CREDIT VALLEY CONSERVATION
TECHNICAL GUIDELINES FOR FLOODPROOFING

1) INTRODUCTION

Floodproofing incorporates the use of designed structural treatments to render structures flood free, impervious and/or immovable. Dry, passive floodproofing to the level of the Regulatory Flood is the preferred approach and shall be given primary consideration for all new construction (CVCA 1990). Ancillary structures such as garages and sheds (usually without basements) are wet-floodproofed to allow free flow and equalized pressure of water through the structure, while also being rendered immovable. Designing floodproofing for a given structure must consider the hydrotechnical effects of the flood. The *Flood Plain Planning Policy Statement Implementation Guidelines*, July 1986 and the *Credit Valley Conservation Authority Policies for Floodproofing of Buildings and Structures*, June 1990, have established threshold criteria for velocity and depth of flooding. Dry-floodproofing is acceptable up to a maximum velocity of 1.7m/sec. and a flood depth from existing grade of 0.8m plus a 0.3m contingency freeboard. These criteria are implemented as upper limits to which flood damages can be acceptably reduced within feasible economic limits. Above and beyond these limits it is argued that uncertainty replaces effectiveness in the design of floodproofing. There are no explicit policy criteria for wet-floodproofing but the above noted figures are reasonable benchmarks.

2) HYDROTECHNICAL DESIGN CONSIDERATIONS

The following phenomena occur during flooding:

- Hydrostatic pressure
- Velocity - Hydrodynamic load
- Velocity - Shear stress
- Frequency of flooding
- Duration of flooding
- Ice jamming effects

<u>Hydrostatic pressure</u> is the single most important consideration in floodproofing design. Hydrostatic pressure is directly correlated with flood depth and saturated soil depth in contact with a structure. Hydrostatic pressure is equal in all directions and acts perpendicular to a given surface. It can be further defined into vertical <u>or</u> down, horizontal <u>or</u> lateral, and uplift <u>or</u> buoyant pressures. The imposition of an enclosed structure in flood waters (including basements below saturated grade) unbalances localized hydrostatic pressures. The tendency of lateral pressure is to overturn, shear, or displace an enclosed structure or vertical elements thereof. The tendency of buoyant pressure is to differentially heave, rupture, or float an enclosed structure or horizontal elements thereof.

For conservative design purposes a fully saturated soil profile, irrespective of soil type, should be assumed to exist at the time of flooding. Hydrostatic pressures should as a result be considered both above and below grade. Below grade hydrostatic pressure is determined by isolating the volume of available water from the volume of soil. In addition, standard foundation design considers lateral earth pressures. For floodproofing, lateral earth pressure should be considered using the submerged unit weight of soil. Total pressure below grade will be a combination of the above considerations.

Saturated subgrade and the bearing capacity (compressive strength) and settlement failure potential in various soil types must also be clearly considered. Note that bearing and settlement design must also respect the extra load induced by the monolithic nature of reinforced foundation walls and floor slabs, that are a design response to the hydrostatic pressures.

Hydrodynamic load is a manifestation of the pressure moment induced on an object by the depth of flood waters in ‘motion’. This can also apply below grade if significant piping of water exists. It is assumed, however, that under fully saturated soil conditions subsurface movement is nominal. The dynamic effect of water in motion can be converted into a correspondent hydrostatic pressure but within the allowable velocity range defined by policy the additional pressure due to hydrodynamic load is minor and further consideration is unwarranted.

Sheer stress is a manifestation of the tractive or constant force required to move an object and keep it in motion. It is a commonly analyzed variable in watercourse erosion study and applies to floodproofing consideration from the perspective of potential scour damage around a structure triggering structural failure. It is a function of water depth, slope and resultant velocity. It is sufficient to say that fill pads, berms, and floodwalls must be designed to be erosion resistant under identified velocities.

Frequency of flooding is a reflection of the observed or statistical recurrence interval of various stages of flooding. Headwater areas, smaller watersheds, and urbanized watersheds may produce a larger peak flow in response to the rainfall distribution of a 1:100 year storm compared to the peak generated from a Regional Storm. Downstream in a major system such as the Credit River the Regional Storm peak will supersede the 1:100 year. Flood susceptible areas under worse case peak flow scenarios (or in other words the Regulatory Flood) will have different recurrence probabilities. It is assumed that no explicit floodproofing design modifications can be made for the above considerations.

Duration of flooding is the result of a complex interaction between runoff response, channel conveyance and storage. Runoff volumes, peak flows, and channel hydraulics can be either calculated or derived from a combination of empirical and gauged data. Generally, the higher the rainfall intensity, and the shorter the catchment length, the quicker the response or rise in flood waters. The change in rainfall intensity over time and the downstream tributary inputs then influence the duration of inundation and recession of the hydrograph. It is assumed that detailed analysis of flooding duration is not a practical requirement that can be incorporated into floodproofing design criteria.

Ice Jam effects are local or reach specific influences creating backwater impoundment and downstream surges upon break-up. Generally, ice jamming is only a significant concern on the main branch, of the Credit downstream of Cataract ie. below the ‘Forks’. There is no known quantitative way to analyze the specific hydraulic effects or statistical frequency of ice jamming in correlation to the Regulatory flood or any lesser flood stage. It is assumed that detailed analysis of ice jam effects is not a practical design consideration.

3) DRY-FLOODPROOFING

3.1 STRUCTURAL

Standard wall construction such as siding on frame, brick veneer on frame, solid brick, and concrete block, provides inferior defence against flooding. Standard techniques are extremely susceptible to leakage damage, hydrostatic pressures, and consequential structural failure.

The most common structural approach to dry-floodproofing a building involves waterproofed monolithic foundation walls i.e. reinforced and extended above grade, reinforced gravity slab basement floors, or slab-on-grade with no basement, and some consideration for subsurface drainage. Floodproofing treatment should respect the structural requirements of the Ontario Building Code 1990, the National Building Code, and the National Standard for Masonry Design (C.S.A. CAN3-S304-M84) as applicable.

The tensile strength of standard masonry block basement walls 8”-10” thick is limited against lateral hydrostatic pressures. The use of cast in place concrete and/or high slump grouting of masonry blocks combined with steel bar grid reinforcement is a traditional consideration to support extra vertical load, and for horizontal temperature and shrinkage control. This style of reinforcement has been translated to floodproofing design. Likewise, the thickening and reinforcement of basement floors has been a simple extension of ‘bigger is stronger’ thinking for floodproofing against buoyant pressures. Reinforced walls must be securely anchored to both the basement floor, typically by cast in place re-bar, and the first floor sill plate, typically by anchor bolts. The first floor header joist should be mechanically anchored to the sill plate or alternatively the first floor joists can be embedded in concrete if a cast foundation wall is used. The use of pilaster wall support for long spans and the use of intermediate structural walls and/or steel post tensioning to transfer loads are additional sound ideas, that have not seen wide use however.

Reinforcement can also be addressed by pressure relief through subdrainage. There are two schools of thought on this subject. The first is to use clay surface caps and/or clay backfill around the foundation to prevent or slow infiltration of rain and/or the capillary rise of groundwater. In a sense this represents the use of relatively impervious soil to 'fatten' the foundation. The argument against clay backfill is that depending on the actual soil grain size and shape some clays are plastic and expansive, meaning that they actually absorb water and swell thus adding to or maintaining the hydrostatic pressure against the wall. Clay backfill can only be used if good quality control exists and if appropriate waterproofing of the foundation is used.

The second and more widely accepted concept is to incorporate a subdrain system with mechanical pumping to alleviate pressure (also to lessen potential frost effects as in a typical gravity subdrain system). The sump system should collect water from free draining backfill along the walls and tinder the slab using perforated pipe surrounding the footings. An automatic submersible pump should be placed in a covered sump pit. The basement floor should have a positive slope to a floor drain connected to the sump pit. The pump can be sized to have adequate capacity in balance with the inflow of water. A flow net analysis will help determine the pumping rate. A continuous source of power and separated operating switch is required for the pump and should be located above the contingency freeboard above the flood elevation. Gravity draining sump systems are often not feasible under flood conditions. Municipal services do not generally exist in rural flood damage areas and as a result a free draining outlet would likely be in the flood plain downslope towards the watercourse. In addition, gravity systems may not be able to discharge water as fast as it inflows. The pumped system should have an outflow pipe located to discharge above the flood elevation or can be connected to municipal storm sewers if a backwater valve is installed in the service connection at the lot line (if allowed by municipal standards).

Foundations should be waterproofed to the flood elevation with an appropriate 'flexible' coating i.e. gap and crack filling synthetic or asphaltic hardening liquid. Geotechnical membrane coatings for waterproofing have also been used but they require high quality placement for a good seal and are susceptible to damage upon backfilling. Uncoated cast in place concrete can be considered waterproofed if certain admixtures or treatments have been included and if watertight expansion joints are used.

The final structural consideration for dry-floodproofing is the use of watertight seals and closures on doors and windows located below the flood elevation. These options are considered active approaches in that they require human intervention at the time of the flood to ensure closure. These treatments do not have a proven record even at less than worse case scenario flooding due to failure under hydrostatic pressure and incomplete seals from negligent maintenance or poor product quality. They are generally not considered acceptable for dry-floodproofing and therefore no openings are allowed below upper threshold policy criteria.

3.2 COLUMNS AND EXTENDED FOUNDATION

Construction on columns (posts, piers, piles) is a consideration for basement free lightly loaded frame structures such as cottages. Heavier load structures such as 1 or 2 story dwellings without basements are more appropriately built on extended foundation walls that create a crawl space. Columns and crawl space foundations are useful on moderately sloping land where a slab-on-grade floor cannot be conveniently located. Column and extended foundation construction cannot be subject to depths and velocity higher than policy criteria. Analysis of hydrostatic pressures cannot be effectively undertaken for columns and/or crawl space foundations and associated footings. There is relatively little water displaced by a column array or flooded crawl space and as a result the free movement of water around respective structural elements equalizes pressures. Buoyant pressures acting on large spread footings may be the only design calculation that can be done.

General principles to be followed for column construction include using only concrete for below grade components and backfilling with compacted free draining material. Lateral knee or cross-bracing between columns and anchoring the column securely to the footing and floor construction adds stability in the face of uncertain hydrostatic effects. The disturbed ground surface around each column should be stabilized for potential scour at flood velocities.

Extended foundation walls must be wet-floodproofed as per the appropriate details in section 4) WET-FLOODPROOFNG.

3.3 FILL PADS

Fill pads are used to raise grades to flood free construction elevations or to at least lower the potential depth of flooding against a proposed structure. Fill pads must be built with appropriate compaction, drainage, side slope stability, and erosion protection. A fill pad does not necessarily require an impervious core. Fill pads cannot be built higher than 1.1m above existing grade i.e. 0.8 m flood depth + 0.3 m freeboard as per policy. Fill pads are not appropriate over deep organic soils. Shallow organic soils can be removed to achieve a sound foundation for a fill pad. It is assumed that hydrostatic pressures are in equilibrium with saturated earth pressures around a fill pad.

Fill pads should be built using well drained clean material compacted for integrity and stability. Existing vegetation and topsoil should be scraped and dry fills should be placed in 0.3m lifts. Compaction to 95% Standard Proctor Density, as per standard practice, is required. Side slopes should be built to 3:1 (h:v) or flatter unless specified differently by the engineer. Well graded sand and gravel with a small fraction of clay (granular 'B') is considered most appropriate for compaction while topsoil coverage should achieve final grades. Fill pads should be planted and rehabilitated with seed/sod and/or native vegetation as appropriate. Only at velocities higher than 1 m/sec should erosion protection of the wet face of a fill pad be considered, with vegetative bioengineered options taking precedence.

3.4 BERMS AND WALLS

Berms and walls are essentially freestanding impervious dams used to hold back or divert flood waters. They differ from fill pads in that hydrostatic pressure will act on the wet face, and potentially on wall foundations, due to the artificially created dry side. They can be used independently or in association, e.g. a berm (with impervious core), a wall, or a berm graded up to a wall. Berms and walls are structures by definition and cannot be subject to flooding greater than policy criteria. Special consideration for drainage on the dry side must be made.

Floodproofing berms can be made impervious by compaction of non-swelling, non-plastic cohesive clayfills. It is usually appropriate to use cohesive and relatively impervious till in the berm core which can be keyed into a deeper excavation to improve the cut-off effect. Surrounding fill quality and placement should follow the guidelines noted for fill pads.

Floodproofing walls must respect the same structural considerations as reinforced foundation walls described for dry-floodproofing, e.g. cast in place concrete or grouted and reinforced masonry block. Design variations from standard gravity wall construction can include cantilevered or expanded spread footings, and tapered or flared wall faces to enhance integrity. The use of precast interlocking 'designer' block walls or armourstone walls can only be considered in combination with impervious fill bermed on the flood side.

Subdrainage and local surface drainage must be considered for berm and wall construction. Conventional subdrains will be inundated during flooding. A sump pit constructed behind a flood wall with either conventional piping or filter/blanket drain ditches would require water to be mechanically pumped away. A deep cut-off wall e.g. sheet pile, sunk below either a berm or wall is an option to help block subsurface water. If a berm or wall will have the effect of ponding surface drainage on the flood free side the sump pit may be enlarged appropriately or grading changes to divert runoff may be made. Flap gates installed on surface drainage pipes put through a berm or wall tend to leak and fail when inundated under flood conditions and are not recommended.

4) WET-FLOODPROOFING

Wet-floodproofing allows water to enter, move within, and exit a structure to prevent differential hydrostatic pressures (lateral and buoyant). Wet-floodproofing is generally only acceptable for non-habitable structures such as garages and sheds. As noted earlier, the hydrodynamic load of flood waters in motion is minimal within policy criteria. As a result, detailed structural treatments designed to transfer the hydrodynamic load of water within a structure to a foundation are not required. Conversely, when a structure is inundated the buoyant hydrostatic pressure is in balance with the vertical or down pressure. Standard construction practice of anchor bolt attachment between wall sills and foundations is adequate. It should be noted, however, that quickly peaking flood waters can rise against a structure faster than the rate of inundation.

A temporary imbalance in hydrostatic pressure may lift or heave light load frame structures such as sheds. This can be overcome by building a concrete slab foundation (instead of wood) with standard anchoring or by sinking foundation posts below grade, e.g. ‘sonotubes’, with standard anchoring. Irregardless of the type of wet-floodproofed structure, every attempt to orient a principal opening to the direction of the flood, to prevent differential change in water levels inside and out, should be made. In turn there should be ideally a second opening opposite to the principal opening to allow flow through of flood water. Openings do not necessarily need to be of equal size.

Building materials subject to water damage, e.g. drywall, panelling, insulation, should not be used within wet-floodproofed structures. Walls should be unfinished concrete or wood. Concrete block walls should be filled with grout to prevent air pockets and ingress of water. Wet-floodproofed structures should not be serviced with anything more than electricity, meeting the specific requirements noted in the following section.

5) ADDITIONAL DESIGN CONSIDERATIONS

A complete analysis of flood conditions must also consider the following points, as appropriate:

- hydraulic grade of existing municipal sewers and the potential to back-up to foundations and basements
- potential for impact to and back-up of private septic systems
- affects to private wells
- maintaining internal building services such as central heating, gas, electricity, water, and telephone
- site design to limit flood ‘exposure’

Check valves or gate valves are options that prevent pressure siphoning of piped sewer flows from reaching private homes.

Septic systems may be subject to lateral and buoyant pressures and may be damaged in a flood. A watertight cap be used to prevent ingress of flood waters to the main tank and appropriate valves can be used to prevent back-up into a structure.

Drilled well casings can be extended to a height above the flood.

Incoming electricity and telephone lines can generally be located above the flood elevation. Electrical control panels, wiring, and outlets must always be above the flood and freeboard elevation. No electrical equipment or appliances should be below the flood elevation except a submersible sump pump with protected wiring. Underground gas and water lines can be served by check valves for closure. If these services enter the structure below the flood elevation a protected waterproof utility shaft can be designed to convey them above the flood. Note that the above considerations are contingencies against leakage and failure of dry-floodproofing treatments that would result in basement flooding.

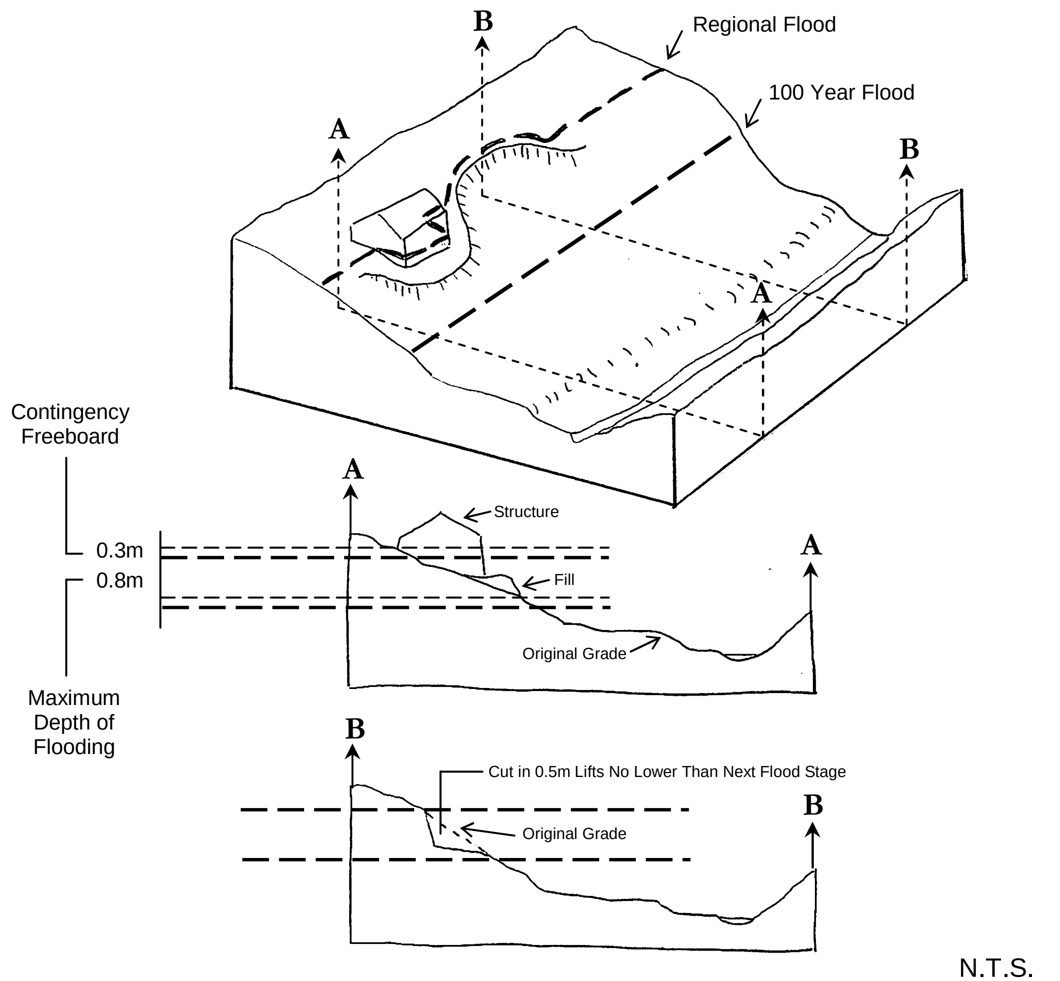
Site design considerations for new construction include orienting and designing a structure so that it presents as small a face as possible to the flood. Deflector berms or planting vegetation to redirect major flows and/or potential debris can also be considered. However, no adverse impact to neighbouring properties or flood plain storage will be allowed.

6) FLOOD PLAIN ALTERATION

Construction and fill placement in the flood plain might have the affect of altering the hydraulic parameters of storage, conveyance, and water level.

Loss of flood plain storage is not acceptable. It is required that a balanced cut be undertaken to offset fill volume and/or and increase in structural intrusion. The cut and fill must occur at essentially equal elevations. The balanced cut must be in lifts of no more than 0.5m equaling the fill/structural volume per lift. The cut can only cross the elevation of lower design flood stages, i.e. 100 yr., 50 yr., 25 yr., 10 yr., 5 yr., 2 yr., if the fill/structural loss of storage falls below these stages. The cut cannot go lower than the next lowest flood stage below these stages. The cut cannot go lower than the next lowest flood stage below the lowest point of intrusion. No alteration as low as the bankfull channel is allowed. See Figure 1 for an example application. An unbalanced cut and fill. i.e. net fill, may have the effect of increasing local flood plain reach water levels and will contribute to cumulative loss of storage and conveyance change throughout the flood plain system.

Figure 1: Cut & Fill



Even if a balanced cut can be achieved it is not acceptable to alter the cross-section of the flood plain such that conveyance is changed by a pinching or deepened channelization affect. This might result in increased downstream velocity and/or water levels and may increase upstream backwater levels, with adverse effects on neighbouring properties. Generally, the cut must occur on the same side of the flood plain in close proximity to the fill/intrusion to limit the change in cross-section.

Hydraulic modelling study (e.g. HEC 2) will not be acceptable to support significant flood plain alterations involving cut and fill volumes equal to or greater than hundreds of cubic metres. Balanced cut and fills are restricted to relatively small sites and small fill volumes. Relatively small net fill volumes will only be acceptable at the discretion of the Authority if overriding hydraulic conditions exist in the flood plain. Hydraulic modelling may be required to determine if overriding local conditions exist.

Flood plain alteration guidelines do not supersede or replace the current version of the C.V.C.A. Watercourse and Valleyland Protection Policies and requirements thereof.

7) SUBMISSION REQUIREMENTS

The submission package must include the following engineering/architectural plans:

- Site Plan & Grading Sections with existing and proposed geodetic elevations confirmed by an 0.L.S. or P. Eng.
- Foundation Sections — showing floodproofing details
- Building Elevations — showing floodproofing details
- Site Servicing

The submission drawings must clearly quote the flood depth and velocity criteria, thus acknowledging that the design addresses the relative severity of the flood. It is also recommended that the submission package include the following:

- Soils Report
- Hydrostatic Pressure calculations
- Bearing Capacity calculations

Specific submission packages will require the following:

- Cut and Fill volume calculations
- Hydraulic Modelling HEC 2 Report including discussion, summary tables, mapping, and hard copy of all input and output data

All plans and supporting reports/correspondence must be stamped and signed by the design engineer.

8) CONCLUSIONS

Floodproofing design must respect many variables including a degree of uncertainty. Existing floodproofed structures have not been widely ‘field tested’ under worse case scenario flooding. Observations from significant post flood events also suggest that phenomena such as surge waves, uneven forces in eddies, backwaters, and secondary flow channels, erosion scour, and debris or ice load impact, are factors with poorly predictable qualities.

Short of not building in the flood plain at all, the safest forms of construction will be those that eliminate the ingress of water and limit the adverse effect of hydrostatic pressures. It has been argued that the economy of scale dictates what can be reasonably achieved in structural treatment for floodproofing. Compromises in structures may be a design decision. For example, eliminating basements is a clear way to reduce the effect of hydrostatic pressure and simplify design. This document does not attempt to support or discount any specific opinion. The intent of this document is to give guidance towards the significant factors of design.

Floodproofing is a viable component of overall flood plain management. These guidelines meet the need to improve the consistency and reliability of implementation.

REFERENCES

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