Factors Affecting Coastal Armour Stability along the Amherst Shore, Northern Nova Scotia

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Background

Changes in the physical and biological environment of Nova Scotia's coastline due to a net rise in sea level have a direct impact on the welfare of its citizens. Examples of these impacts include flooding, coastal erosion and retreat, changing floral and faunal distributions, and destruction of coastal infrastructure.

Jurisdictions across Canada and the United States have undertaken regional and targeted coastal study programs to better map and understand these impacts. One specific example is the study *"Impacts of sea-level rise and climate change on the coastal zone of southeastern New Brunswick* (Environment Canada, 2006)", with research compiled and conducted by a multi-disciplinary group of scientists representing several federal and provincial agencies.

Nova Scotia Department of Natural Resources (DNR) geologists have the expertise to address geological factors affecting rates of erosion, and geological responses to rising and falling sea level, coastline migration, sediment movement, and slope stability. Due to the importance of this issue DNR has assigned staff to undertake a new Coastal Mapping Project as part of a larger Environmental Geology Program. The project's mandate and historical context is described in the accompanying paper (Finck, this volume).

Project Area

A section of coastline along the Northumberland Strait from Tidnish Dock Provincial Park east to Amherst Shore was chosen for an initial study (Fig. 1). This coastal section was selected because many areas along the Northumberland Strait historically report large rates of erosion with resulting property loss and infrastructure damage. Field work and compilation of background information included, but was not limited to, collecting information on rates of erosion, factors affecting coastal erosion, effects on local coastal physical environments, and an examination of the effectiveness and stability of various structures built to prevent erosion. This paper describes the major types of coastal armour observed in the study area and addresses theoretical aspects of barrier stability and wave interaction. It also examines and comments on the stability of present erosion structures and makes recommendations for the future use of coastal armour in the study area.

Coastal Armour

In the present study area coastal armour is typically erected by property owners to prevent erosion of valuable shore-front real estate and the loss of summer cottages or permanent dwellings. An interview with a senior resident indicated that the oldest cottages along this part of the shore were built at Seagrove around 1900. This resident originally purchased a cottage in 1936, by which time the practice of protecting waterfront property from erosion by building wood breakwaters was well established. The shore front has been continuously protected and is still in its original 1937 position, like many other 'breakwater'-protected properties along this shore.

Over the years more waterfront lots were purchased and cottages built, property was subdivided, and the problems and costs associated with moving cottages landward in response to retreating shorelines increased. Concomitant with this was an increase in the use of coastal armour. The study area, except for small gaps, can now be considered armoured and temporarily stabilized (Fig. 2). Exceptions are the Ship Rail Provincial Park, a sand spit immediately east of Ship Rail, several hundred feet of property on the point east of Seagrove, and the headland at and east of Boss Point.

Finck, P. W. 2007: *in* Mineral Resources Branch, Report of Activities 2006; Nova Scotia Department of Natural Resources, Report ME 2007-1, p. 17-32.

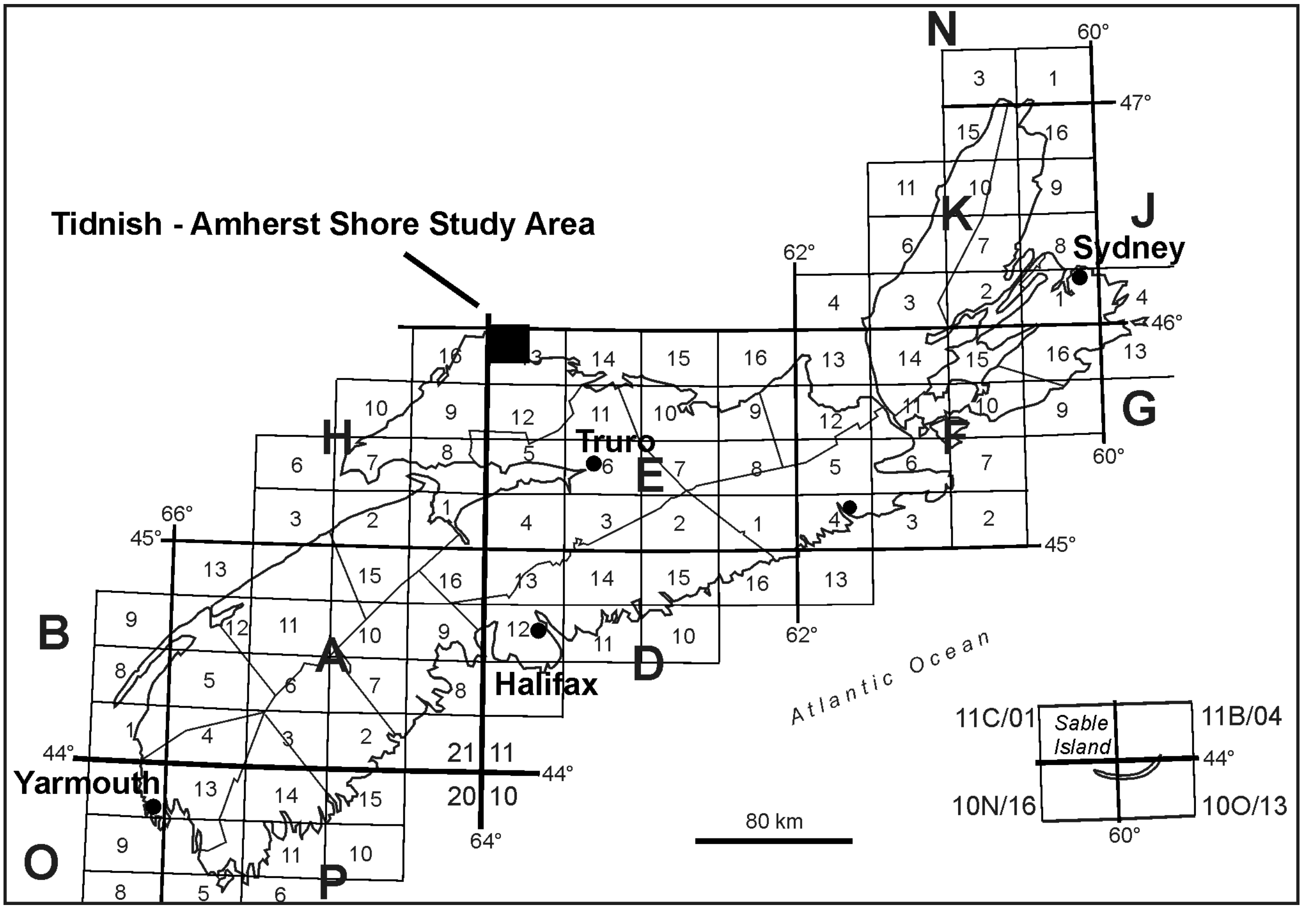


Figure 1. Location of the Amherst Shore study area.

Local Designs and Materials

Structures in the area are essentially sub-vertical or sloping walls, which act as direct facings parallel to the shore front. The structures are composed of a variety of materials such as untreated wood logs, creosote beams, concrete construction waste consisting of pieces of reinforced wall and floor, long monolithic (L-shaped in cross section, Fig. 3) concrete blocks, stone boulders, and clay and concrete bricks. From the perspective of number and quantity, almost all of the structures are built from untreated wood or armour stone. The other materials are rarely observed. Construction debris is visually displeasing. More importantly, it was observed that where slabs of concrete were dumped, the slabs are subject to tipping or sliding (Fig. 4). This, as well as protruding rebar observed at another location, is a safety hazard for people on the beach and in particular individuals who might climb on the debris.

Wood and Stone Retaining Walls

Residents incorrectly refer to the wood retaining walls as ‘breakwaters’. A breakwater is a large wood or stone structure built at an angle to the shore face or as an ‘offshore’ structure on the wave cut platform. Wood breakwaters consists of a series of interlocked but internally isolated bays, each bay having a variety of levels, each level having a heavy timber floor, and each bay being filled with varying amounts of stone ballast on top of the wood floors (Fig. 5). Stone breakwaters can be considered as long narrow piles of boulders with a blunted conical cross section (Fig. 5).

Breakwaters are very different from the wood retaining walls observed in the study area and described below. The use of the term ‘breakwater’ is misleading as this term refers to a far stronger and more massive type of structure usually designed for alternate purposes.

Figure 2. Extensive armouring along the coastline.

The wood retaining walls along the shore were historically built by vertically driving or burying the wide end of large logs in the top of the beach. Other logs were placed horizontally along the inside face of the vertical logs and sporadically spiked or bolted through both logs. There were varying amounts of shoring from the log wall to the bank. In the location illustrated by Figure 6, there is no horizontal bracing and large stones were dumped after the wood wall failed. In general, the hollow between the bank and the retaining walls was filled with locally derived fine-grained material, such as glacial till. Recent replacement wood walls (mid-1980s) appear to have more wall-bank shoring and were filled between the wall and the bank with a quarry run blast stone, generally without large boulders. The original walls were constructed from locally cut trees. A property owner indicated that his recently built retaining wall was constructed of cedar imported from New Brunswick.

The wood palisade referred to in the section on Coastal Armour was built in 1937. It was replaced in the mid-1980s after approximately 50 years of service (with intermittent repairs). Based on the original owner's description and on the author's discussions with other property owners, a typical retaining wall constructed without serious flaws, containing appropriate wood species and periodically maintained, can be expected to provide 40 to 50 years of coastal protection.

Stone Retaining Walls

Stone retaining walls in the study area are typically composed of one rock type. Exceptions occur where different parts of a wall were built at different times or where a property owner

Figure 3. Retaining wall constructed from concrete `L shaped' forms located west of the Ship Rail Provincial Park.

Figure 4. Slabs of concrete construction waste used for coastal hardening.

Figure 5. Examples of common breakwater construction methods; large armour stone breakwater protecting an older creosote-framed, interlocking bay and stone ballast breakwater located at Fox Point, St. Margarets Bay.

Figure 6. View of a failed wood retaining wall later partially backfilled with armour stone. Note the lack of horizontal bracing.

specifically requested a different type of rock. The various rock types include grey-green hard sandstone, grey-brown soft fossiliferous sandstone, red soft conglomerate, red soft sandstone, and various green to black, hard volcanic and metamorphic rocks. Many of the newest walls are constructed of volcanic and metamorphic rocks.

The retaining walls were generally constructed in one of three ways, though variation is common.

(1) Truck loads of heterogeneously sized stone are dumped over and down the shore face with the overall result being a veneer of stone covering the slope (Fig. 7).

(2) A row of large boulders is placed on top of, or dug down into the top of the beach. A landward-sloping layer of variously sized rock and boulders is dumped down the cliff face with some moving and placing of stone. Varying amounts of infilling between the lower stone and the unconsolidated bank was observed (Fig. 8).

(3) A wall of variously sized boulders, typically large stone at the base, is placed on or dug down into the top of the beach to cover the shore face to the top of the slope. This type of wall tends to be more than one boulder thick at the base and is typically backfilled with stone of varying sizes between the lower stone and the unconsolidated bank (Fig. 9).

Many of the recent stone walls are backed with a landscape fabric or geotextile designed to prevent the slumping and washing of the soft bank soil out through the porous retaining walls (Fig. 10).

The life expectancy of the existing stone walls is highly variable. Based on the author's observations and discussions with property owners, some walls require maintenance (e.g. replacing individual stones or sections of stone) within 3 to 4 years. In some cases poor quality stone is disintegrating due to weathering (Fig. 10). In other instances retaining walls are slumping at the base, exposing the geotextile (Fig 10). Rips are occurring and the upper stone work is collapsing and moving seaward. Many of the retaining walls, however, are reported to have been in place for twenty years, show little deterioration, and are likely to continue to provide excellent erosion protection for many decades (Fig. 9). Non-wave related factors that affect the performance and long-term stability of rock walls are discussed further in the section on Failure of Stone Walls.

Wave Energy, Form and Barrier Interactions

The consideration of energy in the form of a wave moving through water, and factors that influence or control the form of the wave when it collides with a structure, are of direct relevance to the design and durability of coastal protection structures. The form of a wave at the instant of impact, along with its actual size, determines the amount of force that is applied to the structure; the structure typically being a wall or barrier composed of wood, concrete, stone, steel or a combination of these materials.

Wave Energy and Movement

To an observer, energy passing through water manifests itself as a wave apparently moving across the water surface. It appears that the water is actually moving. If a floating object is placed on the surface, as the wave passes the object will move up and down but also back and forth in a circular orbit. This is because the actual water particles are also moving in a circular orbit with a slight forward displacement. If the water depth (D) (Fig. 11; after Gross, 1977) exceeds one-half of the wavelength (L) of the wave train then there is little or no effect on bottom sediment. As a wave approaches a beach, however, that sediment is moved when the water depth decreases to less than one-half of the wave length (<L/2; Fig. 11).

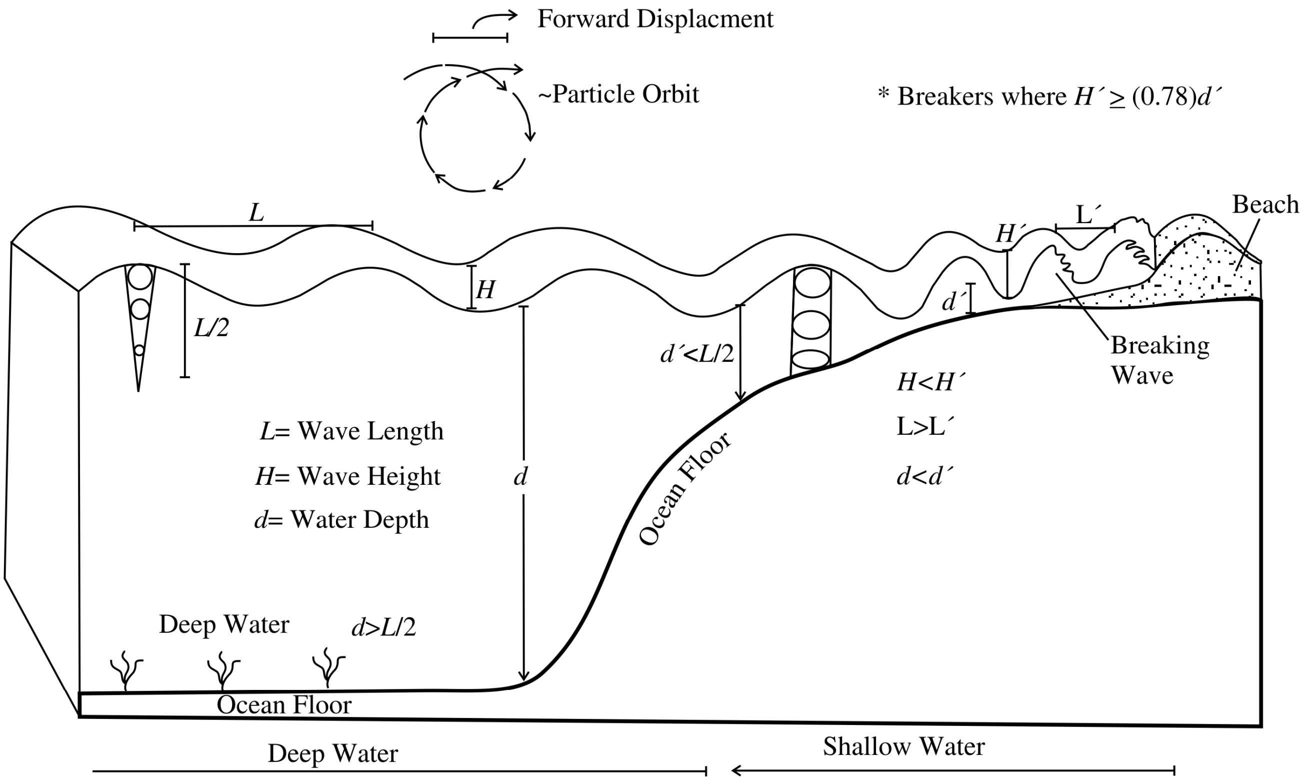
As a wave approaches land, water depth and slope of the foreshore strongly influence the form of the impacting wave on a beach, cliff, or steeply sloping retaining wall. Wave forms are commonly classified as spilling, plunging, collapsing or surging. A spilling wave is associated with a low-angle to almost flat foreshore. The wave breaks offshore by spilling down the front of the wave and much of its energy is dissipated prior to impacting the shore face (Fig. 12a). The swash up the beach rapidly loses speed and the water soaks into the sand so that the backwash is minimal. Plunging and collapsing waves are, respectively, associated with moderately steep to steep foreshores. A plunging wave is a breaker with a curling crest and large splash-up (Fig. 12b). The collapsing wave is a smaller breaker with little curl and minimal splash-

Figure 7. Retaining wall constructed by simply dumping stone over the bank.

Figure 8. Retaining wall illustrating stone placement at base with dumping of stone along upper bank.

Figure 9. A retaining wall with reasonably placed armour stone.

Figure 10. Collapsed retaining wall showing fragmented boulders, substandard sandstone armour stone, improper placement of stone on an eroding till substrate, failure to anchor the toe of the wall below the actively eroding shoreface, and improper use of geotextile.



* For a nearly flat slope. Ratio *H/d* increases as a bottom slope increases

Figure 11. Wave form and energy in the near shore and foreshore as a function of wavelength (L), water depth (d), and wave height (H). Diagram modified after Gross, 1977.

up. A surging wave is associated with a steep foreshore where water depth is sufficient to allow the wave to surge ashore without breaking and is followed by a strong backwash.

Constructive waves are small (< 1 m with low energy) and typically cause a beach to build or maintain sediment. Destructive waves are large (>1 m with high energy) and can within a matter of hours erode a beach, transporting the sediment offshore.

Implications for Coastal Protection Structures

Wave Attenuation and Force of Impact

Within the study area the coastline has a wide wave cut platform and a low-angle to almost flat foreshore (Fig. 13). An abrupt change in slope occurs near the top of the foreshore where there may be a narrow sandy beach ridge about 1 m high. The beach ridge is commonly present in the shallow embayments and typically absent (only a low stone lag is found) along armoured sections of the coast that project seaward.

This indicates that for much of the tidal cycle waves must cross the wide, low-angle foreshore (relatively resistant to erosion due to rock outcrop) prior to striking the unconsolidated banks or low beach ridge. This situation suggests that the larger destructive waves break or otherwise lose significant amounts of energy prior to reaching the shore face. If the foreshore was somewhat steeper, shore front properties would probably take a much more severe beating from plunging and collapsing waves. This may be why many cottages are not simply swept away in storms, given the low elevations and proximity of the structures to the shore face.

Water depth across the foreshore is another important factor. When a wave enters shallow water its height (H) increases and its wavelength

Figure 12a. Examples of different wave forms: spilling breaker.

Figure 12b. Examples of different wave forms: plunging breaker.

Figure 13. View of the wide, flat foreshore with rock outcrop.

(L) decreases. Its steepness (the ratio of H/L) increases until the wave becomes unstable and it forms a breaker. This happens when the height of a wave (measured from trough to crest) is about 78% of the water depth (i.e. H = 0.78 D).

Water depth across the wide foreshore in the study area is typically <2 m. Assuming a 1 m storm surge, the maximum water depth across the wave cut platform is 3 m. The ratio of 0.78 x 3 m equals 2.34 m, thus waves exceeding 2.4 m height will theoretically start to break at a depth of 3.0 m (Fig. 11). Across the wide low-sloping shore face the breaking wave will rapidly lose energy, and potentially continue across the flat foreshore as a spilling wave. It may stop 'breaking' as it crosses the foreshore and at the point where the beach slope steepens abruptly, or if the tide height is below the base of a retaining wall it may break again or simply surge ashore. If tide height (or tide height plus storm surge) is significantly above the base of the retaining wall the wave may simply surge and little energy will be translated to the structure.

This point is important with respect to building stone retaining walls. The limiting of wave height to ~ 2.4 m (varying depending on tidal range and storm surge) provides an indication of boulder size and/or weight below which a directly exposed boulder will wash away. It also provides a maximum size (add a little for safety) above which the effort, labour and cost to move and place the boulder is wasted. Having said this, the actual calculation of this boulder size is outside the author's area of expertise. In addition, though a surging wave will hit a vertical retaining wall with little horizontal force, in the case of a wood wall it will create significant vertical 'lift' and may simply float the wall away.

The amount of energy or force exerted on a structure is not only controlled by the size of the wave but is also strongly related to the form of the wave. When a wave breaks just at the point of impact, its energy in the form of a heavy mass of water moving at a high speed exerts a tremendous force on the structure. This force is commonly seen as crumpled bows and destroyed containers on the front of large container ships entering Halifax Harbour. A much larger nonbreaking swell, however, may have little effect on a structure. One example is a swell passing under a swimmer. Little effect is noted other than the swimmer moving up and down. If even a proportionally smaller wave breaks directly onto a swimmer, however, that swimmer can be tumbled, swept shoreward and driven under water. This is relevant because a swell that doesn't break will impact on a retaining wall with little effect except a vertical component of lift.

Overtopping of Retaining Walls

The height of retaining walls in the study area varies significantly. It typically depends on the height of the bank and whether the bank is walled all the way to the top or only walled for a portion of the bank's total height. The question for property owners is "how high is high enough?", since the height of the wall will strongly influence the cost. To address this question one must determine 'freeboard', defined as the structure height (h) minus the water depth (d) (i.e. $F = h - d$; Fig. 14; after Gross, 1977). Using this number one can calculate a ratio of freeboard divided by wave height (H) where $F/H = (h - d)/H$. If the ratio of $F/H < 1.0$ the structure is easily overtopped by waves. If the ratio is > 1.0 the top of the structure is at least one wave height above the still water level. Two examples are shown below using structure heights of 4 and 5 m.

(1) $h = 4$ m; $d = 2$ m (measured from base of wall);
$H = 2.4$ m
Therefore $F = 4$ m - 2 m = 2 m and
$F/H = (2 \text{ m} / 2.4 \text{ m}) = 0.83$ m or < 1.0

(2) $h = 5$ m; $d = 2$ m; $H = 2.4$ m
Therefore $F = 5$ m - 2 m = 3 m and
$F/H = (3 \text{ m} / 2.4 \text{ m}) = 1.5$ m or > 1.0

In the above scenario overtopping occurs with a 4 m wall, but does not occur with a 5 m high wall. What this indicates is that there is a height above which it is no longer necessary or cost effective to build the wall. Above this height other, less costly erosion mechanisms will be effective (e.g. grading slope, diversion of surface runoff, planting vegetation).

The various numbers used in this section are estimates and/or theoretical values (Gross, 1977). Their significance is in the limiting factors that can be calculated if careful measurments are collected over appropriate time spans and applied to that particular area.

Failure of Wood Retaining Walls

Wood retaining walls in the study area exist in various states of decay. The newest wall was roughly 3 years old, but there are 10 to 20 year old walls that appear to have had stone replaced between the bank and the wall, and 20 or more year old walls that have failed and been breached by tide and waves (Fig. 6). In general the wood walls are remarkably resilient and durable. Obvious causes of failure are rot and rusting of spikes and bolts. In general the posts seem to have been driven deep enough into the substrate to prevent tipping and wash out by vertical lift. As shown in Figure 6, however, the wood walls tip both toward and away from the bank. Note that when they are completely decoupled from the bank they still do not lift and float away. This suggests that a major source of failure is washout behind the walls and horizontal failure due to inadequate bracing and inadequate backfilling. Once a log is broken or otherwise breached, unless the stone backfill at the inner wall face is larger than the opening between the logs, waves will quickly eat away the stone (or soil) behind the wall. In addition, waves may flank the wall at either end. When waves pile up against the shore face the water will take a path of least resistance, this being in part a flow parallel to the shore. Thus, a channel or opening behind the wall will act much like a sluiceway and quickly erode the sediment behind the wall. Failure of wood walls is prevented by reducing or eliminating penetration of sea water behind the wall. Adequate horizontal bracing, properly sized backfill, and adequate end protection to prevent flanking are necessary to optimize the service life of the wall. In addition, construction of small platforms across the horizontal bracing with associated overlying rock ballast would provide increased horizontal and vertical stability. It would also limit flow of water behind the wall in the case of erosional flanking by sea water.

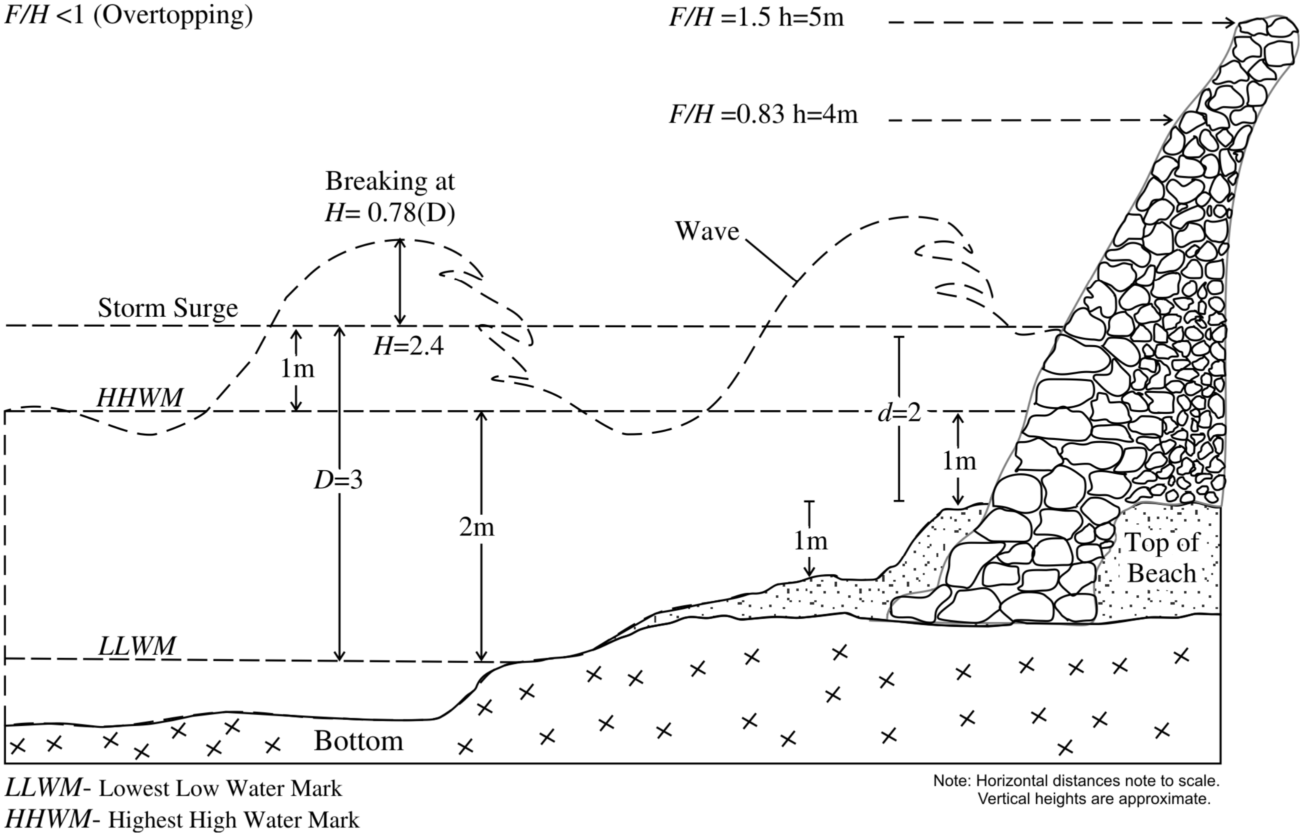


Figure 14. Illustration of freeboard as a function of wave height (H), structure height (h), water height (d; measured at the base of the structure) and it's relationship to wave overtopping of retaining walls. Diagram modified after Gross, 1977.

Failure of Stone Walls

The quality of stone placement in various retaining walls examined and photographed in the study area is highly variable, ranging in the author's opinion from excellent to very poor. In cases of very poor placement and/or low quality stone the walls were observed to be already failing. In situations where there was proper stone placement, the toe of the wall was anchored, and backfill was properly sized respective to gaps in the wall, it is expected that such walls will last many decades with only minor repairs. There seemed to be a large disparity between many well constructed walls and others that were, relatively speaking, 'complete disasters' for the property owner.

Armour Stone Quality

A stone wall is only as stable as its weakest component. Retaining walls in the study area are composed of red conglomerate, red sandstone, green sandstone (massive vs. fractured), and a combination of volcanic and metamorphic rocks. Armour stone from a private quarry can be purchased for a price in the range of $8.50/ton. The rest of the delivered cost is trucking. The various types of sandstone and conglomerate are presumably used because they can be obtained closer to the site than metamorphic or volcanic rocks, lowering the cost of trucking. The metamorphic/volcanic stone is probably obtained from the Cobequid or Antigonish highlands. Variation in trucking costs should be reflected in the overall cost of the retaining wall. Red sandstone and fossil-rich brownish-green sandstone, however, should never be used in the walls. The stone is incompetent, subject to high rates of weathering, and will result in premature failure of the wall (Fig. 10). The green massive sandstone performs better, but blasting for armour stone tends to fracture the stone and these fractures (not readily visible in the large boulders) quickly open when exposed to frost and water. What appeared to be large competent boulders were seen to be split into several smaller rocks that will collapse and wash away (Fig. 10).

The metamorphic/volcanic armour stone is hard, competent even after blasting, and will not weather. Despite additional transportation costs, this stone should be used for all large armour stone and at the very minimum used for any stone exposed in the face of the retaining walls. Green massive sandstone may be arguably used as backfill, though the author does not recommend this practice.

Stone Placement

The first row of armour stone should not be placed on top of beach material or till. It should be dug down and placed so that the base of the first layer of stone is at least 1 m deep. This is a minimum depth since a 1 m high upper beach face composed of sand may easily erode. If erosion is greater than 1 m, the base stones in the wall will shift and wall failure may occur. A depth exceeding 1 m is recommended, but a depth exceeding 2 m is not required as this represents the base level of the foreshore. Ideally the base stones should rest on bedrock, if not possible then till, and only as a last resort should it be placed on beach sand or gravel. The base armour stone should also be thicker than 1 row, several is preferable. This anchors the toe of the wall and allows some room for movement of individual boulders. It is well recognized from numerous studies of coastal retaining walls that failure to anchor the toe of the wall is a leading cause of wall failure.

The rule is to use the largest boulders at the base and they may decrease in size as wall height exceeds the height of effective wave action. A mix of large and small boulders on the face should be avoided unless the small stones are securely anchored and cannot be washed out leaving holes in the face of the wall where water can enter and erode the fill behind the face. Boulder rows should be staggered so that they interlock. Boulders stacked one on top of another will shift dramatically in response to any loss of stone. A properly placed retaining wall constructed of oval shaped rocks can be very stable (Fig. 15). It will be more stable than a wall containing poorly placed and undersized angular stone.

Material used as backfill behind the facing boulders must exceed the size of the largest holes in the face. Consideration must be given to deterioration of the stone. If sandstone is used as fill it may initially be of a suitable size. Over a period of time (possibly as little as 2-3 years), however, the stone will start to crumble and will wash out between the boulders. As the deterioration continues the wash out will accelerate and wall failure is likely.

If a retaining wall is not high enough and is overtopped by waves the bank above the wall may be eroded. In addition, large amounts of water repeatedly overtopping the wall will cause back pressure on the wall and will also tend to wash out the fill from behind the wall. It is obvious from the above discussions that fine-grained, locally excavated till, or any other material, should never be used as back fill.

Geotechnical Barriers

The use of geotechnical barriers (geotextile) has gained popularity and they are being increasingly used between bank material (usually till) and the stone backfill, or between the bank and the large boulder facing of the retaining walls (Fig. 10). A discussion with a contractor indicated that most retaining wall construction was undertaken during winter months when the cottages along the shore were unoccupied and the ground was frozen, minimizing lawn and property damage. It was also indicated that the placing of the geotextile was often difficult because of high winds.

The author questions the value of the use of geotextile in these applications, or more specifically the inappropriate use of the material. Figure 10 illustrates the use of geotextile in a retaining wall where: (1) the stone is disintegrating because of poor quality, (2) the stone is poorly placed, (3) stone size is highly variable, (4) width of the stone wall at the base is insufficient to support the overlying material, (5) the stone is placed directly on till, (6) the toe of the wall is not dug down or anchored in the till, and (7) there is no backfill between the geotextile and the large stone. This retaining wall represents almost a complete list of 'what not to do' in constructing a retaining wall.

The geotextile in the above example is ripping because when it isn't supported it lacks sufficient strength to support the bank material. In addition, it

Figure 15. A well constructed and durable stone pier built using oval shaped granite boulders, Blandford, Mahone Bay. Note the row over row staggered placement of stone.

is being cut by the large sharp boulders. Geotextile should only be used between the bank material and a properly placed wall where stone fill is of sufficient quantity and grain size to properly support the geotextile. In this case the question arises as to the necessity of the geotextile. If proper backfill is used it should be coarse toward the front and finer toward the bank face. The face of the wall and the backfill should absorb and reflect sufficient wave energy so that virtually no energy reaches the bank - fill interface. At this interface properly sized backfill should be sufficient to prevent washout of the bank through the retaining wall by either surface runoff, groundwater or saltwater egress. In addition, the bank material will penetrate the stone fill to a degree producing a strong interface. The presence of a geotextile at this interface, however, will prevent the washout of bank sediment (if it doesn't fail due to other factors) but of concern is its potential to present a plane of weakness or slip face along which slumping and wall failure can occur.

Summary

Wave breaks in the form of wood retaining walls have been built along the Tidnish - Amherst Shore since 1900. Much of the shoreline is now protected by wood walls and more recently by armour stone. Properly constructed wood walls may last from 40-50 years. The service life of stone walls in the area has not been determined, but if properly constructed they have lasted over 20 years. With routine maintenance such a wall may last several generations.

In the long term wood retaining walls fail due to rot and fastener loss. These walls also commonly fail due to a lack of horizontal bracing, inadequate or a complete lack of properly sized backfill, and flanking with associated wash out behind the wall. Improperly constructed stone walls may fail in the first several years due to a variety of factors, including: (1) stone disintegrates because of poor quality, (2) improperly placed stone, (3) variability in stone size is extreme, (4) base width of a wall is insufficient to support the overlying material, (5) stone is placed directly on erodible material (e.g. till), (6) toe of the wall is not dug down or anchored properly so as to be near or below normal wave base, (7) holes large enough to allow wash out of backfill and/or shifting of large armour stone are left in the face of the retaining wall, (8) inadequate, improperly placed backfill, and (9) improper use of geotextile, Recommendations based on basic applications of slope stability and geotechnical considerations of sediment movement are used in the above sections to make detailed suggestions on proper construction of wood and stone retaining walls.

Wave forms are commonly classified as plunging, collapsing, spilling, or surging. The amount of wave energy transferred onto a vertical surface (i.e. the force of impact at the moment of breaking) varies from extreme to low, respectively. Wave height across the foreshore is constrained by water depth and slope. This is in turn controlled by the tidal cycle and height of storm surge. The necessary height for retaining walls is calculated using assumed but realistic values as a function of freeboard, wave height, water depth at the base of the structure, and structure height. There is a point above which wall construction is no longer required due to the limiting size of the impacting waves.

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