per the BCBC, builders may want to consider a minimum footing width of 0.5 metre (18 inches) for foundations constructed on bedrock or glacially consolidated soil and 0.6 metre (24 inches) elsewhere. Greater minimum footing widths may be locally common or recommended if subsurface soil is loose or soft.

Foundations should be located with sufficient depth below adjacent interior grades for confinement purposes, which is typically about 0.5 metre (18 inches).

In general, foundations constructed on soil should be level, should step at no more than 1 vertical to 2 horizontal, and where located near sloping ground, should be placed behind a line rising up from the slope toe at 1 vertical : 2 horizontal. These recommendations are illustrated in Figure 5.

Foundations located on bedrock that slopes nominal 10 degrees or less should generally be dowelled into the bedrock. The dowels should extend through the weathered zone and penetrate into the unweathered zone of the bedrock. More steeply sloping bedrock should be assessed by a geological or geotechnical engineer and rock bolting may be recommended to ensure a sound and stable foundation subgrade. The location, spacing, and dowel specifications should be provided by a structural engineer in conjunction with the Professional Geotechnical Engineer.

6.2 Rock Bolting

Rock bolting (see Photo 5) may be required to secure potential rock failures in planar, wedge, or toppling failure modes, which were previously described in this bulletin. These potential failures could be below the building site, potentially impacting foundation or access stability, or above the building site, potentially impacting safety or access of workers or residents.

Rock bolts should be designed by a qualified geotechnical or geological engineer. Location, inclination, length, bar type, and bonding agent type will generally be specified. Suitable contractors should have methodologies which ensure bonding agent delivery to the entire bond length of the bolt, despite the potential presence of joints in the rock. The professional undertaking responsibility for these elements may require full time field reviews during installation of the rock bolts and/or testing of installed rock bolts to confirm their capacity.

Photo 5: **Example of rock bolts installed to stabilize a rock slope.**

Photo 6: **Example of preload in place on a future building site.**

6.3 **Other Foundation Types**

For sites with potentially compressive or expansive soil, it is best practice, and locally required in some juristications, to include a Professional Geotechnical Engineer on the project team. Possible design and construction strategies include locating footings below the zone where moisture levels fluctuate, sub-excavation of soil in the zone where moisture levels fluctuate and replacement with Engineered Fill, and/or constructing foundations incorporating piles or a raft. For sites with compressive soil, following subsurface investigation, geotechnical design may recommend preloading and/or a weight compensation design approach.

Preloading a site essentially puts a volume of temporary fill material on the building footprint equal to or greater than the expected weight of the building or foundation loads (see Photo 6). The settlement of this fill is monitored. Generally, the rate of settlement decreases with time (i.e., in a logarithmic progression). In general, when the rate of settlement attenuates and the projected future settlement over the design life of the building is determined by the Professional Geotechnical Engineer to be 'allowable', the preload can be removed. Generally, preloading durations for silt, clay, and peat soils can be of the order of weeks to years, respectively, depending on the soil type and proposed loading.

With a weight compensation design approach, the building footprint is 'unloaded' (by incorporating a crawlspace and/or replacing existing site soil with lightweight fill such as pumice) an amount equal to or greater than the expected weight of the proposed development. All sites underlain by peat and other organic soils, ongoing settlement could be expected.

A caution with any site underlain by compressible soil (i.e., peat, clay, and/or silt) is that these soils are inherently variable and differential settlement should be expected. In particular, the loading history of various areas of a site will impact the performance of any preload, as well as the future performance of the building. At sites underlain by peat and other organic soils, ongoing settlement could be expected.

6.4 **Seismic Resistance of Foundations**

In seismically vulnerable areas, building (including foundation) repair should be expected to be required following a significant earthquake. The BCBC 2012 requires that all buildings can resist the forces associated with the design magnitude earthquake event such that they 'not collapse' and are 'safe to exit from'. Post-event cosmetic and structural repair should be expected unless the buildings have been specifically designed as post-disaster structures.

Buildings on sites that are underlain by deposits of poorly consolidated alluvial soils (such as loose, saturated sands that can liquefy and/or sensitive clays and/or organic soils that can amplify ground motions) are particularly vulnerable to seismic events. These subgrade soils are typically associated with a Site Class F designation and may require subsurface investigation to the shallower of 30 metres (100 feet) depth or firm ground in order to suitably quantify seismic ground response for the purpose of structural design. However, the BCBC 2012 (Section 4.1.8.4 (6)) indicates that for design of structures with a fundamental period of vibration of less than 0.5 seconds (which is understood to be generally the case for buildings of 5 storeys or less) that are built on liquefiable soils, the Fa and Fv values may be determined as if the site was not liquefiable. For best practice, the structural engineer in consultation with the geotechnical engineer should determine if this is a suitable approach for the subject building on the subject site.

In areas underlain by potentially liquefiable soil, improved seismic performance can result if foundations are 'tied together'. This is often achieved by using the slab-on-grade to 'collar' columns and/or by dowelling the slab-on-grade into adjacent columns and foundation walls, or by installing footing tie beams in two directions.

Photo 7: **Example of a suitably prepared foundation subgrade.**

6.5 Foundation Subgrade Preparation

Compressible or potentially decomposable soil left on the foundation subgrade will contribute to post-construction settlement. Foundation subgrades should therefore be stripped of organic-rich, loose, disturbed, water-softened, frozen, and/or previously frozen soil. Once subgrades have been excavated using a digging bucket, a clean-out bucket can be used to remove much of the loose soil remaining. Further removal of unsuitable soil by hand is recommended (see Photo 7). This is often effectively accomplished using a spade (rather than a square shovel) held sideways (like a hockey stick) to scrape or slice off the disturbed or deleterious soil. This would include sand and gravel that has been loosened as the excavator bucket scrapes over and disturbs gravel or cobble sized fragments.

It is generally suitable to protect most soil subgrades by placing a 5 to 10 centimetres (2 to 4 inches) thick layer of clear, angular gravel or 2.5 to 5 centimetres (1 to 2 inches) thick layer of lean concrete. These 'blinding' materials, when placed over prepared, undisturbed subgrade materials, can help protect them from water softening and disturbance and save time and labour in removing unsuitable materials prior to pouring concrete. Note that these thicknesses will not necessarily protect subgrades from freezing, and local best practices should be followed in this regard.

Foundations of settlement-sensitive structures should not be supported by fill of unknown quality, depth, or underlying condition (e.g., buried topsoil). If it is desirable to raise grade beneath foundations, well-graded Engineered Fill may generally be used. In some instances, (i.e., where a high water table is present), it may be preferable to use clear, angular gravel as the Engineered Fill. Where fill will be placed to raise grade beneath foundations, the area should first be stripped of existing, unknown fill and any organic-rich or deleterious material, including topsoil. The footprint of the stripped area should extend outside of foundations a distance equal to the depth of fill to be placed, as shown in Figure 6. In general, final grades should not exceed pre-development grades by more than about 0.3 metre (1 foot) unless the area is known to <u>*not*</u> be underlain by compressible soil.

In areas not known to be underlain by glacially consolidated soil or near-surface bedrock, it may be advantageous to seek the advice of a Professional Geotechnical Engineer. In areas underlain by compressible or liquefiable soil or soil prone to swelling, it is recommended that a Professional Geotechnical Engineer be consulted.

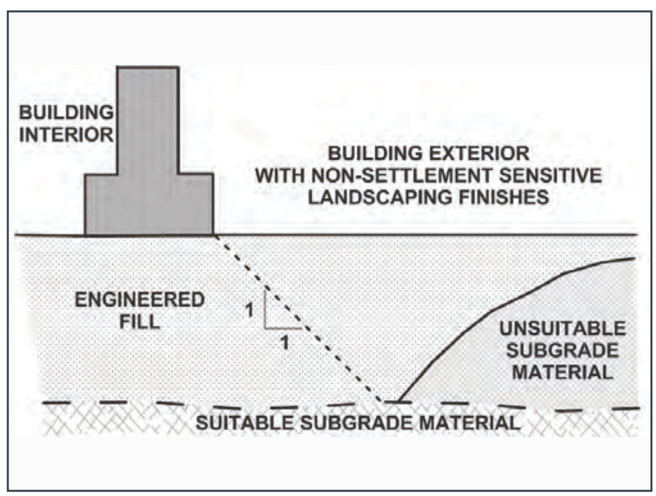

Figure 6: **Engineered Fill should be placed on suitable subgrade material, extending beyond the footprint area a distance equal to its thickness.**

If a Professional Geotechnical Engineer has undertaken responsibility for "Bearing Capacity of the Soil" (i.e., Item 8.1) on the BCBC Schedule B, they should be provided with the opportunity to review the foundation subgrade prior to placing blinding materials or foundation concrete. This foundation subgrade field review should ideally take place before reinforcing steel is placed in footing forms and certainly before wall formwork is erected if foundation walls will be constructed with a single pour. The BCBC Schedule C cannot be completed at the end of the project without having carried out the required field reviews.

KEY TOPICS COVERED

- BCBC provides minimum requirements for conventional foundations
- best practice is for Professional Geotechnical Engineer to determine the type of subsurface investigation required
- best practice to reinforce foundations
- frost protection
- stepping of adjacent foundations
- dowelling foundations into bedrock
- rock bolting of potential rock failures above or below site
- best practice to include a Professional Geotechnical Engineer for sites with potentially compressive, expansive, or liquefiable soil
- preloading, raft foundation, weight compensation strategies
- loading history important with compressible soils
- foundation repair should be expected following significant earthquakes
- deep subsurface investigation in potentially liquefiable soils
- foundation subgrade preparation
- Engineered Fill

7.0 Excavations

Excavations should be carried out in conformance with WorkSafeBC requirements; in particular, Section 20.78 of the *Occupational Health and Safety Regulation.* It is possible that temporary slopes with grades that are steeper than those that meet the WorkSafeBC criteria will be suitably stable and considered "safe" for personnel and equipment to work below for a limited amount of time, but this should be assessed by a Professional Geotechnical Engineer. It is also possible, especially in loose granular deposits and fissured clays, that slopes will have to be sloped at angles much flatter than the WorkSafeBC criteria in order to be safe. For example, in Maple Ridge, large-scale slope failures on gradients as shallow as 7 to 10 degrees from horizontal have been recorded in fissured clays.

All excavations should be expected to move. However, the magnitude of this movement can be minimized by understanding the soil conditions and designing suitable slopes or shoring systems. Following a subsurface investigation and analyses, a suitably qualified Professional Geotechnical Engineer will be able to advise on what is a "safe" and stable excavation slope for a given site and, for many sites, to design excavation shoring to allow vertical excavations to be advanced. Often, safe excavation slopes within the property lines are possible if properly planned, but this opportunity may be lost when earthworks contractors excavate without appropriate professional

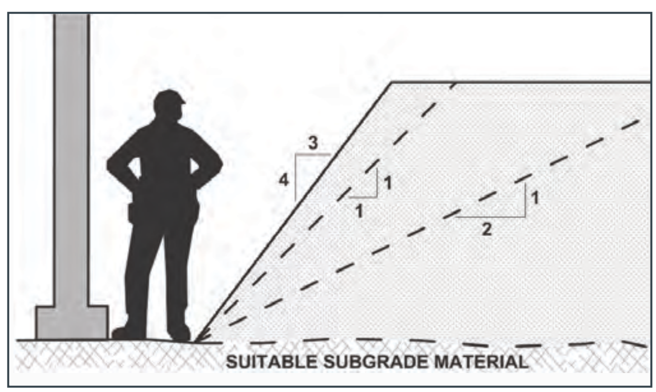

Figure 7: **Examples of possible temporary excavation slope angles at an example site; recommendations would be provided on site by a Professional Geotechnical Engineer based on actual site conditions.**

Photo 8: **Example of an unsafe temporary excavation slope (unsupported).**

guidance, resulting in the need for more costly temporary shoring strategies and/or remedial measures.

It is advisable to consult a Professional Geotechnical Engineer prior to starting the excavation in order to reduce the risks of avoidable ground movement at adjacent properties, compromised safety of site personnel, and potentially costly mitigation works. It is also advisable to promote a positive relationship with adjacent neighbours (as discussed in Section 5.0), as the cost of excavation and shoring options can be minimized if encroachment is a possibility. Sites should be graded to direct surface runoff away from the excavation and exposed soil slopes should be protected from erosion (i.e., commonly, 6-mil polyethylene sheeting is securely staked to the slope). Existing structures, excavation soil, construction materials, and vehicles (including construction traffic) should be located behind a line rising from the toe of a temporary excavation at an inclination recommended by a Professional Geotechnical Engineer. Often, this line ranges from 1 vertical : 2 horizontal to 1 vertical : 1 horizontal, or steeper, depending on the site conditions (see Figure 7).

In commercial developments, it is common to allow 0.6 metre (2 feet) of working space between excavation shoring and the foundation wall and 0.5 metre (1.5 feet) of working space between the toe of a sloping temporary excavation and the foundation wall. This is usually more than sufficient to allow access for and construction of footings and foundation walls, application of damp-proofing and drainage membranes, and installation of perimeter foundation drainage.

Contrary to this, many earthworks contractors for single family houses advance a near-vertical temporary excavation, as shown in Photo 8, commonly leaving 1.5 metres (5 feet) of working space between the slope toe and the foundation wall. This is a problem, especially at the side yards, for many reasons, including the following:

- It is unsafe to work adjacent to the near-vertical slope, especially when the foundation wall is constructed and the subject area becomes confined.
- The stability of the neighbour's property, and possibly the neighbour's house and/or buried utilities, is compromised.
- There is an added project cost to excavate and haul this additional material.
- It costs more to backfill this area relative to an excavation strategically advanced under the guidance of a Professional Geotechnical Engineer.
- Over-steepening of the near-surface soil, which tends to be less competent, can limit the options in terms of achieving a "safe" slope without shoring.
- The failure of an excavation and damage to adjacent structures can be much more costly than installation of temporary excavation support measures, up to and including injury and loss of life.

A stabilized temporary excavation slope is shown in Photo 9.

Photo 9: **Example of a previously unsafe temporary excavation slope that has been stabilized with a Lock Block retaining wall.**

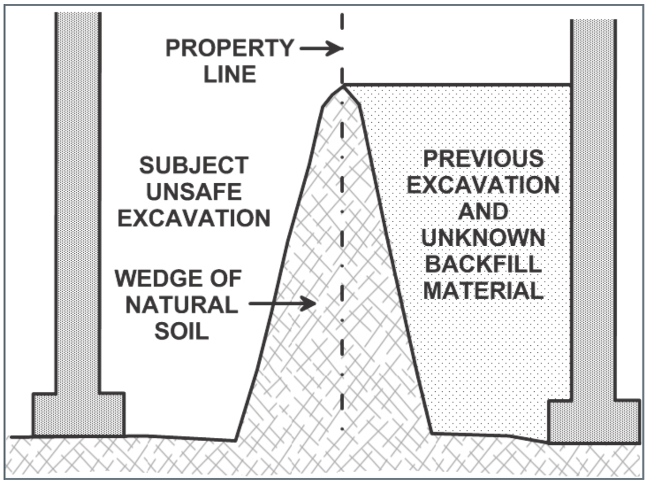

Figure 8: **Example of a potentially unstable slope configuration that can occur when an excavation is advanced adjacent to a previous excavation with unknown backfill material, leaving a wedge of natural soil.**

Soil conditions on an excavation face may appear to be good, when in reality, there may only be a narrow wedge of competent soil separating the near vertical slope from the loose, often wet, and variable backfill for the adjacent basement. This potentially unstable configuration is illustrated in Figure 8. If it is not possible to suitably flatten the slope (which typically requires encroachment onto the neighbouring property), temporary shoring would be required. An example of a non-encroaching temporary shoring system is vertical pipe piles, which is shown in Photo 10.

Photo 10: **Example of a temporary shoring system comprising pipe piles that do not encroach onto neighbouring property.**

The Professional Geotechnical Engineer undertaking responsibility for "Excavation" (i.e., Item 7.1 on the Schedule B) and/or "Shoring" (i.e., Item 7.2) for a site should be contacted in advance of mobilizing excavation equipment to the site. The engineer's final field review of the excavation should be made prior to demobilizing equipment from the site.

KEY TOPICS COVERED

- WorkSafe BC requirements
- worker safety
- stability of adjacent structures and utilities
- temporary shoring when insufficient space for sloping
- erosion protection
- encroachment onto neighbouring property advantageous
- advise geotechnical engineer before starting excavation
- field review prior to demobilizing equipment

8.0 Sediment and Erosion Control

It is considered best practice to implement systems to manage site surface water in such a way that erosion is minimized in order to also minimize impacting property, infrastructure, and natural drainage systems. This could include staging site clearing, mulching, and winnowing as well as the use of temporary sediment treatment infrastructure such as settling ponds, filters, and proprietary systems. Refer to the Environmental Protection Agency documents in the Links section for more details.

In urban areas, it is increasingly a Building Permit requirement to submit documentation for plans and processes to control erosion and sediment laden runoff from impacting off-site property and infrastructure. This requirement is often augmented by requirements for monitoring weekly (to semi-weekly in summer months) by suitably qualified registered personnel.

9.0 Engineered Fill and Backfill

All fill materials that will support settlement-sensitive structures or that embed geogrid should comprise compacted Engineered Fill or clear crushed gravel. Even fills compacted to greater than 100% of their maximum dry density when determined in accordance with ASTM D698 ('Standard Proctor') can be expected to settle of the order of 1% of the total fill thickness. Siltier or poorly compacted fill materials would be expected to settle and could cause cracking of supported structures, create trip hazards, and/or contribute to grading problems such as ponding, which can in turn become an ice hazard or contribute to building envelope issues. 'Bucket-' or 'track-packing' is not considered a suitable method of compaction. When importing fill materials, documentation should be obtained to ensure that the material does not contain environmental contaminants.

In general, sandy fill should not be placed on top of clear gravel without an intermediate filter layer, such as filter cloth. At least the top 15 centimetres (6 inches) of fill beneath slabs-on-grade should typically comprise clear gravel, and 19 millimetre (3/4 inch) clear crushed gravel has been proven to perform well in this application. Clear gravel is also often suitable for use as Engineered Fill when fill must be placed below the water table.

Engineered Fill should generally (notwithstanding the above) consist of select, clean, well-graded, granular material with less than 5% fines content by mass and 100% passing a 75 millimetre (3 inch) sieve. Gradation testing should be carried out on potential Engineered Fill materials in order to determine the distribution of grain sizes. If a material is judged by a Professional Geotechnical Engineer to be suitable for use as Engineered Fill, Proctor testing should be carried out on the material such that compaction criteria can be obtained. Engineered Fill should be compacted to the equivalent of at least 100% of its Maximum Dry Density as determined in accordance with ASTM D698 (Standard Proctor). Field density testing should be carried out to ensure the compaction criteria are achieved.

Any material proposed for imported Engineered Fill should have associated documentation verifying that it is free of contaminants. This documentation should be provided to an environmental consultant for approval before any material is imported.

In general, provided that Engineered Fill is placed within about 2% of its optimum moisture content for compaction, the above compaction criteria can often be achieved with several passes of the following equipment, compacted until no seams are visible between adjacent passes. However, lift (layer) thicknesses should generally be limited to approximately 0.3 metre (1 foot) such that compaction testing of the total thickness of fill materials is possible.

- 1000 lb vibrating plate tamper used on 0.25 to 0.30 metre (10 to 12 inches) thick lifts.
- Walk-behind vibrating roller compactor used on 0.30 to 0.36 metre (12 to 14 inches) thick lifts.
- Ride-on vibrating roller compactor used on 0.4 to 0.6 metre (16 to 24 inches) thick lifts.
- Hoe-pac attached to a backhoe used on 0.6 metre (24 inches) thick lifts.
- Hoe-pac attached to an excavator used on 0.9 to 1.1 metre (36 to 42 inches) thick lifts.

Additional passes of compaction equipment on a lift that is too thick, too wet, or too dry will *not* be successful in achieving the recommended compaction criteria. Only lightweight compaction equipment (i.e., vibrating plate tampers) should be used within 0.9 metre (3 feet) of foundation or retaining walls. Greater offsets or lightweight equipment may also be recommended adjacent to settlement or vibration sensitive structures or features, including buried utilities.

If a Professional Geotechnical Engineer has undertaken responsibility for "Engineered Fill" (i.e., Item 8.3 on the Schedule B), they should be provided with the opportunity to review:

- the subgrade before placement of the Engineered Fill, and
- the Engineered Fill material type, placement procedures, and compaction test results.

Backfilling of foundation walls should not commence until the structural engineer has advised that is it safe to do so. In addition, backfilling should be staged such that significant differences in backfill heights on opposite sides of a structure are avoided, as houses have been known to lean and/or collapse when subjected to significant differential backfill heights.

Backfilling of foundation walls should be carried out in accordance with the best practices methods described in Section 10.3 below.

KEY TOPICS COVERED

- material specifications
- compaction criteria
- potential settlement
- filter cloth over clear gravels
- permission from structural engineer prior to backfilling foundation walls

10.0 Drainage

10.1 Stormwater Management

Increasingly, the capacity of municipal storm sewers in urban and suburban areas, especially in coastal cities, is being challenged as new development increases impermeable areas and, thus, stormwater runoff flows and peak volumes. Often, municipalities will require that stormwater management plans be developed using 'water balance' methodology and submitted at the time of Building Permit application.

Stormwater management elements may include stormwater infiltration trenches or fields, rock pits or dry wells, storage tanks, controlled orifice or gate valve discharge, and pumps. Civil engineers and some geotechnical engineers are experienced in the design of such systems. In general, stormwater infiltration features should not be located at the crest of a slope and it is best practice to direct storm runoff to the toe of a slope in a closed system located so as to not be vulnerable to slope creep.

It has generally been proven to be impracticable to consider re-using rainwater for irrigation. The exception to this might be using rain barrels for hand watering of patio planters or, for large sites, creating ponds.

If a Professional Engineer has undertaken responsibility for "Site and Foundation Drainage" (i.e., Item 4.2 on the Schedule B), they should be provided with the opportunity to review the installation of elements for the stormwater management system for which they have provided design recommendations. In addition, they should be provided with the opportunity to test the entire system. Typically, the professional's responsibility includes elements 'downstream' of the sump, while the plumbing inspector often checks those elements 'upstream' of the sump.

10.2. Drain Pipes and Materials

10.2.1 Sumps

Storm sumps, generally comprising precast concrete, are a requirement of the current building code. They allow debris from surface runoff (including roof runoff) to be collected so as to not enter and potentially plug a drain pipe or sewer. Before 1990, sumps were generally not in wide use, nor were they a requirement of the building code.

10.2.2 Asbestos Cement Pipe

Asbestos cement pipe was sometimes historically used for pipes. Asbestos is a known carcinogen that also has numerous other health hazards. As a result, the removal and replacement of asbestos cement pipe is generally thought to be important but also hazardous. The use of asbestos cement pipe is no longer recommended.

10.2.3 Big-O Pipe

Big-O pipe was often used for perimeter drainage in BC from about 1980 to 2000. This pipe is prone to sagging because it is flexible, and to plugging because the corrugations of the pipe promote deposition of soil. It is also prone to crushing, especially when covered by deeper thicknesses of backfill material. It can be flushed with varying degrees of success, but often cannot be unplugged. The use of Big-O pipe is no longer recommended.

10.2.4 Clay Drain Tile

Clay drain tile was used for perimeter drainage before about 1980. It is prone to ingress from roots. It can be flushed with varying degrees of success. Trying to 'snake' this pipe can result in it breaking and collapsing. The use of clay drain tile is no longer recommended.

Photo 11: **Example of a foundation wall with drainage membrane applied over the damp-proofing agent and PVC foundation drain pipe bedded in clear gravel wrapped in filter cloth.**

*10.2.5 **PVC Pipe***

PVC has been in use for drainage purposes since circa 1980. It is the most easily flushed, snaked, and unplugged pipe material commonly in use and is the least prone to breakage. It is recommended for use for drainage purposes (see Photo 11).

*10.2.6 **Drainage Membrane***

Since about 2005, it has been common practice to apply drainage membrane against the exterior of below grade foundation walls (see Photo 11). This geotextile has a dimpled plastic membrane backed by filter fabric. The filter fabric is intended to allow water to pass through and flow down between the dimples to the perimeter drainage, while retaining soil. Against the foundation wall, the opposite side of the dimpled plastic provides an air gap that is intended to be a capillary break.

This geotextile does not have a long, proven history of use, although it does appear to be working at this time in many applications, provided it is properly affixed and backfill soils are sufficiently free draining. Over time, it is possible that the filter fabric may become clogged with fines and this is now arising as a problem where fills contain fine grained soil. The potential for long term degradation of the plastic comprising drainage membranes, including due to soil pH and other chemical components of soil, is unknown. For best practice, the manufacturer and plumbing inspector should be consulted for local usage recommendations.

*10.2.7 **Gravel***

Clear gravel is a proven and excellent material for use to backfill foundation walls, provide underslab drainage, and as a component of french drains. Clear gravel, per the BCBC 2012, is specified to have less than or equal to 10% passing the #4 (4.75 millimetre / 0.2 inch) sieve. A gradation corresponding to 100% passing the 2.5 centimetres (1 inch) sieve and 100% retained on the 1.9 centimetre (3/4 inch) sieve is expected to provide greater void volume and a longer design life in many applications where 'clear' gravel is a design element.

10.3 **Foundation Drainage Recommendations**

It is best practice to have roof runoff and foundation drainage (also referred to as perimeter drainage) managed by separate systems (see Photo 11), as opposed to roof runoff being directed into perimeter drainage pipes. Where it is necessary to pump water collected in the perimeter foundation drainage system, operating costs are increased if surface runoff is not directed by gravity to the discharge location.

Although the BCBC 2012 allows for perimeter drainage to comprise only clear gravel at the footing elevation (Section 9.14.2.1), best practice would be to include a perforated pipe with perforations facing downwards, bedded on and covered with clear gravel. This pipe could comprise minimum 10 centimetres (4 inches) diameter, rigid, perforated, PVC pipe, sloped at 1%, and directed to a suitable disposal location approved by the authority having jurisdiction. All connections should be made with 45 degree corners rather than 90 degree corners, to allow ease of future clean out.

Foundation drains should be installed with invert elevations at least 0.3 metre (12 inches) below the adjacent interior slab-on-grade elevation. Where there is a step in the slab-on-grade, interior foundation drains are also recommended, and these should be installed below the elevation of the lower adjacent slab.

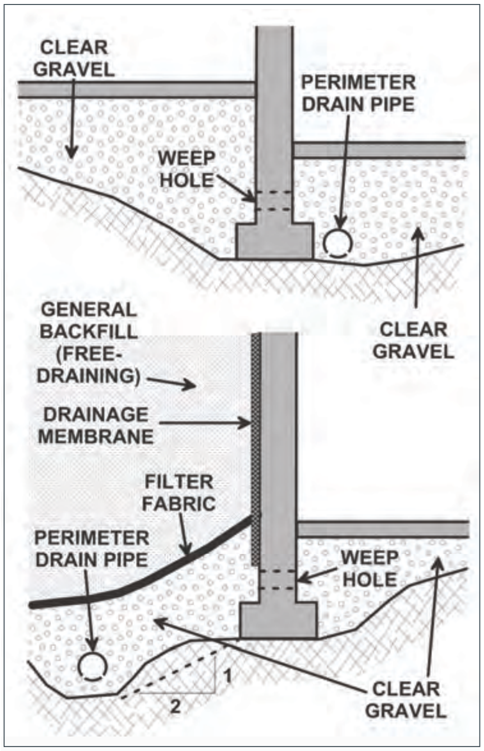

Figure 9: **Examples of perimeter and underslab drainage configurations: interior at steps in the foundation (above) and exterior, with drainage membrane (below).**

The requirement to have the pipes below the slab elevation and to slope them often results in the bedding material for the pipes being deeper than the adjacent foundation. If the excavation for this installation is too close to the footing, the bearing conditions for the footing can be compromised. In general, the excavation to allow for installation of the perimeter foundation drains and bedding should not encroach beyond a line extending down from the foundation at 1 vertical : 2 horizontal, as shown on Figure 9. Where this is problematic:

- This scenario could be planned for and a deeper footing and higher foundation wall could be constructed.
- In some soil conditions, this line can be steepened to as much at 1 vertical : 1 horizontal.
- Filter fabric can be installed between the foundation and drainage subgrade soil and the gravel bedding for the drain pipe, and/or
- With permission from the plumbing inspector for the authority having jurisdiction or upon approval by the professional undertaking responsibility for Site and Foundation Drainage (Item 4.2 on the Schedule B), the recommended minimum slope of 1% could be further reduced.

The BCBC 2012 requires that clear gravel cover the top and sides of drain pipes; however, best practice mandates that clear gravel bedding also be provided beneath drain pipes. Gravel thicknesses of at least 15 centimetres (6 inches) are recommended. It is important to recognize that water will accumulate and travel in the bedding material before it reaches the perimeter drain pipes.

Water will not flow in the drain pipes until it has sufficiently accumulated such that it enters the (downward-facing) perforations of the drain pipes. If there is no bedding material, water cannot easily enter the pipes and may accumulate to a depth that could adversely impact the building basement. In areas where there is significant groundwater seepage or infiltration of surface water into the backfill zone, it would be best practice to continue the gravel around perimeter drain pipes as a 'chimney' adjacent to the foundation wall up to near the finished grade. A layer of filter fabric should separate clear gravel from overlying fine-grained soil such as landscaping medium or sand placed as a levelling course for pavers. In areas where there is significant groundwater seepage, filter fabric could also be installed beneath the clear gravel bedding for perimeter drain pipes and between the clear gravel chimney and adjacent fine-grained backfill or in-situ soil (see Photo 11).

Design and construction of perimeter drains in areas with expansive soils is to be carried out by a qualified professional due to potential adverse impacts of water introduced into the subsurface soil.

In areas where iron ochre is known to be a problem, it is especially important to follow best practices, including consulting the local building or plumbing inspector and suitably qualified professionals. A shortened design life of drainage systems in these areas may be expected, even with an enhanced maintenance program.

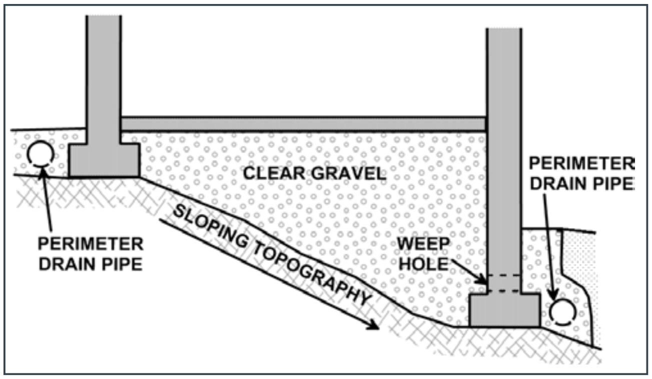

Figure 10: **Best practice underslab and perimeter drainage configuration for a building on sloping topography.**

10.4 Underslab Drainage Gravel

Generally, the success of a perimeter foundation drainage system also relies on a suitable underslab drainage layer. At least a 15centimetre (6 inch) thick layer of clear gravel is recommended immediately below any interior slab-on-grade to provide a capillary break and act as a drainage layer. Sand will generally not provide a suitable capillary break, as water can wick upwards as much as several feet in sand. Polyethylene sheeting is also not an equivalent substitute for clear underslab gravel; however, it is often recommended to cover the gravel (with seams taped and edges caulked to foundation walls) as a second barrier against moisture ingress and as a possible barrier against soil gas.

Careful thought should go into deciding whether to provide a direct hydraulic connection (i.e., through foundation wall weep holes) from the underslab fill to exterior drain pipes. Specifically, considering that water will be collecting in the gravel bedding around perimeter drainage and (if there is a groundwater source within the footprint of the house) in the underslab gravel, it may be desirable to have these weep holes on only the 'downstream' side of the house footprint (see Figure 10).

10.5 Drainage Remediation

Installing defective or inadequate foundation drainage systems can lead to significant water ingress and structural foundation problems, both of which are commonly very expensive to remediate due to both the invasive nature of the repairs and access limitations posed by patios, sidewalks, and landscaping that are installed following construction.

When a drainage system fails to adequately remove water from against foundation walls, increased hydrostatic pressures on the walls can lead to foundation cracking and movement, which in turn allow water into the structure. Where there is seepage or ingress of moisture to the below grade area of a house, remediation is usually iterative and almost always frustrating for the homeowner or house occupant, and often the contractor. Sources of water should be investigated, and the function of existing drainage systems should be reviewed. Sources of water could include, but are not limited to, the following:

- High groundwater table and high hydraulic conductivity of adjacent natural soil resulting in seepage into the backfill zone.
- Upward groundwater flow into the underslab gravel, including by capillary action if sand, rather than gravel, was used as an underslab support material.
- Flow of perched groundwater into the backfill zone.
- Flow of surface water into the backfill zone, including due to changes in upslope, off-site conditions.
- Plugged drain pipes, including due to the effects of iron ochre.
- Under-capacity drain pipes.
- Under-capacity, poorly maintained, or inappropriately triggered pumps (including pumps that burn out because sump volumes are too small).
- Leaking plumbing fixtures in floors above.
- Compromised above-grade building envelope.
- A storm, tide, or flood event or combination of events that exceeds the maximum design event.
- Collection of water vapour due to building envelope systems that are inappropriate.
- Shallowly-sloping drainage systems with downstream inverts that are compromised by sedimentation, vegetation, ice, etc.
- Off-site situations such as a poorly-served munici-pal sewer (downstream ditches that are full of ice, pipes that are under capacity or that have become under capacity with nearby development, pumped systems that improperly trigger, etc.).

These could be exacerbated by cracks in foundation walls or a lack of suitable gravel as bedding under foundation perimeter drainage and/or as an under-slab drainage layer. It makes sense to try the easiest potential solution first. Sometimes a solution can be found by doing something as simple as re-sloping a gutter so that it drains toward a downspout (rainwater leader) that is downstream of the current, destination down-spout. Having a specialty sub-contractor 'camera' and scope existing drain pipes is a useful tool to allow evaluation of the function of existing drainage systems. Doing flow tests is not as conclusive, although insight can be gained by introducing tracer dye into discrete downspouts.

The most cost effective solution for a site will depend on the configuration of the existing drainage system and site access. It is common for several solutions to be necessary in order to achieve complete satisfaction. Some Professional Geotechnical Engineers can provide assistance for sites requiring drainage remediation.

KEY TOPICS COVERED

- separate systems for roof and foundation drainage
- stormwater management plans often required for building permit application
- sumps required by BCBC
- asbestos cement pipe, Big-O pipe, clay drain tile no longer used
- PVC pipe used for drainage systems
- drainage membrane
- clear gravel
- best practice is to use perforated pipe for foundation drainage
- perforations facing downward, pipe surrounded by clear gravel
- drainage chimney against foundation walls
- filter fabric between clear gravel and other soil
- clear gravel underslab drainage layer
- weep holes through foundation walls
- drainage remediation expensive, iterative, and frustrating
- structural problems
- try easiest potential solution first

11.0 Landscaping

Landscaping merits consideration and possibly input from a suitably qualified professional when the site or adjacent downslope area is sloping at more than 20 degrees (or 10 degrees in clay) or areas underlain by peat deposits, subgrade soil is compressible or expansive, the groundwater table is high, and/or the site is below the Flood Construction Level.

11.1 Sloping Sites

Filling at the crest or excavating at the toe of a slope should be discouraged unless a Professional Geotechnical Engineer is providing recommendations.

Removing vegetation from a slope should also be discouraged as vegetation provides erosion protection to surficial soil and limited root mass cohesion. If trees are to be cut down on or adjacent to a slope, their root systems should be left intact, replacement vegetation should be planted, and consideration of long term slope stability should be addressed by a Professional Geotechnical Engineer.

There are many sites in BC where first growth stumps near the crest of a slope have been used to retain soil. The roots that have been integral to slope stability in these areas are now mostly decomposed. Sites with this condition should be assessed and the crest unloaded as deemed appropriate.

It is common for garden debris to be dumped at the crest of a slope in a 'green' effort to compost, while extending the usable area of a yard. Besides often harming the native vegetation, these fill materials impose a surcharge at a vulnerable portion of the slope, thereby decreasing the slope stability. These fills are also inherently loose and often the initiation point of a landslide, especially in extreme wet weather conditions such as rain-on-snow events. Weathered downslope soil can become entrained in the mobilized soil mass and increase the overall landslide volume, runout distance, and velocity. In addition, the resulting landslide scar may be increased in size, and the extent of damage or injury, particularly to properties located downslope, may be increased.

Photo 12: **Example of a geogrid-reinforced SierraScape retaining wall under construction.**

11.2 Ponds, Swimming Pools, and Irrigation

Ponds and swimming pools installed at the crest of a slope are a potential hazard. Landslides have been partly initiated by leaking ornamental ponds at the crests of steep fill slopes; therefore, these types of landscaping features should be reviewed with respect to landslide hazards. Irrigation in the vicinity of foundations on expansive soil should be avoided.

11.3 Retaining Walls

Engineering design is often a requirement of the authority having jurisdiction for retaining walls 1.2 metres (4 feet) in height and higher. The BCBC 2012 requires that all retaining walls are designed to resist the lateral soil pressures retained behind the wall.

Retaining walls can comprise reinforced concrete 'cantilever' walls, geogrid-reinforced proprietary block or modular systems (such as SierraScape as shown in Photo 12, Sierra Slope, Allan Block, Keystone, Pisa Stone, etc.), other 'gravity' systems (such as Lock Blocks, Maccaferri gabions, or stacked boulders), or anchored systems. Timber retaining walls are not recommended due to their limited design life. All retaining walls must be designed not to slide, overturn, or experience a failure through the bearing and/or retained soil. For terraced slope geometries and stepped retaining walls, these failures must be overcome at each terrace and combination of terraces. For most of the above-noted systems, it is the weight of the soil (i.e., on the footing of the cantilevered wall or "sandwiched" between the geogrid) or of the retaining units (i.e., Lock Blocks or boulders), if they are heavy enough, that provides the resistance to sliding or overturning. The resistance of a retention system to a global slope failure is a function of the strength of the subgrade and retained soil types, with consideration of geogrid or anchor type, length, and spacing. It should be noted that geogrid may have a preferential strength direction; therefore, proper orientation of geogrid is important.

Figure 11 indicates a terraced retaining wall geometry that is often allowed without a building permit. However, this configuration is inadequate from an engineering perspective, as best practice is for an engineering design to consider the possibility of internal, sliding, and overturning failures, as well as bearing and circular global slope failures within the underlying soil. Suitable Factors of Safety against these types of failures for static loading conditions are prescribed in the Canadian Foundation Engineering Manual (CFEM). For seismic loading conditions, especially where slopes are proximate to a residence, guidance can be found in the Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC published in May 2010 by the Association of Professional Engineers and Geoscientists of BC (see the links section at the end of this document).

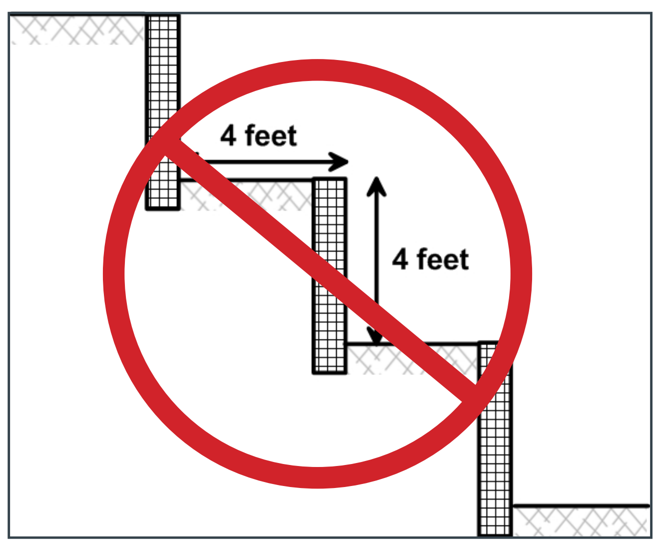

Figure 11: **Example of a terraced retaining wall configuration that is not designed according to best practice.**

As a general rule, in order for two retaining walls to act independently, the separating distance must be at least twice the height of the lower wall. This approach may be conservative but will afford the designer or wall builder with an assurance that the walls are likely to stand by themselves and have no impact on adjacent walls. This configuration is also generally applicable to a building foundation adjacent to a retaining wall: the separating distance must be at least twice the height of the lower wall or the upper wall will induce a surcharge load on the lower wall.

In areas where seismic design of retaining walls is required, site specific conditions should be accounted for by the Professional Geotechnical Engineer.

11.4 Pavements

After removing any fill, loosened, softened, disturbed, organic, or otherwise deleterious material from beneath new pavement footprint areas to expose suitable subgrade materials, the following pavement section is often recommended as being able to support fire truck access on a competent subgrade. It is noteworthy that some municipalities may have minimum pavement section requirements, which should be implemented.

- 8 centimetres (3 inches) of asphaltic concrete
- 10 centimetres (4 inches) of 19 millimetre (3/4 inch) minus crushed sand and gravel base course
- 20 centimetres (8 inches) of 100 millimetre (4 inch) minus, well graded, clean, sand and gravel subbase course

The sand and gravel base and subbase course materials should be compacted in lifts to at least 98% of the material's maximum dry density as determined in accordance with ASTM D698 (Standard Proctor), and be within 2% of its optimum moisture content for compaction. The actual densities achieved should be measured by in-situ density tests. Laboratory soil gradation tests should be carried out on the base and subbase course materials to confirm that the particle size distribution is well graded.

Any Engineered Fill required to raise grades to support paved areas should be placed directly on the approved subgrade material. This fill shall be compacted to at least 95% of its maximum dry density as determined in accordance with ASTM D698 (Standard Proctor), and be within 2% of its optimum moisture content for compaction, with the actual densities achieved measured by in-situ density tests.

KEY TOPICS COVERED

- consult Professional Geotechnical Engineer when site slopes more than 20° (10° in clay) or is below FCL
- consult Professional Geotechnical Engineer when site underlain by organic, compressive, or expansive soils
- slope destabilization
- don't dump garden debris near crest
- ponds and swimming pools near crest should be reviewed by Professional Geotechnical Engineer for landslide hazard
- don't irrigate near foundations in expansive soil
- design retaining walls and combinations of retaining walls to resist overturning, sliding, bearing, internal, and global failures due to retained earth and internal pressures
- retaining walls often require geotechnical design when higher than 1.2 metre (4 feet)
- terraced retaining walls
- seismic design of retaining walls

12.0 Surface Water Management

12.1 Flood Construction Level and Flood Considerations

The Ministry of Environment's Flood Hazard Area Land Use Management Guidelines requires that the underside of the floor system supporting living space be above the Flood Construction Level (i.e., the elevation corresponding to a flood event with a 200 year return period, or "Q200"). The Q200 level is <u>NOT</u> the 'high water level' at the nearest water body, as is often determined by a BC Land Surveyor. The Q200 elevation is most accurately determined by a hydraulic engineer and can include considerations of storm runoff, tide, wind, and freeboard, as well as an element of sea level rise due to climate change.

Geotechnical engineering services relating to flood-proofing a site or portion thereof may include raising site grades, designing a flood protection berm, designing scour protection of berms and foundation subgrades, or providing recommendations for water-proofing and dewatering structures built below the Flood Construction Level. This design of these elements may be done in conjunction with a hydraulic engineer and should consider off-site impacts.

12.2 Grading

Appropriate grading of sites may be combined with other management strategies for success in dealing with surface water problems, whether due to storm-water runoff or to a high groundwater table. Elements that may be incorporated into a grading plan may include swales, ditches, and french drains. These would require ongoing maintenance during the life of the development.

12.3 French Drains

French drains can be an effective method of controlling surface and near-surface water in gently sloping landscaped areas with suitable soil conditions.

A french drain is typically a gravel-filled trench oriented parallel to topographic contours (perpendicular to the downslope direction). The trench generally extends down through surficial, high permeability soil, deep enough to penetrate into underlying low permeability soil. Groundwater that is perched on the deeper, low permeability soil layer can flow into the trench and be purposefully directed elsewhere. It is beneficial to extend the gravel to the surface or cover it with filter fabric prior to placing fine grained soil. Installing a perforated pipe near the bottom of the trench, with clean-outs as appropriate, is also beneficial as, with suitable maintenance, it can extend the design life of this feature. This pipe should discharge at an approved location.

KEY TOPICS COVERED

- Flood Construction Level
- Q200 is not the surveyed 'high water level'
- best practice to consult a Professional Geotechnical Engineer for design of flood-proofing measures
- grading to provide surface water management
- french drains

13.0 Septic Systems

Septic systems are registered with the local health department. They are designed by qualified engineers and should be constructed by Registered On-Site Wastewater Practitioners.

A septic system for a single family home (or equivalent) may comprise a grinder, aerator, package treatment system, septic tank, and septic field. Generally, the more treatment that effluent receives before it is directed to the septic field, the smaller the field needs to be. The size of the field is determined based on effluent volume, treatment, and natural soil conditions at the field. The intent is to allow a biomass to develop in the field at a suitable depth that allows for aerobic decomposition without the biomass reaching the surface. Optimally, the flow of the effluent is such that pathogens have a sufficient length of time in the biomass so as to be treated. Thus, depending on the linear and hydraulic loading rates for the field, some fill may need to be imported. This is expected for 'mound' systems and typically comprises a specific sand product referred to as "C33 sand" or "concrete sand".

KEY TOPICS COVERED

- septic systems are registered with local health department
- septic systems are designed and constructed by qualified engineers / practitioners, respectively
- general septic system design

14.0 Other Geotechnical Considerations

14.1 Soil Gas Management

Methane is a product of decomposing organic matter, such as peat; it is flammable and may be hazardous if it is allowed to accumulate. Radon is a naturally occurring gas that is emitted from some types of soil and bedrock; it is a radioactive carcinogen. Radon gas is the second most common cause of lung cancer in Canada, and lung cancer is the leading cause of cancer death in both men and women in Canada.

Buildings constructed over organic soil or in areas affected by radon or other soil gases (such as building sites located over landfills) should incorporate soil gas management systems. These systems should include sealing the underside of the building and incorporating soil gas collection and venting systems into the subgrade beneath the building seal in order to inhibit ingress of these harmful substances into the living space. The local building inspector should be consulted with regard to the prevalence of radon in the area.

14.2 Operating and Maintenance Manual

The design life of a residential structure is commonly considered to be 50 to 75 years. Homeowners should expect that components of the building will require replacement and that the schedule for replacement can be postponed with a suitable maintenance regimen. It is best practice for a builder to provide the homeowner with an operating and maintenance manual that describes what this maintenance regimen should include. This manual could also include product information for building and mechanical components, including sump pumps for the stormwater management system. Information to be included in the manual should also be solicited from the Professional Engineers on the project team.

Homeowners do *NOT* expect that the building foundation will require replacement, so this is an area of construction where special attention is required. Although replacement of drainage systems is not unexpected, the cost of replacing buried systems is generally proportional to the difficulty of access.

Careful consideration during the planning for both construction and operation / maintenance can add value, which the experienced builder provides to the discerning client. The operation and maintenance manual could also include a list of "do's and don'ts" for the owner. This could include such considerations as:

- Do not irrigate in areas underlain be expansive soil.
- Do not place fill or stockpile heavy items in areas underlain by compressive soil.
- Do not remove vegetation from sloping sites.
- Do not place fill or garden debris at the crest of slopes.
- Do clean out gutters, downspouts, catch basins, trench drains, and sumps.
- Do check the battery on your sump water level alarm.
- Do have your sump pump serviced.

14.3 British Columbia Building Code Exceptions

It is noteworthy that the BCBC does not require the involvement of a Professional Geotechnical Engineer for development of Part 9 buildings, though there are two exceptions:

- When a building is designed in accordance with Part 4 of the BCBC, and
- When a building designed in accordance with Part 9 of the BCBC contains some structural components that must be designed under Part 4 (refer to Division C, Section A-2.2.7.1.(1)(c)(i) of the BCBC) and that require geotechnical design.

KEY TOPICS COVERED

- soil gas management systems
- postpone schedule for building component replacement with an adequate maintenance regimen
- best practice for builder to provide homeowner with an operating and maintenance manual
- foundations are not expected to require replacement during design life

15.0 Disclaimer

The greatest care has been taken to confirm the accuracy of the information contained herein. However, the authors, funder and publisher assume no liability for any damage, injury or expense that may be incurred or suffered as a result of the use of this publication including products, building techniques or practices. The views expressed herein do not necessarily represent those of any individual contributor or BC Housing. It is always advisable to seek specific information on the use of products in any application or detail from manufacturers or suppliers of the products and consultants with appropriate qualifications and experience.

The recommendations presented herein may not be suitable for every project or building site; therefore, every site must be considered on an individual basis. These best practice guidelines were judged to be current at the time of publishing this document; however, best practice guidelines in geotechnical engineering are ever-evolving and may not be considered best practice in the future. Inclusion of a qualified Professional Geotechnical Engineer on the project team who is current with regard to professional development and industry standards could be expected to lend to a project's success.

16.0 Glossary

Definitions are provided in the context of this document.

ablation till	soil that was contained within or accumulated on the surface of a glacier and was deposited during melting of glacial ice
acid rock drainage and metals leaching	naturally occurring processes that are caused when minerals containing metals and sulphur (called sulphides, found in some rocks) come in contact with both air and water
arid	excessively dry (as in climate)
best practices	methods or techniques that typically lead to results that are superior to those achieved with other means, such as typical Building Code minimum standards; note that best practices evolve
biomass	a mass of living biological organisms used to treat effluent in a septic system
bonding agent	typically cementicious grout or epoxy used to structurally connect an anchor or dowel to the surrounding soil or rock mass
building code	could refer to the National Building Code of Canada (NBC), the British Columbia Building Code (BCBC), or the City of Vancouver Building Bylaws.
building envelope	the physical separator between the interior and exterior environments of a building
capillary action	the process by which soil moisture may move in a direction through the fine pores of the soil, under the influence of surface tension forces between the water and the soil particles
capillary break	a means of halting capillary action, typically by means of a high void ratio material in the con text of a slab-on-grade
carcinogen	a substance or agent that causes cancer
cohesion	the ability of particles to stick together without dependence on interparticle friction
concrete exposure class	concrete durability categories typically specified by the structural engineer, selected specific to the site
consolidation	the processes of soil becoming compacted by a slow reduction in voids and an increased density under an applied load
deep foundation	a building foundation that is embedded well below the design foundation elevation, typically specified at sites with poor ground conditions such as compressible or liquefiable soils; deep foundations typically include piles, piers, or caissons
debris fan	a fan-shaped deposit at the toe of a slope, created by landslides, debris flows, and/or creek deposits
debris flow	a fast moving gravity flow composed of large fragments (rocks, trees, etc.) supported and carried by a mud and water mixture
desiccation	the process of extreme drying
differential settlement	settlement with magnitude varying between two locations
discontinuity	a discrete brittle fracture in a rock along which there has been no movement; also referred to as a "joint"

effluent	(with respect to septic systems) sewage that has been treated in a septic tank or sewage treatment plant
Engineered Fill	select, clean, well-graded, granular material with less than 5% fines content by mass and 100% passing a 75 millimetre (3 inch) sieve
erosion	movement of soil and rock material by agents such as water, wind, ice, and gravity
fault	a joint surface in a rock across which displacement has occurred
field density testing	testing of soil, typically Engineered Fill, to confirm that compaction criteria are met; typically involves use of a portable nuclear densometer; must correlate to laboratory testing of subject soil
filter cloth	best practice is non-woven (as opposed to woven), needle-punched synthetic fabric; typically used to minimize migration of soil
fine grained soil	silt and clay; grain sizes less than 0.075mm; passing a #200 sieve
first growth stump	(also known as "old growth") a stump from a tree that attained great age without significant disturbance; in BC, old growth is defined as 120 to 140 years in the interior of the province, where fire is a frequent and natural occurrence, while in the coastal rainforests, old growth is defined as trees more than 250 years, with some trees reaching more than 1,000 years of age
Flood Construction Level	the elevation corresponding to a flood event with a 200 year return period
foliations	closely spaced structural fabric that develops within metamorphic rocks exposed to high temperatures and pressures beneath the Earth's surface
french drain	a gravel-filled trench oriented parallel to topographic contours constructed to intercept and direct surface and near-surface water
geogrid	synthetic material that improves the structural integrity of soils in roadways, retaining walls, and slopes by reinforcing and confining fill materials and distributing load forces; may have a primary strength direction (uniaxial) or not (biaxial)
geomorphological landforms	surficial features resulting from natural mechanisms of weathering, erosion, and deposition
geomorphologist	a scientist that describes and classifies the Earth's topographic features and landforms and understands or seeks to understand associated hazards
geotextile	woven and non-woven synthetic fabric used for reinforcing, filtering, stabilizing, draining, and/or separation purposes during earthworks (includes filter fabric, geogrid, and drainage membranes)
global slope failure	a large circular slope failure that mobilizes a significant portion of a slope
gradation testing	laboratory testing that determines the relative proportions of grain sizes within a soil
headscarp	a scar of exposed soil at the upper limit of a landslide or slope failure
hogfuel	wood waste, including wood chips and sawdust
hydraulic conductivity	(often known as "permeability") the ease with which fluids pass through a rock or soil mass
impermeable	not permitting passage of fluid through a material

in-situ	in its natural condition; intact and undisturbed
iron ochre	the result of oxidization of the iron in soil when exposed to water and oxygen. This process forms an iron hydroxide mud that can build up in drainage systems.
jack strawed trees	trees leaning in various directions as a result of slope instability
joint	a discrete brittle fracture in a rock along which there has been no movement; also referred to as a "discontinuity"
Letters of Assurance	standard Forms of the British Columbia Building Code (and other authorities having jurisdiction such as the City of Vancouver Building Bylaw and Indian and Northern Affairs Canada) informing authorities having jurisdiction which aspects of a project design and field reviews are the re sponsibility of a particular registered professional
liquefaction	temporary transformation of soil to a fluid state due to a sudden decrease in shearing resistance caused by a collapse of the structure associated with a temporary increase in pore water pressure; typically caused by earthquakes
natural hazard	a threat of a naturally occurring event that will have a negative effect on people or the environment
Part 4	the 'Structural Design' section of the British Columbia Building Code that pertains to larger buildings (more than 600 m^2 and four or more stories)
Part 9	the 'Housing and Small Buildings' section of the British Columbia Building Code that pertains to smaller buildings (less than 600 m^2 and less than four stories)
pathogen	an organism or substance capable of causing disease. The four major types of human pathogens organisms (bacteria, viruses, protozoa, and helminthes) all may be present in domestic sewage.
peat	organic material consisting of a light, spongy material formed in temperate, humid environments by the accumulation and partial decomposition of plant remains under conditions of poor drainage
perched groundwater	groundwater that occurs above the regional groundwater table, often separated from it by an underlying impermeable horizon
perforated pipe	PVC pipe, typically used for foundation drainage, with a line of holes into which water can migrate; holes should be installed facing down
permafrost	permanently frozen ground
pile	a long, slender column usually made of timber, steel, or reinforced concrete, driven or drilled into the ground to carry a load; part of a deep foundation system
pistol butted trees	trees that have formed curved bases as a result of slow moving slope instability
Proctor testing	laboratory testing that determined the maximum dry density and optimal moisture content of a soil
Professional Geotechnical Engineer	a member registered by the Association of Professional Engineers and Geoscientists as a Professional Engineer who specializes in the art and science of quantifying the response of the ground to changes resulting from construction
ravelling	fall of typically small (rock) fragments from a slope

raft foundation	a thick, reinforced concrete slab foundation that covers the entire building footprint area; typically constructed to attenuate settlement over compressible or low bearing capacity subgrade soils by spreading out the building load
rock slope stabilization	measures designed to reduce the hazards of rockmass failure, ravelling, and rockfall; common measures include scaling, trim blasting, benching, and installation of rock bolts, secured or draped mesh systems, shotcrete and anchors, etc.
root mass reinforcement/ cohesion	apparent cohesion provided to a soil mass by tree and vegetation roots; for best practice, should not be relied upon for design or slope stabilization measures
runout distance	the maximum travel distance of a landslide
scaling	removing loose or potentially hazardous rock fragments from a (rock) slope; typically carried out by excavator, fire hose, compressed air hose, or manually
sedimentation	the tendency for particles in suspension to settle out of the fluid in which they are entrained
seismic	of, subject to, or caused by an earthquake or other earth vibration
shoring	temporary or permanent slope retention
sinkhole	a depression or hole in the ground caused by some form of collapse of the surface layer; commonly caused by natural or anthropogenic erosion of underlying soil and occurring in erodible or dissolvable soil
static conditions	non-earthquake (seismic) conditions
subgrade	a soil or rock surface onto which a foundation or engineered structure is placed
sulphate	a group of naturally occurring, non-silicate minerals; commonly known to degrade concrete upon contact
surcharge	an additional or applied load
swale	a shallow ditch or depression, typically used to control and direct surface water
tectonic uplift	mountain building in response to movement of the plates that comprise the earth's surface
tension crack	a crack, often curvilinear in plan view, that forms on the ground surface near the headscarp of a landslide or imminent landslide
topographic	of, relating to, or concerned with the configuration of the Earth's surface, including its relief and the position of its natural features
tsunami	a seismic sea wave of long period, produced by a submarine earthquake, underwater volcanic explosion, or massive undersea landslide
underpinning	temporary or permanent retention of a slope and overlying structure
weathering	the breakdown of rocks and minerals at and below the Earth's surface by the action of physical and chemical processes
winnowing	surfacing a sloping site with continuous, shallow ridges parallel to slope contours; intended to control surface water and minimize erosion

17.0 **Links**

- **Advice on Hiring a Professional Engineer or Professional Geoscientist in British Columbia** by the Association of Professional Engineers and Geoscientists of British Columbia: *www.apeg.bc.ca*
- **Guidelines for Geotechnical Engineering Services for Building Projects** by the Association of Professional Engineers and Geoscientists of British Columbia: *www.apeg.bc.ca*
- ***Guidelines for Professional Structural Engineering Services for Part 9 Buildings in British Columbia*** by the Association of Professional Engineers and Geoscientists of British Columbia: *www.apeg.bc.ca*
- **Discrete Scope Projects Directory** by the Association of Professional Engineers and Geoscientists of British Columbia: *www.apeg.bc.ca*
- **Professional Practice Guidelines: Legislated Flood Assessments in a Changing Climate in BC** by the Association of Professional Engineers and Geoscientists of British Columbia: *www.apeg.bc.ca*
- **Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC** by the Association of Professional Engineers and Geoscientists of British Columbia: *www.apeg.bc.ca*
- **Professional Practice Guidelines: Onsite Sewerage Systems** by the Association of Professional Engineers and Geoscientists of British Columbia: *www.apeg.bc.ca*
- **Surficial Geology of Vancouver Map 1486A:** *apps1.gdr.nrcan.gc.ca*
- **Surficial Geology of New Westminster Map 1484A:** *apps1.gdr.nrcan.gc.ca*
- **Surficial Geology of Mission Map 1485A:** *apps1.gdr.nrcan.gc.ca*
- **British Columbia Geological Survey MapPlace Geology Map:** *webmap.em.gov.bc.ca*
- **Vancouver's Old Streams** map: *abacus.library.ubc.ca*
- **Peat Areas City of Vancouver** map: *livinginubc.com*
- **British Columbia Livestock Watering Fact Sheet - Winter Considerations** for frost depth determination: *www.agf.gov.bc.ca*
- **WorkSafe BC: Part 20 - Construction, Excavation, and Demolition:** *www2.worksafebc.com*
- **Flood Hazard Area Land Use Management Guidelines** by the BC Ministry of Water, Land, and Air Protection: *www.env.gov.bc.ca*
- **Floodplains, Alluvial Fans, and Geotechnical Hazards** by the Central Kootenay Regional District: *www.rdck.bc.ca*
- **Natural Hazards in British Columbia** by the British Columbia Ministry of Transportation and Highways: *www.th.gov.bc.ca*
- **Illustrated Guide for Seismic Design of Houses: Lateral Bracing Requirements, Part 9 BCBC 2012** by the Homeowner Protection Office: *www.hpo.bc.ca*
- **EPA Document No. EPA-832-R-92-005: Chapter 3 – Sediment and Erosion Control** by the United States Environmental Protection Agency: *www.epa.gov*
- **EPA Document No. EPA-833-R-060-04: Developing Your Stormwater Protection Pollution Prevention Plan – A Guide for Construction Sites** by the United States Environmental Protection Agency: *www.epa.gov*
- **The National Building Code of Canada**: *www.nationalcodes.nrc.gc.ca*
- **Vancouver Building Bylaw 9419** by the City of Vancouver: *vancouver.ca*
- **Residential Construction Performance Guide** by the Homeowner Protection Office: *www.hpo.bc.ca*
- **Engineering Guide for Wood Frame Construction** by the Canadian Wood Council: *www.cwc.ca*
- **Archaeologist Impact Assessment Guidelines** by BC's Ministry of Forests, Lands, and Natural Resource Operations: *www.for.gov.bc.ca*

18.0 **References**

- British Columbia Building Code 2012
- National Building Code of Canada 2010
- Canadian Foundation Engineering Manual, 4th edition
- Surficial Geology of Vancouver Map 1486A, Surficial Geology of New Westminster Map 1484A, and Surficial Geology of Mission Map 1485A, Geological Survey of Canada
- Physiography of British Columbia (In: Compendium of Forest Hydrology and Geomorphology in British Columbia), Church, M. and Ryder, J.M. 2010. p. 17-45.
- Geological Landscapes Highway Map of Southern British Columbia
- Geoscape Nanaimo
- Surficial geology and landslide inventory of the middle Sea to Sky corridor, British Columbia
- GeoTour guide for Kamloops, British Columbia
- City of Kamloops flood plain information: *www.kamloops.ca*
- Field trip: landslides and natural hazards throughout the Canadian Cordillera: technical tour guidebook
- BC climate information: *www.hellobc.com*
- Seismic hazard interpolator: *www.earthquakescanada.nrcan.gc.ca*
- British Columbia Geological Survey surficial geology information: *webmap.em.gov.bc.ca*
- Engineers and Geoscientists Act: *www.bclaws.ca*
- The Canadian Lung Association: *www.lung.ca/*
- The National Building Code of Canada
- City of Vancouver: Vancouver Building Bylaw 9419
- Homeowner Protection Office of British Columbia – Residential Construction Performance Guide

19.0 Acknowledgements

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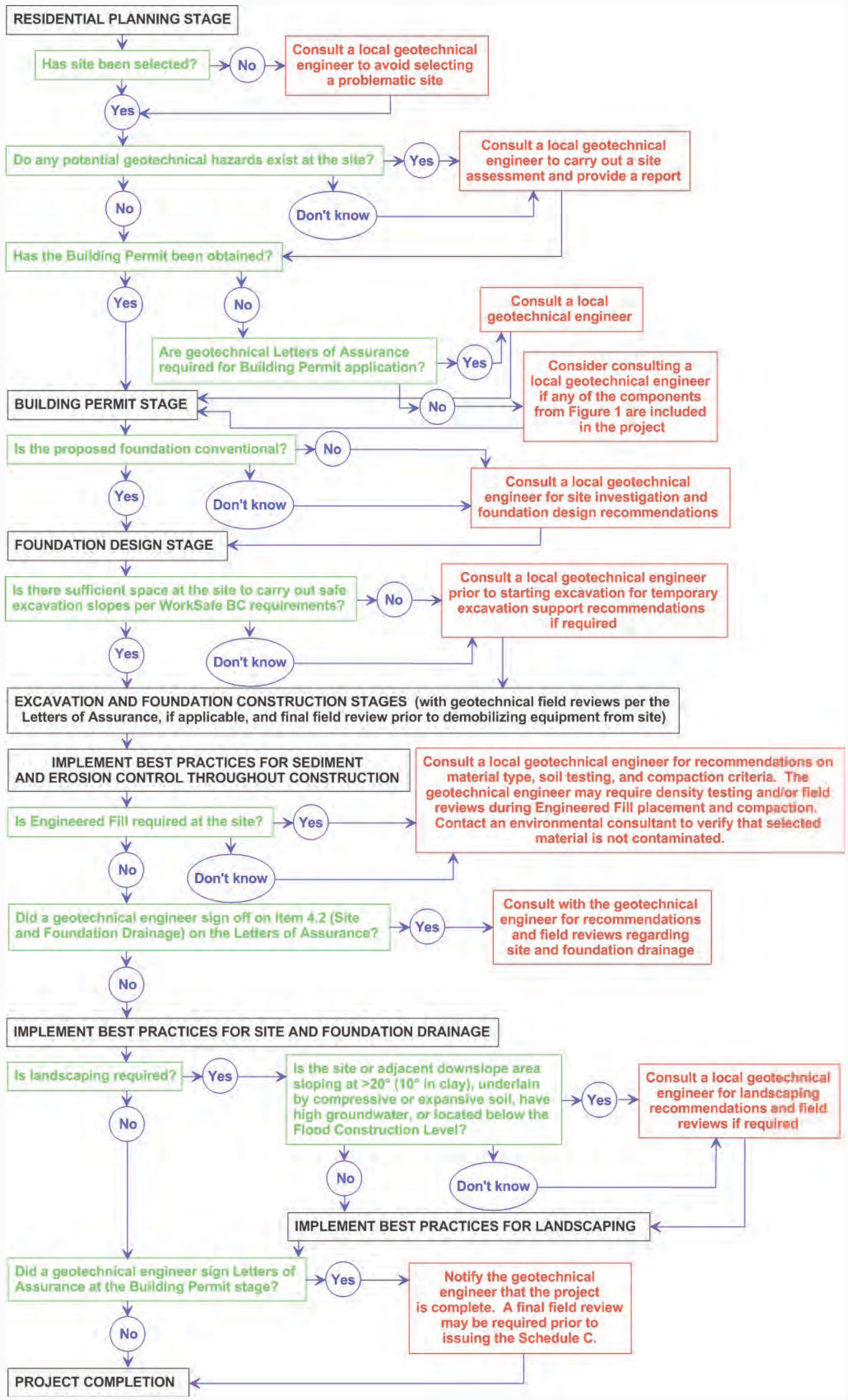
Appendix A: **Professional Engineer Consultation Flow Chart**



Appendix B: **Lower Mainland Surficial Geology**

- **Fill:**

  Large landfill deposits can be found in areas where land has been reclaimed, such as False Creek, Granville Island, the south side of Burrard Inlet, and islands within the Fraser River. Landfill soil types and densities are expected to range significantly and typically require significant site specific investigation.

- **Tertiary and Pre-Tertiary Bedrock:**

  Bedrock is exposed at or near the ground surface at higher elevations on the North Shore and above the Fraser Valley. Typically, bedrock is a good foundation subgrade material, though rock slope stability and dowelling foundations into bedrock should usually be addressed.

- **Vashon Drift:**

  Mostly comprises glacial till, which is typically dense to very dense and a good foundation subgrade material. No other significant geotechnical challenges are typically associated with this material.

- **Vashon Drift and Capilano Sediments:**

  Generally comprises Vashon Drift overlain by fine grained marine deposits 3 to 10 metres (10 to 30 feet) thick and overlying bedrock. Typically dense to very dense and a good foundation subgrade material. No other significant geotechnical challenges are typically associated with this material.

- **Capilano Sediments:**

  Comprises marine and alluvial deposits from the most recent glacial event (Vashon era) that melted after the Ice Age (overlying Vashon Drift and Capilano Sediments), generally comprising sand to gravel but locally comprising fine grained soils. Particle sizes and soil density can vary significantly, and some areas have been identified as being potentially liquefiable. Significant groundwater is often encountered in this material due to its generally high porosity and permeability.

- **Sumas Drift:**

  Glaciofluvial outwash sediments generally comprising sand and gravel.

- **Fort Langley Formation:**

  Glacial and glaciofluvial sediments ranging from glacial till to gravel, sand, and clay deposits. Till deposits are typically dense to very dense, a good foundation subgrade material, and not associated with other potential geotechnical challenges.

- **Fraser River Sediments:**

  Alluvial sand and silt deposited within the Fraser River floodplain. These soil types are typically loose/soft, saturated, potentially liquefiable, potentially compressible, and may include peat. They are typically unsuitable for heavy foundation loads without subgrade improvement. Site specific investigation is recommended in areas underlain by this deposit.

- **Salish Sediments:**

  The youngest natural sediments in the Lower Mainland, overlying all of the above deposits (except fill, as previously described). These soil types are typically alluvial sediments, including fluvial and lacustrine deposits. These alluvial soil types range from clay to gravel to organic soil and are typically found at the mouths of rivers. Where not organic, these soil types are typically suitable as foundation subgrade materials for single family residences. However, these soil types can be liquefiable and are generally associated with a high groundwater level. Lacustrine soil types include bog, swamp, and shallow lake deposits that typically comprise peat, which is highly compressible and is therefore unsuitable to support foundation loads without geotechnical engineering design. Maps have been published that show the locations of peat deposits and buried streams in the Vancouver area, both of which are referenced in the Links section.