Flood Barriers

Summary: It's been over a decade since I posted the Flood Manual (available online at http://karol.us/flood.html) which was earlier developed under Flood Mitigation Best Practice Notes. General flood awareness raised since then, particularly after Hurricane Sandy inundated some highly populated areas along the East Coast, including the New York City in 2012. We were returning to re-examine the subject, particularly as it refers to prevention. I had this project in the making for so long, that I plan to start publishing its draft, as it probably going to be most effective this way, so what you have in front of you is an unfinished version, and your comments and suggestions are most welcome.

Many buildings are designed and built or refurbished these days to be dry flood-proofed far below their BFE (base flood elevation), with the most visible and famous attempts located perhaps in Venice, Italy, which currently builds the largest flood barrier system in the world, in a form of bottom-hinged gates. Most of these attempts resemble a penstock: a rigid mechanical gate sealed at the perimeter, and their variations are mostly driven by the feasibility of certain technical solutions. Industry standards were developed to quantify their performance.

Two questions that we would deal here are as follows: how to choose the right flood mitigation, and how to verify whether it works. Working in the building enclosure diagnostic business, I participated and developed my own flood testing methods, and realized that this modest work made me sort of a floodproofing guru, (a one eye man is a king - the perception I get often in the U.S.), so I decided to share this knowledge for the common benefit.

This section is devoted to deployable flood barriers that protect openings, such as doors and windows.

Flood resistance expectations.

Designers may believe that the floor below BFE could remain dry during flood. Such an apparent expectation could lead to many costly mistakes, such as e.g. use of moisture-sensitive and slow-drying interior materials, such as gypsum board and mineral wool, even in the bottom areas directly above the floor, as well as electrical installations, including generators installed further below. On one project, we observed unrealistic tightness criteria in architectural specifications, that the product chosen by architects as the basis of the design never met, and an emergency generator was located in a cellar twenty feet below the flood elevation, while none of the bottom floors were equipped with sump pumps. Therefore, a flood event could cause widespread damage, and defeat the goal of immediate re-opening of a building following a flood event. On the other hand, the building rode successfully through a recent flood event, proving that some buildings may be overdesigned anyway.

Reading through standards, we were surprised to see definitions of adjectives such as "watertight" "impermeable" to vary significantly from common meanings. These confusing standards and definitions contribute to such a situation, and our goal is to simplify it. Careful reading and review of available solutions on the market leads to an obvious discovery: all flood barriers on the market leak water, and are actually classified by how much they could leak. The typical standard would use the length of the perimeter gasket as a baseline. E.g. German DIN 19569-4, divides leakage by classes: e.g. class 4 allows max. 0.05 l/s/m, that translates into approx. 90 buckets of water per hour through the average floodproofed door (0.05 liters*60 seconds *60 minutes *5meters = 900 liters).

The most commonly used standards are summarized in the table below:

DIN 19569-4 Class	FM Global 2510 (ANSI 2510) **	U.S. Army Corps of Engineers Flood Proofing Regulations EP 1165-2-314, #701.1 *	Maximum allowed leakage in litres per sec. per metre gasket length (l/s/m).
1			0.3-1
2			0.1-0.3
3			0.05-0.1
4			0.02-0.05
5			under 0.02
	#4.3.1	Type 2 (vaguely described)	0.00028 (equiv. 0.08gph/ft)
		Type 1	Impermeable ***

Other such standards include BS 7775, and AWWA C 561.

***) *U.S. Army Corps of Engineers [USACE] EP 1165-2-314, Floodproofing Regulations.),"* describes "substantially impermeable" (similar to ASCE 24 Section 1.1) as: "*a space free of through cracks, openings, or other channels that permit unobstructed passage of water and seepage during flooding, and which result in a maximum accumulation of [100 mm] 4 inches of water depth in such space during a period of 24 hours*." This is a slightly subjective standard, that makes a product comparison or verification of an individual barrier's fitness impossible until it's too late. Similar subjective description one finds in FEMA.

Sources

The market is actually driving this industry, and it is in constant flux, so we found internet search and discussions with representatives of the industry to be most stimulating. Here are some keywords that could help you with your search, besides the standard names mentioned earlier: "шандора" "szandory" "śluza" "防汛挡水墙"

*) publicly available under the following link:

https://www.publications.usace.army.mil/Portals/76/Publications/EngineerPamphlets/EP_1165-2-314.pdf

**) publicly available under the following link:

https://pos.driver-project.eu/sites/default/files/public/2019-11/FM%20Global%202510.pdf

***) https://www.constructionspecifier.com/time-to-rethink-floodproofing/

Typical Solutions.

A log (or plank) closure system is one of the most popular family of flood barriers employed commonly in many locations and countries. The log system assumes plenty of advance notice and manual labor would be available to install planks prior to the forecast flood, and dismantle them later. It requires storage, preferably in vicinity of the dedicated openings, and an excellent logistics and marking systems that would allow to quickly determine which log goes where. It could be considered just a tighter and neater version of the traditional pallets full of sandbags. Such storage is generally unsightly. Logs are normally installed from the exterior by at least two workers, and they semi-permanently lock the interior, preventing escape until dismantled. However, the primary weakness of those systems are the discontinuities of seals at plank ends.

Other typical solutions include hinged door-like assemblies, and sliding gates. Solutions that allow for a continuous perimeter gasket, and particularly such a gasket that is placed in compression by the hydrostatic load itself offer superior water tightness. Naturally, permanent hinged assemblies shine in this comparison.

Comparison of log system and sandbags. Photo credit: FM Global. https://www.fmapprovals.com/products-we-certify/products-we-certify/flood-mitigation-products

Typical pallet of sandbags stored next to entrance doors. Log system could be considered just a tighter version of the traditional pallets full of sandbags. Photo by author.

Typical logs unpacked and ready to be deployed. Photo by author.

Such systems would typically easily pass the criteria of DIN 19569-4 class 1, which allows for the maximum flow of 1 l/s/m, an approx. equivalent of 52 gal/min/ft or 3,120.14 gal/hr./ft. Translating it into buckets as in the previous example, every door would leak 1,800 buckets of water per hour. We found one manufacturer in the U.S. who claims that his flood log system meet and exceed the FM 2510 standard, which is the strictest one, and would let only half a bucket through.

Typical Procedures.

Water testing is unpredictable, and water would often defeat our every premeditated strategy and humiliate even most experienced researchers. Ask me how I know. Therefore, testing such flood barriers is tricky. To compound this issue, everyone is left on their own. We found not a single testing laboratory in the entire U.S. that is equipped and conducts such tests, neither in a laboratory, nor in the field. Manufacturers are apparently expected to build their own chambers and equipment, calibrate them independently, and only invite third party witnesses to verify them.

The FM Global procedure requires maintaining a stable water head, which in turn makes the setup expensive and/or laborious. It's because of three challenges: 1) measurement of leaks require building a dedicated base and plumbing to collect the spill below a massive chamber structure, which in turn makes it difficult to fix or modify, 2) maintaining the stable water head requires either a full-time crew's attention, or at least overseeing a dedicated apparatus similar to the average toilet flusher: with an intake valve opening upon sensing water level drop. 3) Separation of extraneous (chamber, over the top, and during modifications) leaks.

The former challenge #1 is often the deal breaker: weight and bulkiness of the chamber and barrier caused by its structural strength makes modifications impractical, so even a setup originally intended for the "pure" procedure we saw eventually abandoned and used for "modified" testing procedure.

Also, measurement of the spill is a challenge: would require either elevating the spill by pumping it up, while at its stage the water is dirty and would therefore require filtration to safeguard pumps and gauges, or elevating the testing chamber to fit the necessary plumbing below, which would require dedicated, heavy structure underneath. We saw attempts to replace the spill measurement by a metered intake, which failed due to inability to account for extraneous leaks.

Add to it the need to test the actual width of the opening, and the actual BFE, which both would vary widely, and therefore promote a flexible chamber setup that few could afford, and the landscape fills with single-use cheap concrete chambers. The actual chamber would normally be built for the widest and tallest opening, representing the worst case, which should suffice until an even larger opening would need to be spanned, but FM Global also wants to see the smallest size tested of each kind.s

It's hard to avoid impression that American standards set somehow unrealistic expectations, until one starts reading the procedures and realizes some latitude in their interpretation. E.g. "over any fifteen-minute period" would probably lead to choose the very last 15 minutes of the testing, after 21 hours and 45 minutes. This is when any such assembly would leak the least, because leakage rate generally diminishes over time.

Challenges experienced during field testing are compounded by many more considerations and randomness of the actual substrates may explain why we found not a single source for such testing apparatus or the actual testing in the U.S. We had to build and conduct it ourselves. In this case, we faced the same challenges, with extraneous leaks at perimeters of the chamber beyond reasonable control, and practicable limits to the chamber's height.

Such an approach required some interpolations. The easiest one was extrapolation of the water head. The more challenging would be the mathematical relationship between the "last 15-minutes" measurement versus the more typical "water head drop over time" measurement. Leakage generally diminishes over time, making the "any 15-minute period" standard less strict than "the overall water drop ratio divided by the total time" practice. A large water drop ratio frequently observed in such circumstances diminishes the discrepancy, and again a mathematic formula could be developed to establish the exact relationship.

Collection and measurement of the internal spillage would require a very extensive apparatus, because the quantities involved would normally defeat any attempts at pumping it (the average range is between 90 and 1,800 buckets of water per hour through a single door, and it's an optimistic scenario that the barrier performs as certified). However, field testing typically yields much worse results than lab testing.

Also, the field testing seldom would last the specified 24 hours, because that much water inside would seldom be tolerated even if the building is still in its construction stage. The first reaction is "that cannot possibly be true," upon seeing hundreds of gallons of water just flowing in, while the crew originally was prepared to suck it up with some wet shop vacs, to avoid flooding occupants working at their desk next door.

The most typical procedure would just fill the chamber to the prescribed height, and then capture the water table drop in time. This would normally be accomplished by either measuring water drop at given time intervals, or measure the time when water table passes certain height marks.

With such modified procedure, the "wetted perimeter" just as the "water depth" should be interpreted as continuously diminishing with the drop of the water head.

Impact

Flood barriers combine watertightness, hydrostatic load, and impact resistance, which adds a twist to the testing. E.g. FM 2510 requires two impact tests at 80% height followed with post hydrostatic loading. In case of the typical extruded aluminum log assemblies, produced by multiple manufacturers, and therefore exhibiting similar structural performance, such a test may seem to be superfluous, so we did not question, nor perform it. Btw. Hitting logs with a hammer, observed in the lab testing, (among other departures from the procedure) actually improved their water tightness.

Perimeter Seal

The chief difference among individual solutions falls into the perimeter interface. Any solution that allows for a continuous lip gasket, carried continuously at corners, and carried below the door's saddle would offer a superior performance. Any solution that would best accommodate field challenges, such as a concrete overspray, dirt, wear and tear and shrinkage of gaskets, provide permanent and intuitive markings and operation, ease of storage, etc, would also win. Add to it the adaptation to a variety of substrates, and you get the full picture. The typical systems come in two options: inserts to be embedded in concrete, and retrofit jambs to be bolted and sealed to the opening's perimeter.

Operation

A provider is normally expected to provide an on-site training for the owner's personnel, that includes distributing manuals and hand-on tutorials. Observing the differences between the relevant procedures utilized prior to testing, and the crew training speaks volumes. The typical deployment involves following steps:

1) finding the flood barrier dedicated to the certain opening (uneasy task when there are tens of them palletized and stacked one on another),
2) picking these pallets up and transporting them closer to their openings (with a forklift),
3) dismantling and storing away whatever permanent beauty covers may be installed at jambs and thresholds, collecting and storing their fasteners so they could be reused,
4) cleaning the perimeters of their receivers (particularly difficult task at thresholds and sills, where debris tend to accumulate),
5) renewing or resealing any damaged perimeter gaskets,
6) inspecting the logs for damage, resealing any damage found,
7) and installing them in the opening.
8) This is when first surprises sometimes happen, e.g. pallet straps permanently indented gaskets, logs don't fit the opening size, resulting in scramble in search for any properly sized logs that could be swapped (e.g. mismarked or spare).
9) Compression. Horizontal gaskets are not compressed hydrostatically, and their manual compression at the top is insufficient, therefore they need to be individually compressed manually, typically using the same threaded wrenches that would eventually need to be installed on top. Assuming the operation needs to be repeated every three logs (the typical log is 6 inches high, so the operation needs to be repeated every 1-1/2 foot), then the wrenches undone, next three planks installed, and so until the top is reached. (Obviously, a quick clamping mechanism that would allow to accelerate the process by skipping the majority of the threaded portion of the rod to only utilize the portion that would actually compress the gaskets would speed things up. Unfortunately, for convenience of this initial phase of installation, some manufacturers utilize a

wider thread pitch, and short wrench's arm, with the unfortunate result of making it impossible to obtain a good gasket compression. Good gasket compression requires a tighter thread pitch and larger arm, and therefore some additional ad-hoc tools like arm extending rods, pipes, hammers, and levers were seen utilized in lab settings in preparation for testing and during the testing to help gaskets to settle in place, while the manuals were mute about them.

10) Every manufacturer tries their own ingenuity to improve the status quo, and we present some examples below, e.g. teflon-covered leaders reduce friction.

Perimeter Seals in the No-Man's Land

Conditions outside the prefabricated barrier assembly are outside the provider's scope, but very much a concern for building owners and occupants.

In majority of cases, a flood barrier interfaces a solid cast concrete wall on slab, engineered specifically for flood resistance. Any discontinuities that may be formed by a veneer or any screen (as in rain-screen, or even floating sidewalk slabs, etc.) obscuring the bare flood walls and slabs, would need to be bridged by the assembly. In most cases it would necessitate installation of beauty covers, that would need to be dismantled prior to barrier deployment and stored away, and then re-installed back. Building construction such as flood walls are built with tolerances much poorer than those required for flood barriers. E.g. the average concrete jamb may easily be poured 1" off mark, together with the embedded track. The average jamb tracks of a log barrier system accommodate significant tolerances along the plane of a wall, but not perpendicular to the wall, particularly not the popular "twist" resulting from lower portions of formwork moving under concrete pressure more than the upper, less stressed part.

These interfaces would normally need to be sealed. Solid assemblies are never actually solid, they are typically divided by myriad of joints, with "day" or "dry" joints particularly susceptible to leaks. Concrete is porous and permeable to water. Also, control and movement joints are seldom operational for reasons that extend beyond our scope, with cracks propagating around openings as the chief result. Such cracks are particularly often seen at corners of doors and windows, where they are coincidentally often most difficult to remediate. Waterproofing of these components is typically left to structural engineers. Engineers are seldom waterproofing experts, and those engineers who are such experts tend to work in different realities: such as e.g. deep excavations, tunnels, bridges, etc. meeting different expectations than average building occupants. Therefore, results may vary, and we refer the interested reader to our treatise on water stops to show how much.

Let's focus on the immediate surroundings instead. All surfaces interfacing gaskets should be prefabricated, and preferably come with self-aligning corner assemblies, that would not only set the geometry right, but also seal the corners. We noted assemblies where the base interfaced a troweled concrete (instead of an embedded stainless-steel plate as tested), resulting in significant leakage at this interface when tested in the field, in comparison to the laboratory testing. Concrete embeds should be equipped with expandable water stops or dedicated sealant bead interfaces, otherwise cracks forming between the concrete and steel would allow seepage. Retrofit interfaces present yet another challenge: fastening. Typical expandable masonry and concrete bolts require sufficient distance from edges and joints, otherwise cracks would form, or the substrate chunks may be spalled. Sufficient edge distances are seldom available around openings. In such circumstances, a chemical anchor would allow for installation, but prevent adequate tightening, so a combination of methods may be required.

Practical Considerations

Best floodproofing barriers are those with continuous perimeter gaskets, compressed by hydrostatic force. In building enclosures, it would normally entail permanent hinged or sliding doors or shutters, that could be unsightly, explaining why log systems are preferred by architects. Their storage would create an unsightly landscape, with either scattered stacks of pallets, or entire shipping containers obstructing passageways, driveways, and permanently occupy parking spaces, but that would become owner's and occupants' problem. Not to mention laboriousness of their application and inherently inferior performance. The best compromise would involve sliding assemblies hidden in the building skin, yet with adequate access panels to allow for periodic maintenance.

Continuous gaskets would require a trough that would need to be created below openings, in order to develop a vertical substrate for the gasket interface at e.g. a window sill or door threshold. Such a trough needs to be shown on architectural drawings early enough to allow for sufficient distancing throughout the later stages of the design, and would need to be covered with flush saddles durable enough to withstand traffic, and meeting the typical access requirements e.g. ADA.

Outswinging doors should leave enough space behind the flood barrier to allow their full opening after the barrier is deployed, for multiple practical reasons: last minute modifications and repairs, egress for any trapped individuals, etc. In many instances there is some latitude in choice of direction of opening, e.g. not all exterior doors must be out-swinging, as there are sometimes more doors than necessary for egress requirements. At the very least, one door per served space should allow for such egress. Where no such distance could be afforded, in-swinging doors, (wherever legal), would be more practical, as the typical flood proves to be relatively shallow in comparison to the full BFE and would require only a few bottom logs, while the door could still be in use.

Integrated floodproof doors would offer a two-in-one solution. (At the same time, we were also asked to water spray test the doors themselves, confirming what occupants already complained about: they leaked badly during rain. The building was less than one year old. It wasn't clear why the entire door assembly wasn't specified and ordered floodproof, offering an unsurpassed performance, addressing both rain and flood.)

Research – Hydrostatic Testing

We field-tested a flood barrier assembly, and then observed its laboratory testing, comparing the results and experiences. The specimen consisted of a single-span flood barrier with stop logs that requires assembly (per descriptions in FM 1-40/ 3.7.1.6 and 3.7.2.1) intended for a single pedestrian door. It was a log barrier protecting a single 2-1/2" ft wide door opening with BFE over 8 ft high. In both cases a chamber was erected on the wet side of the assembly. The testing was conducted by filling the chamber with water, arresting the supply, and measuring the loss of water over time, while the water elevation was allowed to drop, per the diagram attached below. It's notable that in both cases the chambers sprouted leaks, that needed to be resealed, taking a long time to allow for intermittent drying. Neither chamber was high enough to test at the project-specific water head.

The lab testing chamber with a meticulously prepared and saddle and sealed end of vertical gasket. The following two photos explain the primary difference between the actual building.

Actual Building: Flood Barrier Gasket Substrate Uneven: Caked With Concrete and Dirt, visible debris, missing vertical gasket.

Actual Building: Flood Barrier Gasket Substrate Uneven, Caked With Concrete and Dirt, visible debris. Flood Barrier Vertical Gasket -Oblique and not Square Cut.

The lab testing chamber: installation of the first log. Visible additional foam gasket placed across the sill, not always provided in the actual building.

In these three intervals, water leakage rate dropped successively. The observed leakage chiefly took place between the first log and the saddle, and their corners were the largest contributors. Minor leakage was observed at horizontal and vertical gaskets above the first log. Leakage was allowed to run in the ground, and its volume was not measured. No extraneous leakage was observed from the chamber. First hour resulted in measured drop of 1'-6 ¼" corresponding to loss of 130 gallons, after second hour we measured drop of 1'-4 ¾" (113 gallons of water), and third 1'-2" (97 gal.), respectively.

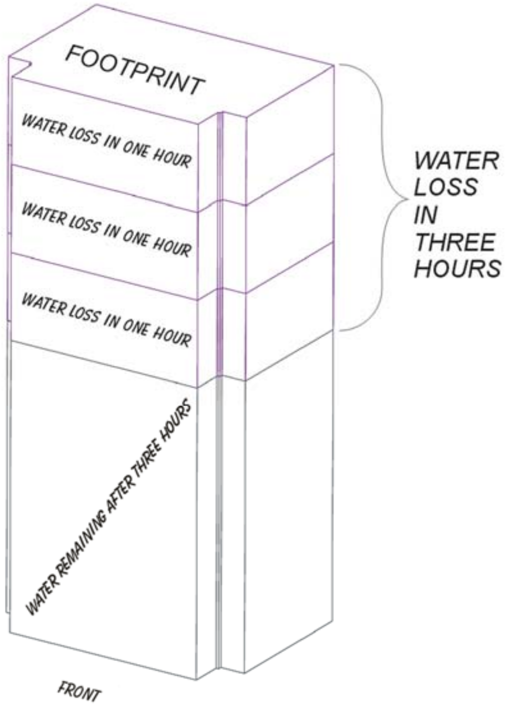


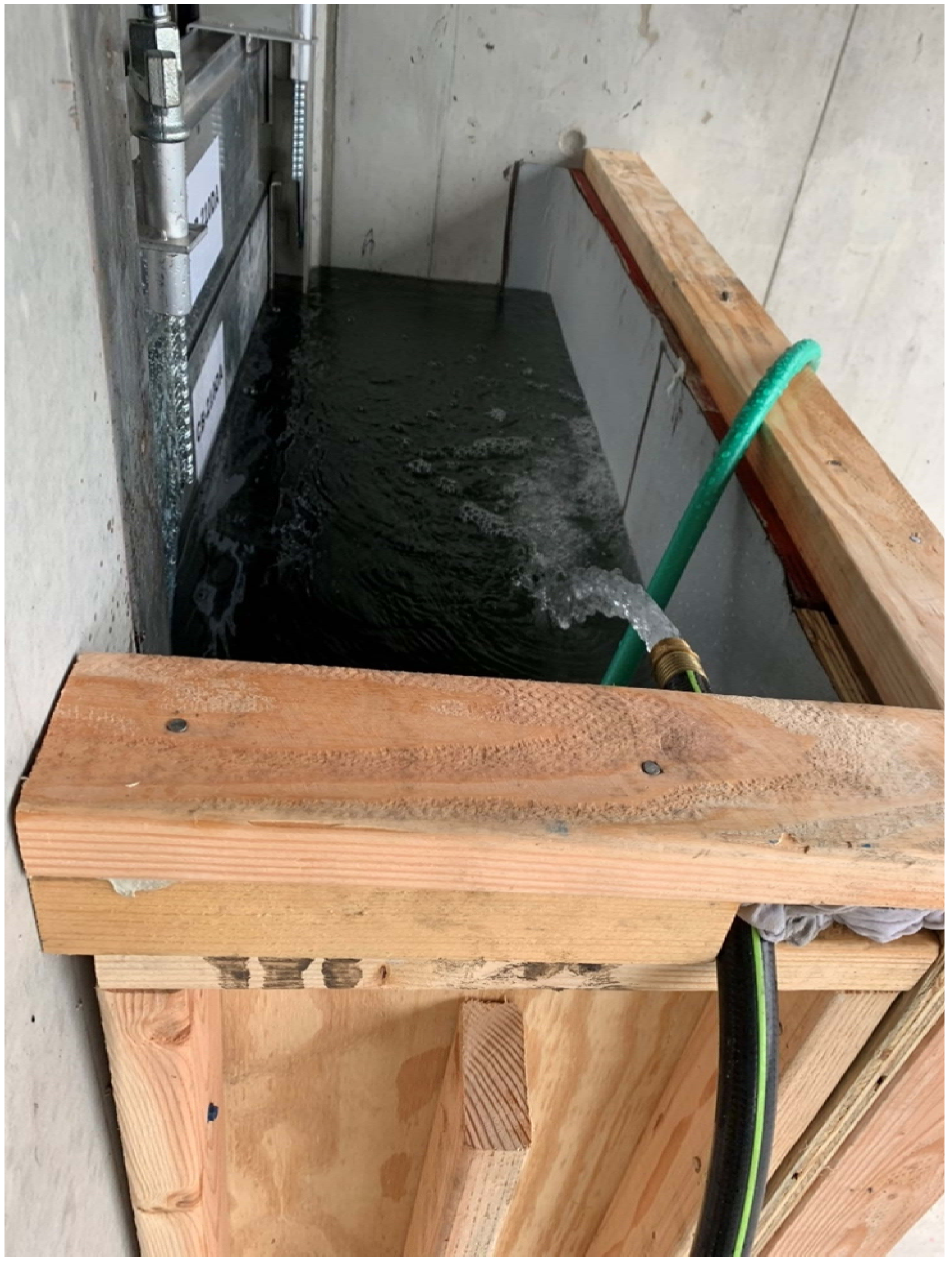
DIAGRAM OF THE MOCKUP
(ONLY THE BODY OF WATER SHOWN, EVERYTHING ELSE REMOVED FOR CLARITY)

These results averaged 5.53 gph/ft or 0.019 l/s/m, meeting Class 5 of the DIN standard. This was with the assumption of the wetted gasket footage remaining constant, otherwise, the result updated for the actual time-weighted wetted gasket length would result in 0.021 l/s/m meeting Class 4 of the DIN standard.

Would it meet ANSI 2510, with approx.. 75x times more stringent threshold? Hard to say, as there wasn't enough data to interpolate. However, the leakage ratio diminished more than would be justified by just the corresponding water head drop, suggesting a better result could be obtained at the 22nd hour, if anyone would care to wait this long.

In our field testing, we erected an 8 ft tall wooden chamber lined with a waterproofing membrane and sealed at the edges, and then re-sealed it again when it proved to leak at the perimeter seal. Eventually the best we could achieve was the chamber leaks appeared negligible, and leaked significantly less voluminous than the flood barrier. The chamber was emptied, and then filled up to approximately 73% of the specified water head, water intake was stopped, and 12 minutes later, a 19-inch drop was observed, corresponding to a loss of approx. 97 gallons, and corresponding with leakage rate of 486 gph, with a significant fountain-like leakage observed through the flood barrier (e.g. a 12oz coffee cup held in front of the interior side of the chamber filled in 1.07 min, indicating 0.018 l/s leakage rate just at this single spot). The result of our testing needed to be extrapolated to the specified flood elevation, and yielded approx. 0.135 l/s/m, placing it in Class 2 of the DIN standard, which seems to be an average result in comparison with similar products sold on European market.

Field testing of similar assembly. Exterior view.



Field testing of log flood barrier in front of single pedestrian door. Filling chamber with water. Exterior view.

Field testing of log flood barrier in front of single pedestrian door. Water gushing out of the gaskets, and streaming out of the threshold area. Interior view. Visible insufficient space between the door and the flood barrier preventing opening the door for interior access to the barrier. Door and log labels were anonymized on the photo.

Practical Application

It's easy to get lost in the intricacies involved with different standards and measurement methods, and practical challenges of testing. However, the chief questions that need to be posed: "what was it that your building needs?"

And that answer involves a lot of coordination, to identify functions, materials, and services located in the potentially affected areas. Based on our back-of-envelope calculations, in this particular building, the total length of openings was found to add to approximately 3,000 linear feet on the ground floor. Therefore, a 48-hour flood event would deposit approximately 3'-6" of water (this is a simplistic scenario, as the building had a cellar where an emergency generator was installed, which would be inundated first). In the optimistic scenario that the flood barriers would perform as well as in they did in the lab testing, it would be over 6"deep water sheet on the floors. In either scenario, there would need to be sump pumps installed inside, and the emergency generator installed high enough to energize the sump pumps. This brand-new building had none, which illustrates the common lack of understanding and coordination, and which is why I am typing this writeup for the common benefit.

In progress.

This is an in-progress draft. As I realized how many such half-finished drafts I banished on a back-burner, I spent and extra day typing and proofreading it and decided to just publish it. Let me know your comments and suggestions.

I also have large quantity of video footage that I intended to use for the movie related to the topics, but simply didn't have the time to sort it out. We are looking for volunteers to help us sort and process it.

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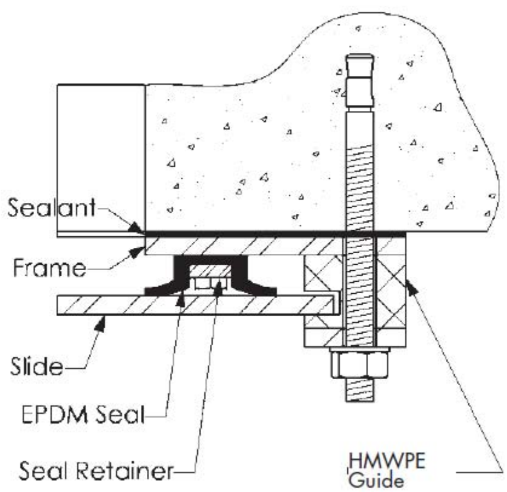
Details

Prominent manufacturers share details of their applications, from which some practical challenges and solutions could be gleaned.

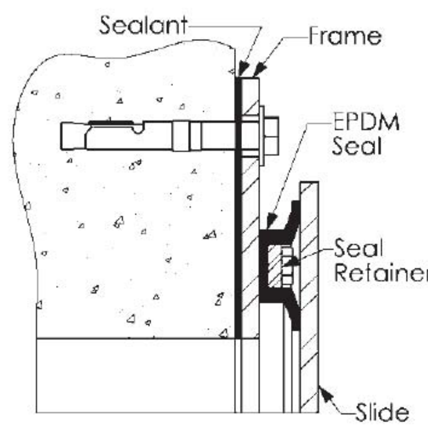
Leakage Allowance:
The leakage rate on MU model is lower than the maximum allowable defined by different standards under normal conditions:

- DIN 19569-4 (class 5): 1,20 l/min per meter.
- AWWA C-561: 1.24 l/min per meter.

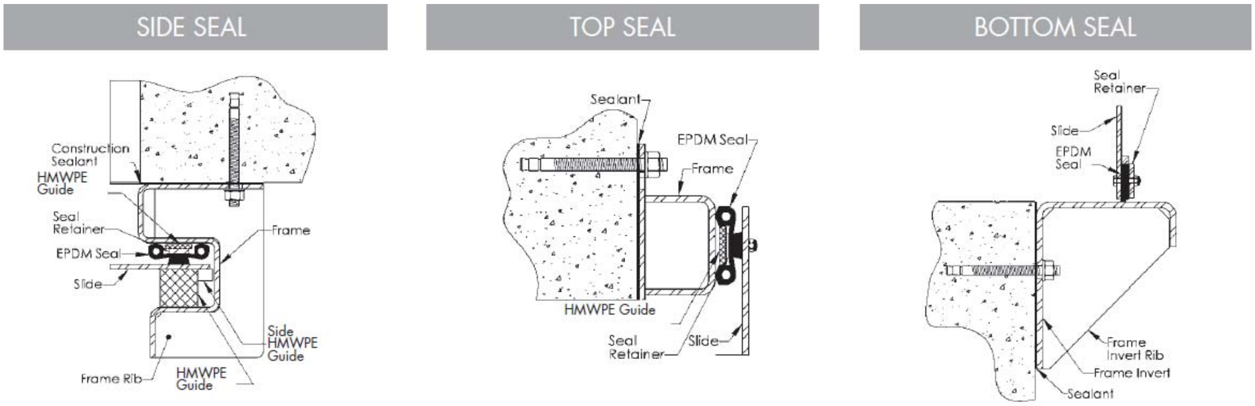
SIDE SEAL



TOP SEAL



Details from Orbinox, showing the perimeter seal of a sliding flood gate.

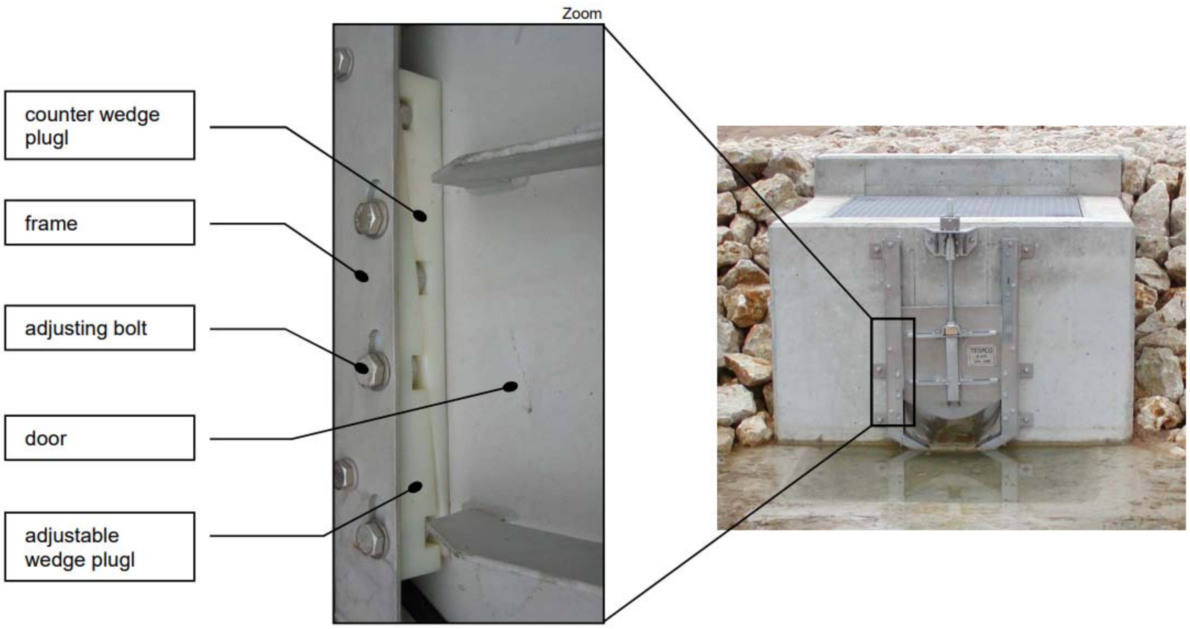


DIN 19569-4, class 1:

Detail from Orbinox, showing the perimeter seal of a sliding flood gate produced with bent profiles.

Details from Buesch, showing smart solutions for a corner seal of a log barrier.

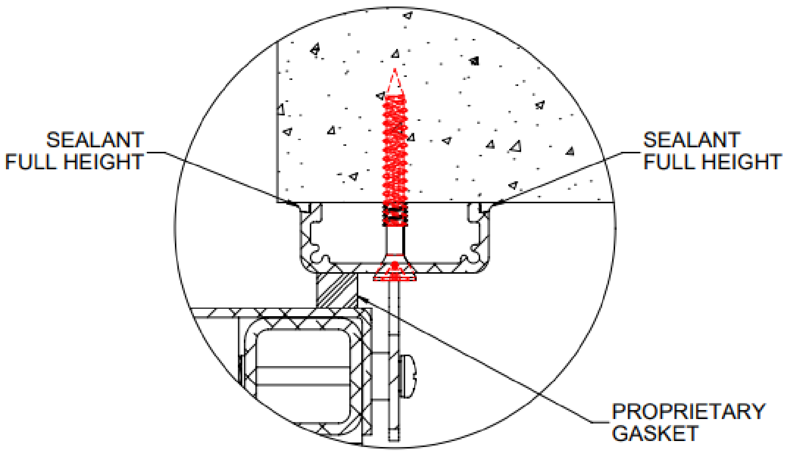
Detail from Buesch, showing a winch with a very dense thread. See earlier discussion about the winches, and the photo of a wide pitch thread combined with a small arm on the right side for comparison.



Details from Orbinox, showing a wedge providing initial compression for a perimeter seal of a sliding barrier.

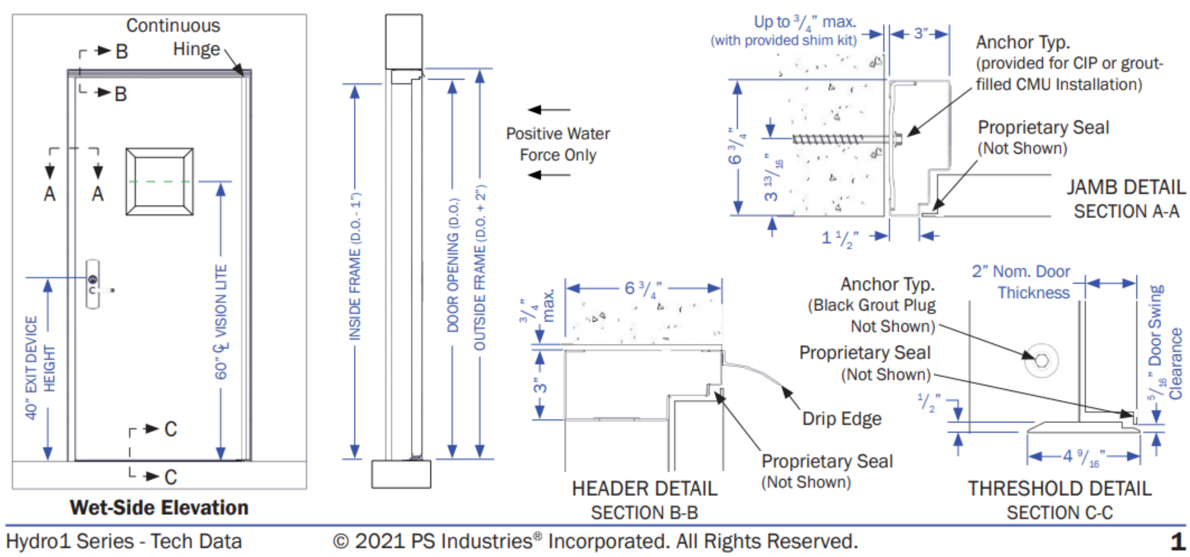
A flood gate jamb with a base receptor and post anchors. Could not find credits for this photo. If you recognize it, please let me know.

Visible variations and discontinuities in Floor Surfaces Interfacing the Bottom Seal of Flood Barriers: Perpendicular Control Joints and cracks. The entire sidewalk surface at this location is floating over a discontinuous waterproofing installation, so the flood barrier would be bypassed under the sidewalk.



DETAIL F

An interesting jamb detail from PS Industries. A fastener drawn a little too close to an edge.



An pedestrian door from PS Industries that achieved 0.025 gallons per hour per linear foot of wetted perimeter (gal/hr/lin_ft), which is 69% less than the maximum allowed leakage rate of the ANSI/FM 2510 standard, and translates into 0.00009 l/s/m.