Oak Ridge National Laboratory

SERRI Report 80024-01

Floodproof Construction: Working for Coastal Communities

SERRI Project: Floodproof Commercial Construction and
Fortified Residential Construction for
Neighborhood-Scale, Mixed-use Buildings

SERRI Southeast Region Research Initiative

Project Principal Investigator:
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FLOODPROOF COMMERCIAL CONSTRUCTION: WORKING FOR COASTAL COMMUNITIES

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ACRONYMS

ADA	Americans with Disabilities Act
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BFE	Base Flood Elevation
BHA	Biloxi Housing Authority
CFR	Code of Federal Regulations
CMU	Concrete Masonry Unit
DEM	Digital Elevation Model
DFE	Design Flood Elevation
DFIRM	Digital Flood Insurance Rate Map
DHS	Department of Homeland Security
FEMA	Federal Emergency Management Agency
FFE	Finished Floor Elevation
FIS	Flood Insurance Study
FIRM	Flood Insurance Rate Map
GCCDS	Gulf Coast Community Design Studio
GIS	Geographic Information Systems
IBC	International Building Code
IBHS	Insurance Institute for Business and Home Safety

ICF	Insulated Concrete Formwork
LimWA	Limit of Moderate Wave Action
MWFRS	Main Wind Force Resisting System
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
ORNL	Oak Ridge National Laboratory
SERRI	Southeast Region Research Initiative
SFHA	Special Flood Hazard Area
SIPs	Structural Insulated Panels
RFD	Regulatory Flood Datum
USACE	United States Army Corps of Engineers

SOUTHEAST REGION RESEARCH INITIATIVE

In 2006, the U.S. Department of Homeland Security commissioned UT-Battelle at the Oak Ridge National Laboratory (ORNL) to establish and manage a program to develop regional systems and solutions to address homeland security issues that can have national implications. The project, called the Southeast Region Research Initiative (SERRI), is intended to combine science and technology with validated operational approaches to address regionally unique requirements and suggest regional solutions with potential national implications. As a principal activity, SERRI will sponsor university research directed toward important homeland security problems of regional and national interest.

SERRI's regional approach capitalizes on the inherent power resident in the southeastern United States. The project partners, ORNL, the Y-12 National Security Complex, the Savannah River National Laboratory, and a host of regional research universities and industrial partners, are all tightly linked to the full spectrum of regional and national research universities and organizations, thus providing a gateway to cutting-edge science and technology unmatched by any other homeland security organization.

Because of its diverse and representative infrastructure, the state of Mississippi was chosen as a primary location for initial implementation of SERRI programs. Through the Mississippi Research Initiative, SERRI plans to address weaknesses in dissemination and interpretation of data before, during, and after natural disasters and other mass-casualty events with the long-term goal of integrating approaches across the Southeast region.

As part of its mission, SERRI supports technology transfer and implementation of innovations based upon SERRI-sponsored research to ensure research results are transitioned to useful products and services available to homeland security responders and practitioners. Concomitantly, SERRI has a strong interest in supporting the commercialization of university research results that may have a sound impact on homeland security and encourages university principal investigators to submit unsolicited proposals to support the continuation of projects previously funded by SERRI.

For more information on SERRI, go to the SERRI Web site: www.serri.org.

EXECUTIVE SUMMARY

Dry floodproofing is one of several methods for mitigating flood risk. Each local jurisdiction can determine the standards for dry floodproofing to best suit their floodplain management plan. Typically, a dry floodproofed building is a non-residential structure which has been certified by an architect or engineer of record as substantially impermeable to the passage of water and capable of resisting flood forces.

The scope of opportunity to use dry floodproof construction is small; it is constrained by regulatory, technical and economic limits. However strategic use of dry floodproof construction as part of an overall mitigation plan can promote economically and socially resilient neighborhoods by achieving levels of design integration and building accessibility other mitigation techniques cannot.

After Hurricane Katrina, many commercial corridors in communities devastated by the storm surge were also negatively affected by being included in the newly expanded FEMA Special Flood Hazard Area (SFHA). The many difficulties of building commercial space in a SFHA, such as insurance challenges and lack of technical expertise have drastically stalled commercial development in these areas.

The Gulf Coast Community Design Studio (GCCDS) and its community partners observed that small-to-medium scale commercial development in communities along the Mississippi Gulf Coast were struggling to build after the storm. This was in part due to a need for contemporary information on options for dry floodproof construction. With funding from the Southeastern Regional Research Initiative (SERRI), the GCCDS sought to investigate and report on the policy, methods and effects of dry floodproof construction and to increase interest in dry floodproof construction.

The research has been classified into four tasks:

- Understand Hazards: a survey of precedent studies & policy history
- Plan Neighborhood Land Use: a planning & urban design study
- Investigate Materials and Assemblies: full scale construction testing
- Design a Mixed-Use Building: schematic design & budgeting

In the area of planning, GIS technology was used to identify commercial properties that have suitable characteristics for both the physical and regulatory requirements of dry floodproofing. Using similar techniques interested communities could create land use and zoning policies which aid in the development of dry floodproof commercial property. Dry floodproof construction allows commercial spaces to be built closer to grade, thereby increasing building accessibility, the quality of commercial corridors and the value of property.

Buildings and structures are built everyday to resist a wide range of hydrostatic forces. Beyond the question of achievability, this research explored whether floodproof building performance could be achieved using materials and techniques already used along the Mississippi Gulf Coast. The result was a focus on common building materials and techniques for the research.

The GCCDS developed and tested a variety of different wall assemblies in several full-scale test models through a series simulated floods of 3′ depths in an outdoor flood tank. Using observations taken from the first flood simulation and data gathered from a subsequent drying period, the GCCDS revised several wall assemblies to improve dry floodproof performance. Through simulation testing, multiple construction types were identified as viable options for dry floodproof construction, including concrete masonry blocks with sprayed- and sheet-applied water resistive membranes, Insulated Concrete Formwork (ICF), and metal Structural Insulated Panels (SIPs). Finding a variety of options for dry floodproof construction was a goal of the project due to the need for system flexibility when dealing with differing regulatory, technical and economic development limits.

Included in the research project was a designed study for a mixed-used building in the SFHA, done in collaboration with the Biloxi Housing Authority. The process of schematic design and cost estimating for this mixed-use building focused on combining all the gained knowledge from earlier material and planning research with a community based scenario. The direct and indirect cost of building and maintaining a dry floodproof building was considered within context of building cost, operation and insurance.

Through this research, several technical solutions for dry floodproof construction along with several planning and urban design techniques were identified. Combining current construction techniques with progressive can allow for the strong community impacts from dry floodproof construction projects despite its limited role in a larger mitigation plan.

1. INTRODUCTION

Hurricane Katrina affected existing commercial corridors along the Gulf Coast by physically destroying or severely damaging buildings. As a result of this disaster, the Flood Insurance Rate Maps (FIRMs), which assign flood zones and Base Flood Elevation (BFE) heights were revised to include large areas that were not previously located within Special Flood Hazard Areas. The revision of these maps significantly impacted the rebuilding and development opportunities for property owners. Additional elevation requirements derived from the revisions of the FIRMs have made it difficult to build new commercial buildings in areas that have historically been economically viable. The Federal Emergency Management Agency (FEMA) has provisions to allow non-residential buildings to be built below the BFE, using dry floodproof construction. Dry floodproof construction is defined as being substantially impermeable to water. This alternative can be employed to relieve the strain of elevating commercial development in established coastal neighborhoods.

However, the limited applicability and knowledge of dry floodproof construction has resulted in a very small number of projects successfully taking advantage of this alternative. In areas subjected to high elevation requirements, dry floodproof construction may not be economically or architecturally feasible. Other factors impacting the applicability of dry floodproof construction include building performance specifications and urban design issues pertinent to commercial corridors, which are discussed in Chapters Two and Three of this report.

It is not surprising that many Gulf Coast stakeholders are unfamiliar with the opportunities associated with the option of dry floodproof construction; the complexities of dry floodproof construction involve collaboration between property owners, developers, engineers and architects, zoning officials, and municipal floodplain managers, all under the direction of federal policy. At the time of this research, many parties that could be involved in the development of new dry floodproof commercial spaces do not appear to understand the regulatory or performance requirements of this type of mitigation. Of those that seem to be aware, none appear to have had sufficient experience with designing, building, cost estimating, and insuring dry floodproof buildings.

For coastal communities to build back in a resilient manner, small business owners, local builders, architects and engineers must be better informed of the available range of technically sound and affordable methods of building dry floodproof buildings. The Gulf Coast Community Design Studio (GCCDS) has leveraged its association with a variety of local groups to research and disseminate information regarding the advantages of dry floodproof construction. Mitigation through dry floodproof construction allows businesses and cities a wider range of flexibility to act as a steward for existing commercial streets, thereby promoting economic resiliency and sustainability.

1.1 Problem Statement and Objectives

The purpose of this project is to research and combine knowledge of technical and regulatory requirements with construction practices and material specifications to better understand dry floodproof construction as a viable method for flood mitigation on the Gulf Coast. In order to synthesize the research, a sample mixed-use building was designed for an existing site within the flood plain in Biloxi, Mississippi, using the knowledge gathered.

This research is intended to address FEMA Knowledge Gap RA5 "*Advanced Materials and Design of Sustainable Commercial Construction in the Coastal Environment*".

The following questions guided the research:

a) What new advancements in commercial construction methods or technology will make dry floodproofing more effective or more affordable than current practice or written sources suggest?
b) How can dry floodproof construction, in combination with good urban design, improve the physical and economic resiliency of Mississippi Gulf Coast communities and cities?
c) What information needs to be clarified and communicated to those in the business, construction, and government sectors to encourage the use dry floodproofing?

1.2 Scope of Research

Several methods of research were used to complete this project, including compiling source materials, physically testing materials and assemblies, and designing a sample building. Architectural design is a form of research; it requires systematic investigation of the assembly and configuration of a building through diverse and interrelated parameters. Advantages, disadvantages and idiosyncrasies of various materials and construction strategies are discovered, as the process, performance, program and maintenance of the building are all considered simultaneously. GCCDS staff worked with stakeholders and professionals with expertise in mitigation, engineering, construction, community development, financing and insurance to complete the research process.

1.2.1 Task One: Understand Hazards

Physical hazards that can damage buildings during a coastal flood event were researched using reports from previous storms, along with guidance from local engineers and consultants. Resulting forces were calculated from this research. The information gathered during this research was then presented to stakeholders through community presentations and web posting.

1.2.2 Task Two: Investigate Materials and Assemblies

Investigating materials and assemblies was a multi-stage process. Working closely with local builders and engineering firms, along with input from local mitigation specialists, distinct wall assemblies were investigated and developed. Six test wall assemblies were then constructed in an outdoor tank. A 24-hour flood simulation tested the wall assemblies against conditions similar to a coastal flood event. Visual observations, water depth measurements and electronic moisture measurements were recorded before, during, and after the flood simulation. Results from the flood simulation were used to inform a series of assembly revisions, which were then subjected to an additional flood simulation with similar observations and measurements taken.

1.2.3 Task Three: Plan Neighborhood Land Use

Sets of data from topographic maps, Digital Flood Insurance Rate Maps (DFIRMs), and land use maps were overlaid to produce a series of analytical maps. These maps revealed sites where opportunity for dry floodproof commercial construction on the Mississippi Gulf Coast is feasible, in the context of regulation and existing social and environmental conditions.

1.2.4 Task Four: Design a Mixed-Use Building

A sample mixed-use building was designed in collaboration with the Biloxi Housing Authority (BHA). The design was a vehicle for research regarding the financing, constructing and insuring a dry floodproof commercial property in the case study community of East Biloxi, Mississippi.

1.2.5 Task Five: Inform the Development Community

The development community was engaged through partnerships, informational events, community presentations, and web-based publishing. This engagement will continue as knowledge gained is integrated into the existing and future work of the GCCDS.

2. SUMMARY OF COASTAL FLOOD HAZARDS

2.1 Summary of Design Loads of Coastal Hazards

Since most major coastal flood events are associated with hurricanes, flood hazards in coastal areas occur as a result of storm surges and unusually high tides. Riverine flooding varies in character from coastal flooding due to the difference between current flow and wave action. Therefore the following explanation is specific to coastal flood loads.

In order to calculate coastal flood loads for a specific building and site, the Design Stillwater Depth needs to be determined. This is the vertical distance between the eroded ground elevation and the Stillwater Elevation associated with the design flood. This vertical dimension will help designers and engineers determine Design Flood Elevation (DFE), or the Design Flood Protection Depth, which is the height at which floodproof construction methods should be employed to resist flood-related damage to a building. The Design Stillwater Depth is used to determine the hydrostatic load, hydrodynamic load, flood velocity, design wave height, local scour depth, and debris impact loads. *(FEMA 55 2005)*

Local variables included in flood load calculations can be found in the Flood Insurance Study (FIS) Reports that are compiled to create the Flood Insurance Rate Map (FIRM) for a community. Chapter 11 of *FEMA 55: Coastal Construction Manual* provides extensive instructions on how to determine site-specific loads regarding coastal flood hazards. Additionally, *American Society of Engineers (ASCE) 7-98 Minimum Design Loads for Buildings and Other Structures* is an accepted reference to determine other loads, such as dead and live loads, to be used in combination with coastal flood loads to determine structural capacities of building components. Scott Sundberg, a structural engineer working on the Mississippi Gulf Coast, provided consultation services during the investigation of coastal flood hazards.

2.1.1 Flood-Related Loads

The following is a summary of forces acting on buildings as result of rising floodwaters during a flood event.

2.1.1.1 Hydrostatic forces

Hydrostatic loads result from vertical and lateral forces that act on a building from standing or slowly moving water. Lateral hydrostatic loads are applied to a building face at a point 2/3 below the depth of the Stillwater Elevation (Fig 2.1). Vertical hydrostatic loads (otherwise known as buoyant forces) act on a building from below the foundation structure. The Design Stillwater Depth is determined by the local FIS provided by the National Flood Insurance Program (NFIP). (*FEMA 55 2005*)

$$F_{STA} = [(1/2)\ \gamma\ d_s^2]\ (w)$$

where:

F_{STA} = lateral hydrostatic force on a structure (in lb)

γ = specific weight of water
= 64.0 lb/ft³ for saltwater

d_s = design stillwater flood depth

w = width of building (in ft)

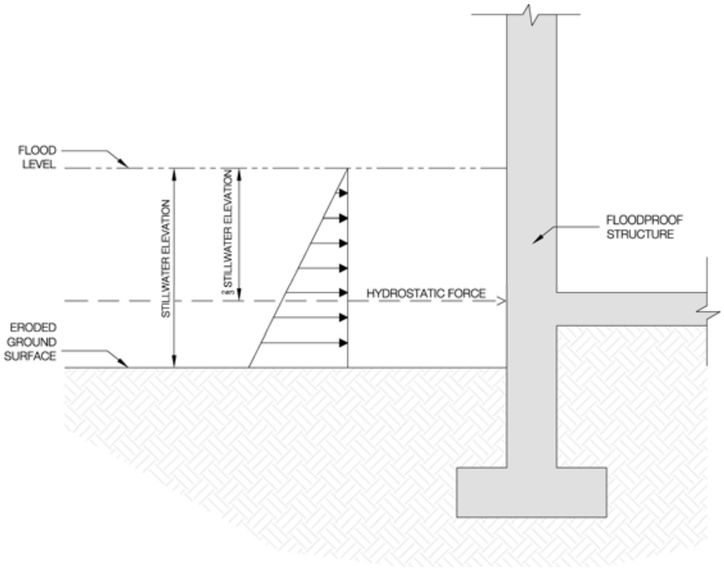


Fig. 2.1. DIAGRAM: Lateral hydrostatic force diagram.

These loads produce little damage to buildings when the flood depths on either side of a wall are similar, hence the requirement for flood vents and openings in foundation walls located below the BFE in A flood zones to equalize flood depths (Fig 2.2).

Fig. 2.2. PHOTO: Flood vent in foundation wall.

Dry floodproof buildings are designed to keep nearly all floodwater from entering the envelope of the building below and above the BFE (see definition of dry floodproof construction), and therefore need to be able to completely withstand the hydrostatic forces acting on the exterior walls. Fig. 2.3 shows an example of a building failure due to lateral hydrostatic forces; the building envelope failed to resist the intrusion of water, which flooded the entire interior of the building.

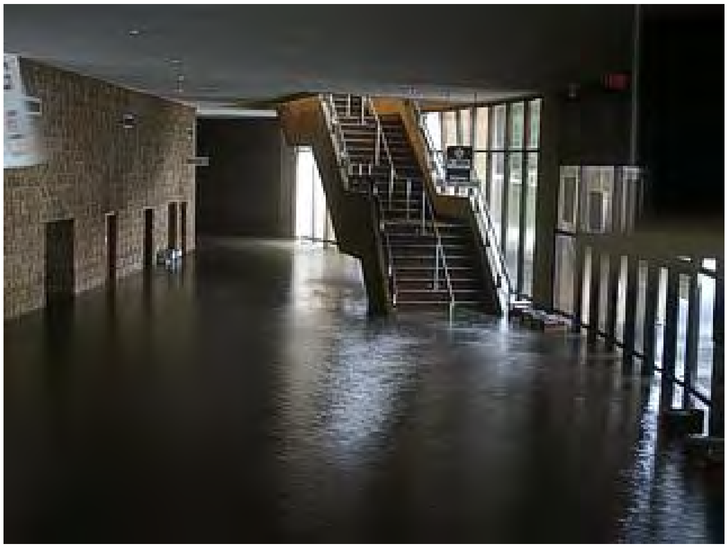


Fig. 2.3. PHOTO: Failure due to hydrostatic forces. (*Collura, 2005*)

2.1.1.2 Hydrodynamic forces

Hydrodynamic loads are forces which act on a structure due to moving water around exterior walls. These loads impact all sides of a building: directly to the seaward face (the exterior wall perpendicular to the flow of water), drag along the sides (the exterior walls parallel to the flow of water), and negative pressure (suction) on the downstream face (the exterior wall opposite of the seaward face) (Fig. 2.4).

Fig. 2.4. PHOTO: Failure due to hydrodynamic forces. (*FEMA 549 2006*)

Hydrodynamic loads are a function of expected flood velocities, which are subject to high uncertainty. For flow velocities less than 10 ft/sec, the hydrodynamic load can be converted to a hydrostatic load. For buildings within an A flood zone, flood velocities are expected to be less than 10ft/sec. Buildings within V, VE, or Coastal A zones are subject to hydrodynamic forces (Fig. 2.5). The hydrodynamic load can impact a building at localized points when the flow velocity is increased unevenly around a building. This happens when the flow is obstructed and more water is forced through smaller openings (i.e. between two buildings that are close to each other). (*FEMA 55 2005*)

$$F_{dyn} = \{\gamma d_s[(1/2)C_d V^2/g]\}w$$

where:

F_{dyn} = lateral hydrostatic force in lb acting at the point 2/3 below the stillwater elevation

γ = specific weight of saltwater (64.0lb/ft^3)

d_s = design stillwater flood depth

C_d = drag coefficient for width to depth ratio

V = velocity of water in ft/sec

g = acceleration due to gravity (32.2ft/sec^2)

w = width of structure in feet

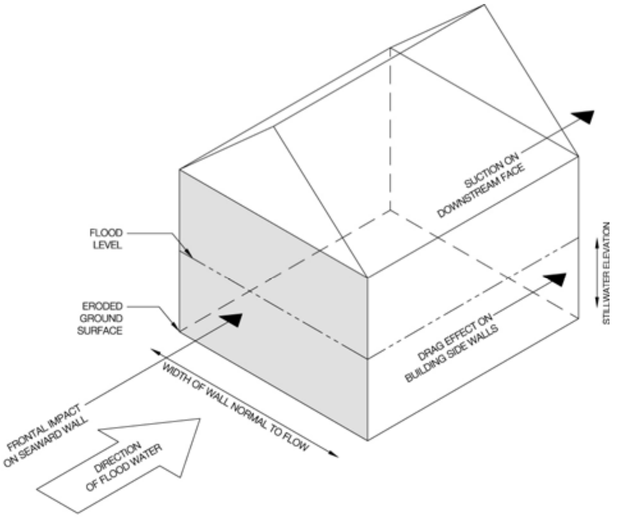


Fig. 2.5. DIAGRAM: Hydrodynamic forces.

The most common means of mitigating hydrodynamic forces in building design is to elevate the floor of the structure so that it is above the expected Design Flood Elevation (DFE), and anchor it properly to an open foundation (driven piles, concrete piers with deep footings). If portions of the enclosure are to be built below the DFE in an area subject to flow velocities higher than 10 ft/sec, the enclosure needs to be built as a breakaway wall, so that it does not damage the primary structure above it in a flood event (Fig. 2.6). See *FEMA Technical Bulletin 5: Free of Obstruction Requirements* for prescriptive information on design and installation of structures below the DFE.

Fig. 2.6. PHOTO: Damage as a result of non-breakaway stair design. (*FEMA TB-5 2008*)

2.1.1.3 Wave action

Wave loads are forces acting on the seaward face of a building at the Design Stillwater Elevation, as a result of four types of wave forces: non-breaking waves, breaking waves, broken waves, and uplift (as a result of wave run up on vertical or sloping surfaces, or waves peaking under protruding horizontal surfaces). Because breaking waves produce the highest load acting on a building, they are used to calculate the design wave load (Fig. 2.7). Wave loads affect buildings in all types of flood zones, but their impact is greatest in V, VE, and Coastal A zones, where the height of the cresting waves are expected to be higher than in other flood zones. (*FEMA 55 2005*)

$$F_{brkw} = [1.1C_p \gamma d_s^2 + 2.41\gamma d_s^2](w)$$

where:

F_{brkw} = wave load per unit length of wall acting at the stillwater level

C_p = dynamic pressure coefficient (as a Function of Probability of Exceedance, Walton et al. 1989) = 3.2

γ = specific weight of water = 64.0 lb/ft^3 for saltwater

d_s = design stillwater flood depth in feet

w = width of wall normal to flow of flood water

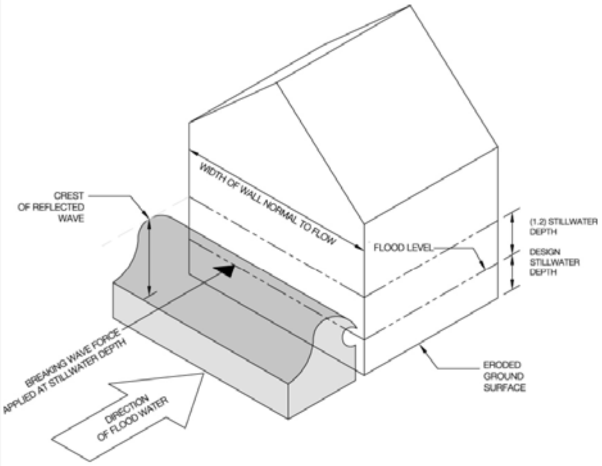


Fig. 2.7. DIAGRAM: Breaking wave forces.

Because breaking wave loads are associated with hydrodynamic forces, mitigation strategies are similar. Elevating the structure above the DFE, choosing durable materials and installing them with proper anchorage, and using open foundations with breakaway structures below the DFE are all common methods used to decrease damage to buildings in flood zones that experience high wave loads. The photo in Fig. 2.8 demonstrates extensive damage to a building due to high breaking wave forces.

Fig. 2.8. PHOTO: Damage as a result of breaking waves. (*FEMA 490 2005*)

2.1.1.4 Localized scour

Scour is the erosion of soil adjacent to a building as a result of turbulence from floodwater moving toward and against the foundation structure of a building. The removal of this soil can affect the bearing capacity and the anchoring resistance of the remaining soil around the foundation (Fig. 2.9).

Fig. 2.9. PHOTO: Damage as a result of localized scour. (*FEMA 549 2006*)

Scour depths are influenced by the flood depth, flood velocity, soil characteristics and the Flow Angle of Attack (the angle of the floodwater in relation to the building). The design scour depth is calculated using the maximum variables, such as the upper bound flow velocity and the highest impact Flow Angle of Attack, which is 60 degrees to normal (Fig. 2.10). Choosing a foundation type that is installed well below the anticipated scour depth is the most effective way to mitigate against damage from scour during a flood event. (*FEMA 55 2005*)

$$S_{max} = d_s\{2.2(a/d_s)^{0.65}[V/(gd_s)^{0.50}]^{0.43}\}K$$

where:

S_{max} = max. localized scour depth (in feet)

d_s = design stillwater flood depth (in feet)

a = half the width of the foundation perpendicular to the flow of water

V = velocity of water in ft/sec (upper bound)

g = gravitational constant (32.2 ft/sec^2)

K = factor applied for Flow Angle of Attack

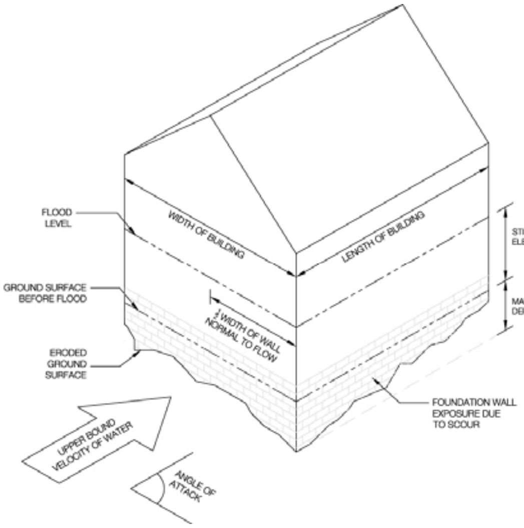


Fig. 2.10. DIAGRAM: Localized maximum scour diagram.

2.1.1.5 Debris impact

Debris impact loads are lateral forces that act on a building as a result of debris floating in floodwater and colliding with the face of a building (Fig. 2.11). The magnitude of this load is extremely difficult to predict, as it is a function of the weight of the debris and the velocity at which it is travelling. Additionally, the type of debris cannot be accurately predicted for a flood event. Here, it is assumed that the design object weighs 1,000lbs and is moving at the Design Floodwater Velocity.

$$F_i = wV/gt$$

where:

F_i = impact force, in lbs, acting at the stillwater level

w = weight of the debris object = 1,000lbs

V = velocity of floodwater in ft/sec = $(gd_s)^{0.5}$;

g = gravitational constantat 32.2 ft/sec^2

t = duration of impact (in seconds) = 0.1 for reinforced concrete

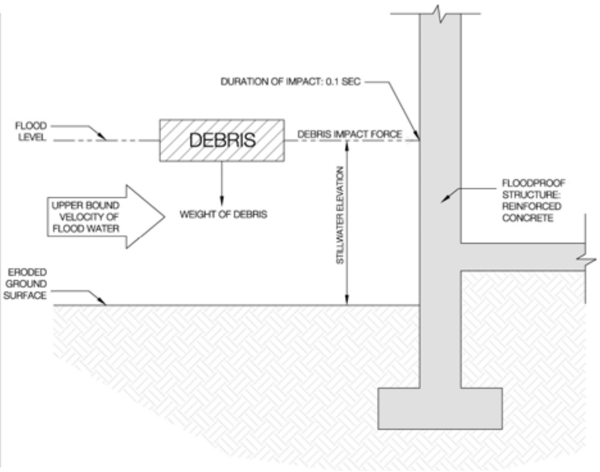


Fig. 2.11. DIAGRAM: Debris impact.

Also, the duration of impact of the debris is influenced by the "rigidity" of the building materials. The City of Honolulu building code has determined this by the type of construction method employed. Subsequently, FEMA has adopted this method for determining the design duration of impact of debris. (*FEMA 55 2005*)

Table 1. Duration of impact

	Duration (t) of Impact (sec)	
Type of Construction	**Wall**	**Pile**
Wood	0.7-1.1	0.5-1.0
Steel	n/a	0.2-0.4
Reinforced Concrete	0.2-0.4	0.3-0.6
Concrete Masonry	0.3-0.6	0.3-0.6

Because debris impact is extremely difficult to predict, mitigation strategies are somewhat limited. Choosing building materials that can withstand higher impact loads, elevating the structure above the DFE, limiting the amount of obstructions in the structure below the DFE, and removing or anchoring large objects around the structure prior to a flood event are ways to decrease the risk of damage due to debris impact. Below (Fig. 2.12), damage was recorded to a building due to debris that traveled over two miles during Hurricane Opal in Pensacola Beach, Florida.

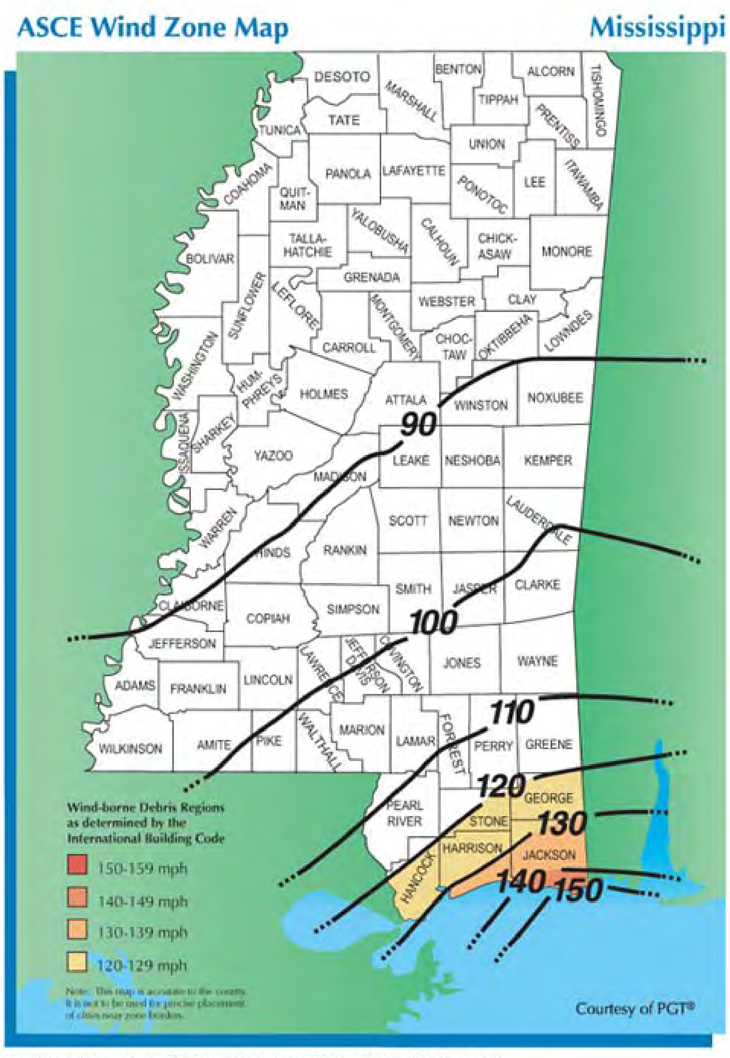
Fig. 2.12. PHOTO: Damage as a result of debris impact. (*FEMA 55 2005*)

2.1.2 Wind-Related Loads

The following is a summary of forces acting in conjunction with flood hazards as a result of a high-wind event, such as a hurricane.

2.1.2.1 Wind load

Wind pressures are forces acting in various directions on a building as a result of heavy wind events (hurricanes, thunderstorms, or tornadoes). Lateral and vertical (uplift) forces can cause damage if buildings are not properly designed or constructed to meet or exceed the wind load. FEMA's accepted standard for determining wind force is the *ASCE 7-02 Minimum Design Loads for Buildings and Other Structures.* Fig. 2.13 shows the ASCE Wind Zone map used to determine design wind speeds for Mississippi.



SOURCE: ASCE MINIMUM DESIGN LOADS FOR BUILDINGS AND OTHER STRUCTURES

Fig. 2.13. MAP: ASCE Wind Zone Map for Mississippi. (*ASCE 7 1998*)

Wind pressures are calculated both for the capacity of the structural frame--known as the Main Wind Force Resisting System (MWFRS)--consisting of the foundation, floor supports, columns, roof rafters or trusses, bracing, walls, and any diaphragms assisting in transferring loads, and also for the capacity of building components and cladding (elements not directly related to the structure, such as roof sheathing, coverings, exterior siding, windows, doors, soffits, fascia).

The following factors influence the impact of wind forces:

a) Wind speed (Fig. 2.13)
b) Size and shape of the building (height above the ground, proportion of length to width, the exposed faces in relation to the wind direction)
c) Strength of the structure and envelope (including the number and sizes of openings), along with the strength of components and their connections
d) Measures taken to protect the building, such as shutters, site topography and orientation, and vegetation

During a high-wind event, an enclosed building will experience high pressures on the exterior of the building envelope. When even a small piece of cladding becomes detached, and wind and rain are allowed to enter the building, the building can fail substantially because of the uncontrolled forces acting upon the interior walls (Fig. 2.14). (*FEMA 55 2005*)

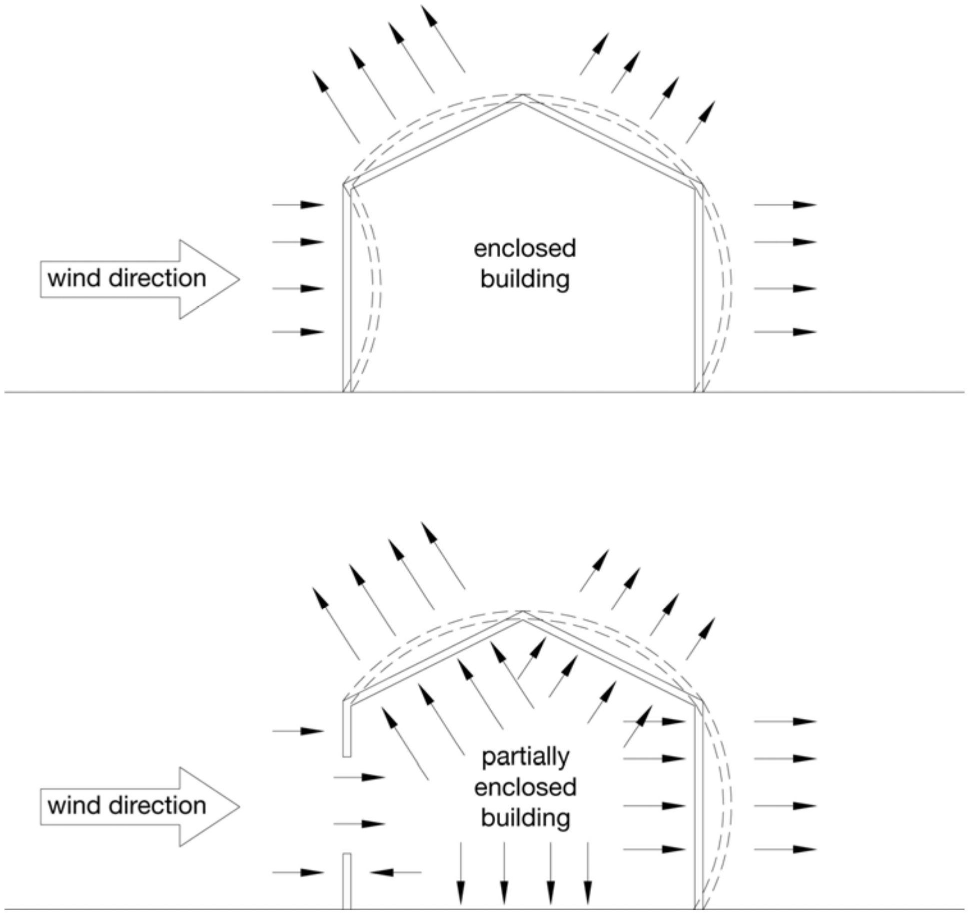


Fig. 2.14. DIAGRAM: Wind loads. (*FEMA 55 2005*)

Mitigation strategies used to decrease the risk of damage to buildings located in areas prone to high wind speeds are: using building materials and components that meet wind speed requirements, using correct fastening and anchoring systems (and also using fasteners that will not corrode if exposed to water such as stainless steel or galvanized coated), designing appropriately shaped buildings to meet wind loads, using impact-resistant windows and doors, placing shutters or protective panels over openings in walls, and refraining from using light-weight cladding systems. Fig. 2.15 shows how a building with vinyl siding (a light-weight cladding system) was damaged when wind entered the attic of the building through a failure in the porch soffit, and 'blew out' the gable end wall.

Fig. 2.15. PHOTO: Damage as a result of pressure differences. (*FEMA 549 2006*)

2.1.2.2 Missile impact (windborne debris)

Windborne debris colliding with a building during a high wind event can puncture the envelope and components, leading to differentials in wind pressure between the exterior and interior of the building. Additionally, punctures in the building envelope lead to damage to interior finishes and the structure due to rainfall and wind-driven rain entering the building envelope unintended. Since high wind events in coastal areas are generally associated with hurricanes, water damage as a result of missile impacts can produce damage up to nine times the dollar amount of damage produced by missile impacts alone (*FEMA 55 2005*). Fig. 2.16 demonstrates how the glazing on a New Orleans building was damaged heavily during Hurricane Katrina when aggregate from a nearby roofing system was blown off, puncturing the building envelope.

Fig. 2.16. PHOTO: Damage as a result of missile impact. (*FEMA 549 2006*)

Damage caused by windborne debris is a function of the size, shape, and weight of the missile, the velocity at which it is travelling, and the strength of the building that it collides with. The *2009 International Building Code* specifies that openings in buildings located in high wind areas need to be protected by impact resistant products that meet American Society for Testing and Materials (ASTM) E1886 and ASTM E1996 (*IBC 2009*). Wood structural panels may be used to protect openings that do not already meet these requirements, if local building codes permit.

2.2 Summary of Dry Floodproof Regulatory Requirements

In order to understand the breadth of regulatory publications of floodproof construction in the United States, it was necessary to follow the influential documents through networks of research, design, and governance. Pivotal sources for floodproof-related standards, developed by federal agencies, industry groups, and academic research organizations have informed the research presented in this report. The GCCDS created a diagram showing the choronology of floodproof construction publications (Fig 2.17) in order to map relationships within existing research with reference to important flood events in history. The regulations that are enforced at a local level for floodproof design and construction projects have been influenced through a number of publications presented within this diagram. This map was intended to be used as a working document during the research phases of this project, and does not represent all publications and research related to the topic of floodproof construction.

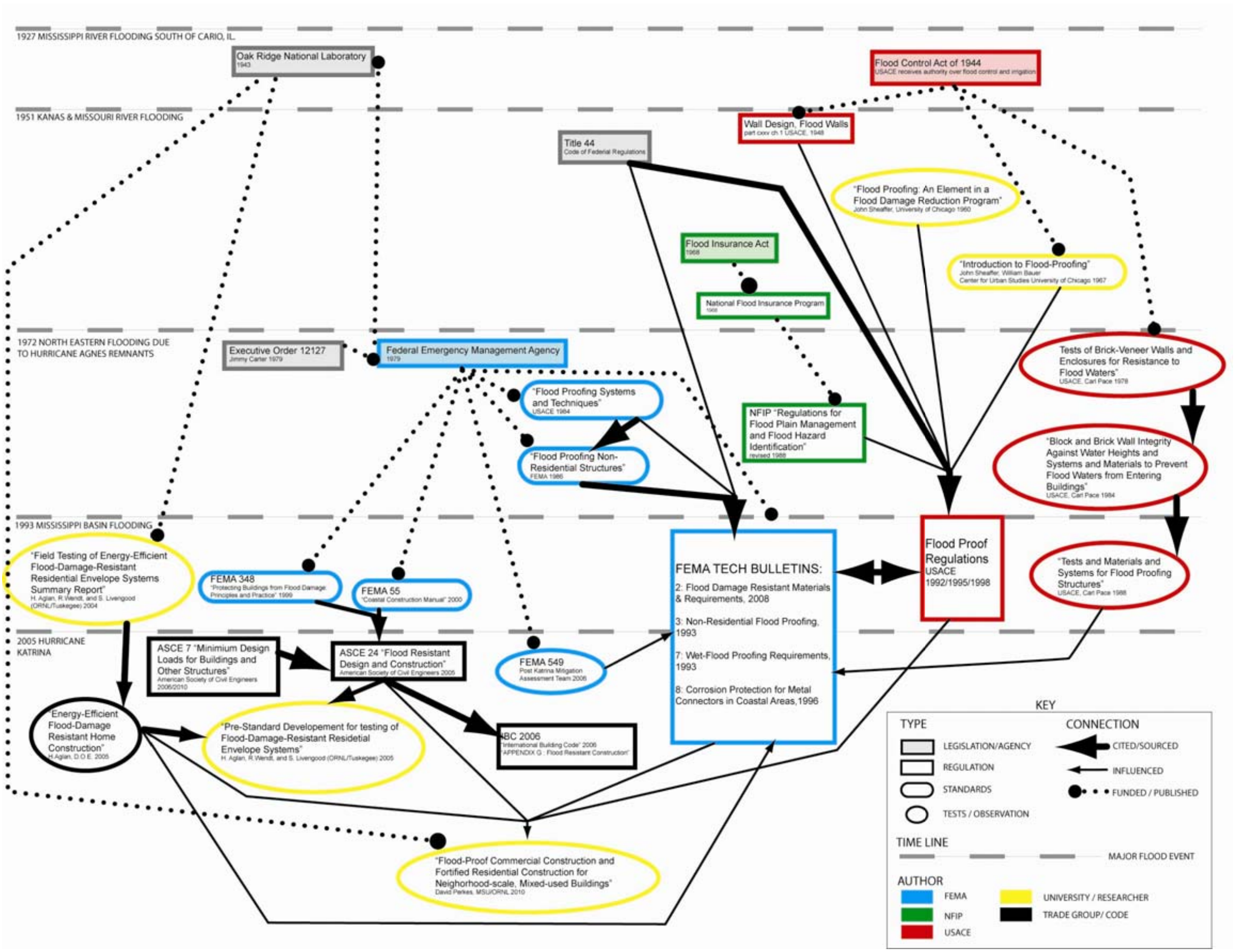


Fig 2.17. DIAGRAM: Chronology of floodproof construction research publications.

2.2.1 National Flood Insurance Program (NFIP) Requirements

Communities participating in the NFIP must implement a floodplain management ordinance. This ordinance establishes certain standards that must be met in order for the community to receive favorable flood insurance rates under the NFIP. Community Floodplain requirements are based on NFIP regulations, in addition to state and regional building code regulations. Fig. 2.18 shows the relationships between the agencies and the documents that inform flood zone regulation.

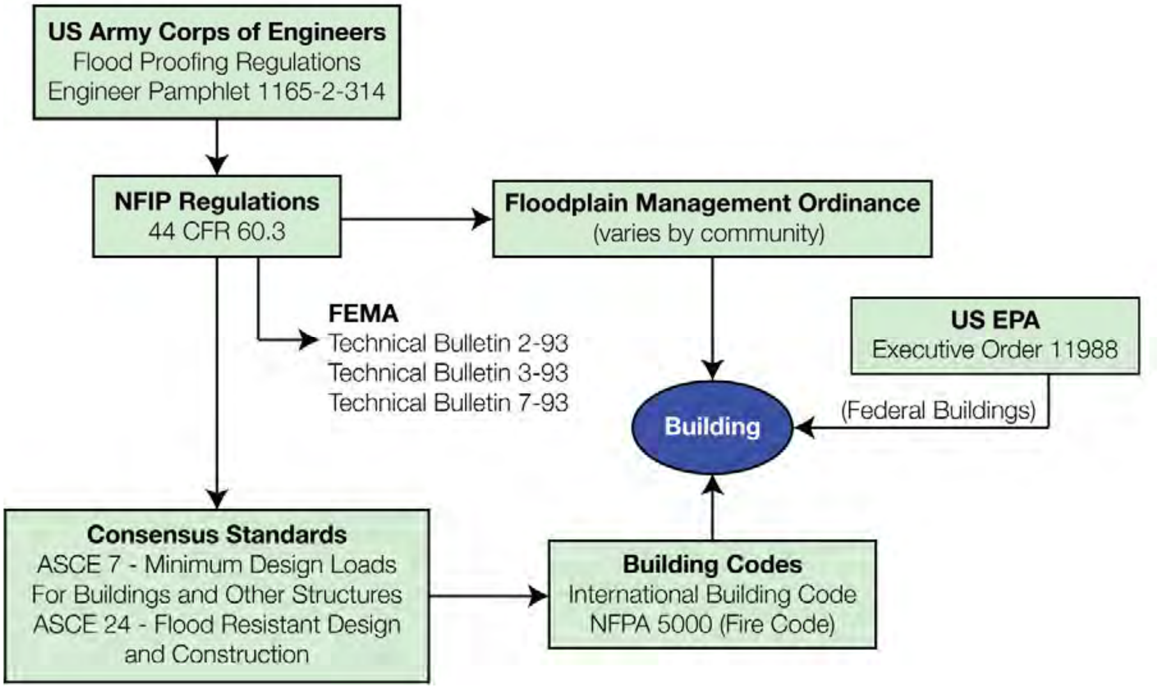


Fig. 2.18. DIAGRAM: Flow chart of flood regulation influence on building design. (*Jones 2009*)

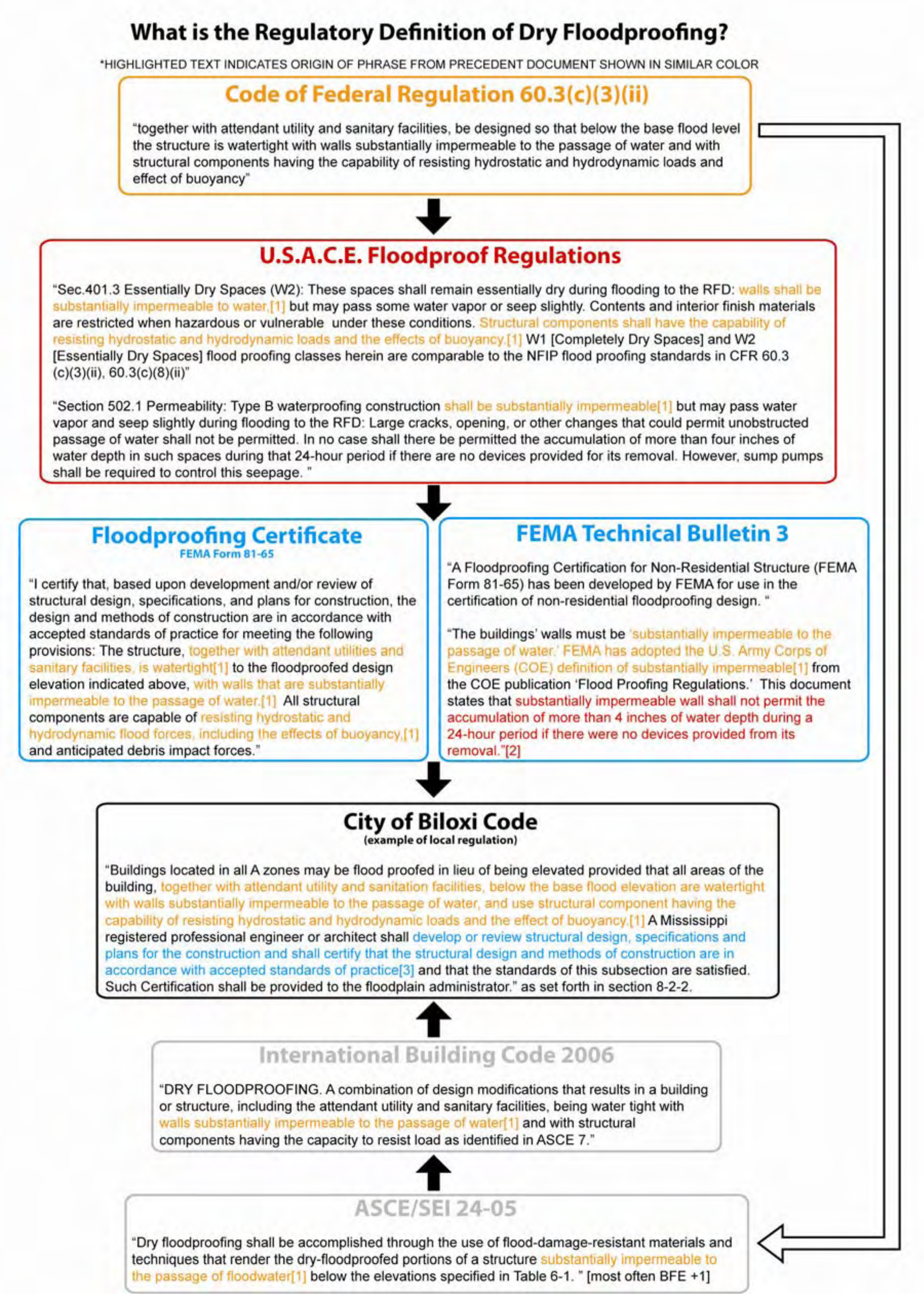
Floodplain management ordinances are designed to mitigate hazards associated with flooding, such as: direct damage from inundation, high velocity flow, waves, erosion, sedimentation and/or floodborne debris, degradation of building materials and contamination of the building due to floodborne substances or mold. (*Jones 2009*) Preferred mitigation techniques in flood zones vary; the most common techniques are the relocation of buildings outside of the flood hazard area or the elevation of buildings' FFE above the BFE. Non-residential buildings may be permitted to have a FFE below the BFE, if dry floodproof construction methods are allowed and applied correctly according to the floodplain management ordinance. A dry floodproof building should be materially and structurally resistant to damages from flooding in all areas of the building below the BFE. Residential uses below the BFE are strictly forbidden under the NFIP; the chance of injury or death to a person inhabiting a building during flood event is too high.

2.2.1.1 44 CFR 60.3 Floodplain management criteria for flood-prone areas

The federal precedent for the NFIP requirements for dry floodproof construction is *44 Code of Federal Regulations (CFR) 60.3 Flood plain management criteria for flood-prone areas*. This code defines the following requirements for dry floodproof construction below the BFE:

a) Must be a non-residential structure
b) Restricted to Zones A1-30, AE and AH zones on the community's FIRM
c) The structure below the BFE is to be watertight with "walls substantially impermeable to the passage of water with structural components having the capability of resisting hydrostatic and hydrodynamic load and effects of buoyancy"
d) A registered professional engineer or architect shall develop and/or review structural design, specifications, and plans for the construction and shall certify that the design and methods of construction are in accordance with accepted standards set forth for dry floodproof buildings
e) A record of certification of the building should be maintained with the floodplain manager

Exact prescriptive requirements for dry floodproof construction vary based on location and local interpretation of regulation. A series of documents citing federal code and best practices contribute to the floodplain regulations enforced at the local level through the floodplain management ordinance. Fig. 2.19 demonstrates the influence of federal codes in the City of Biloxi (case study area) code for dry floodproof construction.



What is the Regulatory Definition of Dry Floodproofing?

*HIGHLIGHTED TEXT INDICATES ORIGIN OF PHRASE FROM PRECEDENT DOCUMENT SHOWN IN SIMILAR COLOR

Code of Federal Regulation 60.3(c)(3)(ii)

"together with attendant utility and sanitary facilities, be designed so that below the base flood level the structure is watertight with walls substantially impermeable to the passage of water and with structural components having the capability of resisting hydrostatic and hydrodynamic loads and effect of buoyancy"

U.S.A.C.E. Floodproof Regulations

"Sec.401.3 Essentially Dry Spaces (W2): These spaces shall remain essentially dry during flooding to the RFD: walls shall be substantially impermeable to water.[1] but may pass some water vapor or seep slightly. Contents and interior finish materials are restricted when hazardous or vulnerable under these conditions. Structural components shall have the capability of resisting hydrostatic and hydrodynamic loads and the effects of buoyancy.[1] W1 [Completely Dry Spaces] and W2 [Essentially Dry Spaces] flood proofing classes herein are comparable to the NFIP flood proofing standards in CFR 60.3 (c)(3)(ii), 60.3(c)(8)(ii)"

"Section 502.1 Permeability: Type B waterproofing construction shall be substantially impermeable[1] but may pass water vapor and seep slightly during flooding to the RFD: Large cracks, opening, or other changes that could permit unobstructed passage of water shall not be permitted. In no case shall there be permitted the accumulation of more than four inches of water depth in such spaces during that 24-hour period if there are no devices provided for its removal. However, sump pumps shall be required to control this seepage. "

Floodproofing Certificate

FEMA Form 81-65

"I certify that, based upon development and/or review of structural design, specifications, and plans for construction, the design and methods of construction are in accordance with accepted standards of practice for meeting the following provisions: The structure, together with attendant utilities and sanitary facilities, is watertight[1] to the floodproofed design elevation indicated above, with walls that are substantially impermeable to the passage of water.[1] All structural components are capable of resisting hydrostatic and hydrodynamic flood forces, including the effects of buoyancy,[1] and anticipated debris impact forces."

FEMA Technical Bulletin 3

"A Floodproofing Certification for Non-Residential Structure (FEMA Form 81-65) has been developed by FEMA for use in the certification of non-residential floodproofing design. "

"The buildings' walls must be 'substantially impermeable to the passage of water.' FEMA has adopted the U.S. Army Corps of Engineers (COE) definition of substantially impermeable[1] from the COE publication 'Flood Proofing Regulations.' This document states that substantially impermeable wall shall not permit the accumulation of more than 4 inches of water depth during a 24-hour period if there were no devices provided from its removal."[2]

City of Biloxi Code

(example of local regulation)

"Buildings located in all A zones may be flood proofed in lieu of being elevated provided that all areas of the building, together with attendant utility and sanitation facilities, below the base flood elevation are watertight with walls substantially impermeable to the passage of water, and use structural component having the capability of resisting hydrostatic and hydrodynamic loads and the effect of buoyancy.[1] A Mississippi registered professional engineer or architect shall develop or review structural design, specifications and plans for the construction and shall certify that the structural design and methods of construction are in accordance with accepted standards of practice[3] and that the standards of this subsection are satisfied. Such Certification shall be provided to the floodplain administrator." as set forth in section 8-2-2.

International Building Code 2006

"DRY FLOODPROOFING. A combination of design modifications that results in a building or structure, including the attendant utility and sanitary facilities, being water tight with walls substantially impermeable to the passage of water[1] and with structural components having the capacity to resist load as identified in ASCE 7."

ASCE/SEI 24-05

"Dry floodproofing shall be accomplished through the use of flood-damage-resistant materials and techniques that render the dry-floodproofed portions of a structure substantially impermeable to the passage of floodwater[1] below the elevations specified in Table 6-1. " [most often BFE +1]

Fig. 2.19 DIAGRAM: Federal regulatory influence on definition of dry floodproofing.

2.2.1.2 Engineering Pamphlet 1165-2-314

Within *44 CFR 60.3*, the term "substantially impermeable" is used to describe the structure of a dry floodproof building without providing a clear definition within the document. The USACE document *Engineering Pamphlet 1165-2-314* states that waterproof construction shall be "permitted the accumulation of [no] more than four inches of water depth in such a space during a 24-hour period if there are no devices provided for its removal…" This definition is used throughout the NFIP regulations and is also found in FEMA publications.

2.2.1.3 Technical Bulletin 3-93 Non-Residential Floodproofing

FEMA Technical Bulletin (TB) 3-93 Non-Residential Floodproofing—Requirements and Certification provides guidance for complying with the NFIP regulations for dry floodproof construction. Key requirements from *FEMA TB 3-93* include:

a) "The building must be watertight to the floodproof design elevation, which is further defined as being at least the BFE." However, "to receive a flood insurance rate based on 100-year flood protection, the structure must be dry floodproofed to an elevation of at least one foot above the BFE."
b) A watertight building must be "substantially impermeable" to the passage of water" as defined by the USACE in *Engineering Pamphlet 1165-2-314*.
c) Hydrostatic and hydrodynamic loads, buoyancy, and debris impact forces must be calculated for the site based on the FIS formulas defined in the requirements. (Guidelines for these calculations can be found in *FEMA TB 3-93*)
d) "Where human intervention is required to implement floodproofing measures, such as the installation of flood gates or flood shields, a Flood Emergency Operation Plan is required. This plan must be produced by the design professional to ensure that floodproofing measures can be implemented in a safe and timely fashion."
e) "A Floodproofing Certificate is required for all non-residential buildings to be floodproofed and is to be completed by the design professional."
f) "Like all construction that falls under NFIP regulations, the building must meet the requirements of all applicable portions of local and state building codes, including the provisions of the ADA, life-safety codes for ingress/egress and clearing; and venting and combustion requirements."

2.2.2 Regional Building Codes

Building code requirements relating to dry floodproof construction can be found withinin the IBC and the NFPA 5000. These codes pertain to the use and safety of components within a dry floodproof building. These code requirements are drawn largely from standards developed by the ASCE. The ASCE provides relevant standards in *ASCE 7 Minimum Design Loads for Buildings and Other Structures* and *ASCE 24 Flood Resistant Design and Construction*. The standards within *ASCE 24* are similar to the NFIP standards. However, *ASCE 24* is “more restrictive than the NFIP regulations with respect to the identification of flood hazard areas subject to damaging wave action and some other areas.” (*ASCE 24 2005*)

2.2.2.1 ASCE 24 Flood Resistant Design and Construction

The requirements within *ASCE 24* state that “dry floodproofing of non-residential structures and non-residential areas of mixed-use structures shall not be allowed unless such structures are located outside of High Risk Flood Hazard Areas, Coastal High Hazard Areas, and Coastal A Zones.” Coastal A Zones are not specifically marked on FIRMs, nor do NFIP regulations differentiate between Coastal A Zones and A Zones. Coastal A Zones are located between the Limit of Moderate Wave Action (LiMWA)—where the potential for breaking wave heights is greater than or equal to 1.5 feet—and a Velocity Zone. Fig 2.20 shows the floodplain delineations for East Biloxi, Mississippi, per the 2009 adopted FIRM.

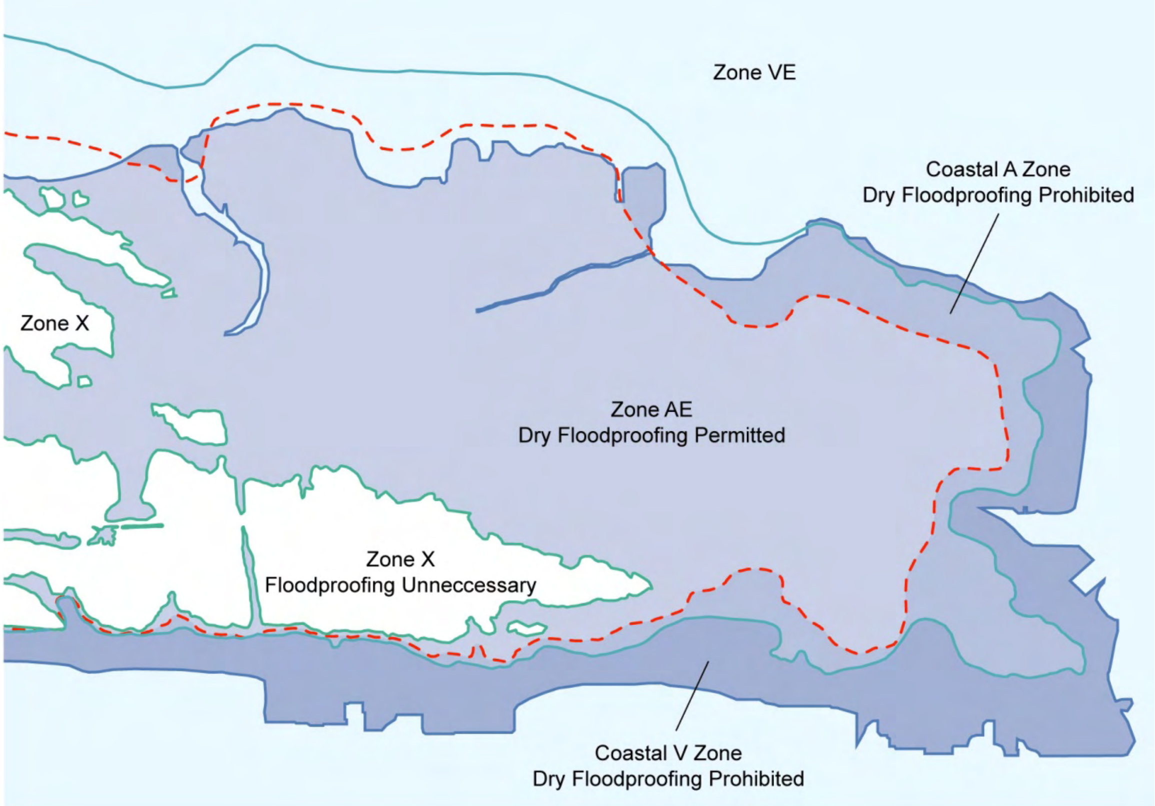


Fig. 2.20 MAP: East Biloxi flood zones.

Additionally, *ASCE 24* limits dry floodproof projects to areas “where flood velocities adjacent to the structure are less than or equal to 5 ft/sec during the design flood”. *ASCE 24* also sets standards for flood warning time within human intervention plans in *Section 6.0 Dry and Wet Floodproofing.* In nearly all cases, *ASCE 24* requires at least one exit door at or above the DFE, which must be capable of providing ingress and egress during design flood conditions. The majority of the remaining requirements within *ASCE 24* reiterate those found within FEMA, NFIP and USACE documents.

2.2.3 Biloxi, Mississippi

In Biloxi, Mississippi, where this research was conducted, the *Code of Ordinances, City of Biloxi, Mississippi* states that a certified dry floodproof building has been certified by an engineer or architect to be watertight with walls substantially impermeable to the passage of water and structurally capable of resisting hydrostatic, hydrodynamic and buoyancy forces. The FFE of the floodproof building must be no more than three feet below the BFE with floodproofing construction details extending a foot above the BFE. Additional floodproof construction requirements found in the City of Biloxi Code of Ordinances are drawn directly from the NFIP regulations listed earlier in Section 2.2.1.1 of this report, as well as drawn from the *ASCE 24* regulations listed in Section 2.2.2.1 of this report. (*City of Biloxi 2011*)

2.2.4 Conclusions

Dry floodproofing is a viable flood protection technique for non-residential spaces in areas subject to low to moderate flood elevation, floodwater velocity, and wave action. Municipalities are responsible for the regulation of dry floodproof construction through building codes and floodplain management ordinances. However, the challenge of designing and certifying a dry floodproof building is the responsibility of the professional engineer or architect.

3. LAND USE PLANNING AND URBAN DESIGN

Moving forward with the rebuilding from Hurricane Katrina and preparing for inevitable flood hazards in the future require cities along the Gulf Coast to use a variety of flood risk mitigation methods addressing different site conditions, construction budgets and land use regulations. In combination, different mitigation methods have the potential to strengthen and unify neighborhoods that are currently beset with high rates of vacant and underutilized property. However, consideration must also be given to how mitigation methods used on one property relate to adjacent properties. Integrating new buildings into the existing urban fabric is especially important in older neighborhoods, where buildings have been constructed to meet a range of codes and regulations.

The previous chapter discussed the hazards and regulations associated with natural disasters common to the Gulf Coast. This chapter will discuss the benefits of dry floodproof construction with regard to urban design and accessibility of neighborhood commercial districts common to the Gulf Coast. The focus is on neighborhood commercial districts; dry floodproofing is limited by regulation to non-residential structures, and small businesses operating at the neighborhood level are most likely to benefit from this research. Among the communities and cities on the Gulf Coast striving to rebuild, dry floodproof construction has the potential to create viable neighborhood commercial districts when implemented in accordance with best practices in urban design.

This chapter will examine the regulatory framework that enables dry floodproofing as a flood risk mitigation strategy alone or in combination with other mitigation methods and discuss the implications of different site design techniques for dry floodproofed structures. The application of these ideas will be examined in a case study of neighborhood commercial corridors in East Biloxi, a Gulf Coast community in the midst of rebuilding from Hurricane Katrina.

3.1 Neighborhood Commercial Districts

The NFIP insures floodproof structures up to $500,000. Small business and property owners with structures valued below $500,000 are therefore more likely than business owners with more expensive properties to take advantage of the NFIP. However, small business owners, who tend to operate at the neighborhood level, are also more likely to have difficulty meeting flood risk mitigation requirements due to lack of information and leverage. This research is intended to provide information on affordable and effective mitigation techniques and construction methods to augment current practices. In particular, this chapter discusses the ways in which neighborhood commercial districts can reap the greatest benefits from dry floodproof construction as a flood risk mitigation method.

Neighborhood-level commercial districts serve many important functions in sustaining nearby residents, small business owners and cities. Neighborhood businesses provide accessible goods and services to nearby residents, who may not have time or money to travel longer distances by car for daily shopping needs. They also build wealth within the community by promoting ownership and a local tax base. These benefits can be wrought through careful consideration and implementation of flood risk mitigation methods that are appropriate for neighborhood commercial districts.

3.2 Benefits of Dry Floodproof Construction for Urban Design and Accessibility

3.2.1 Comparison of Flood Risk Mitigation Strategies

Developers and property owners intending to construct a building within the floodplain have several options for mitigating flood risk. The building can be elevated to bring the FFE to the required height, as determined by the local floodplain ordinance. Alternatively, the building can be constructed with a FFE below the BFE by using dry floodproof construction techniques, so long as the building is a non-residential structure. Finally, a building can be relocated outside of the floodplain and built with conventional construction techniques. These three mitigation strategies are diagrammed in Fig. 3.1. Of these three basic mitigation strategies (elevation, dry floodproofing and relocation), dry floodproofing is preferable from a land use and urban design perspective.

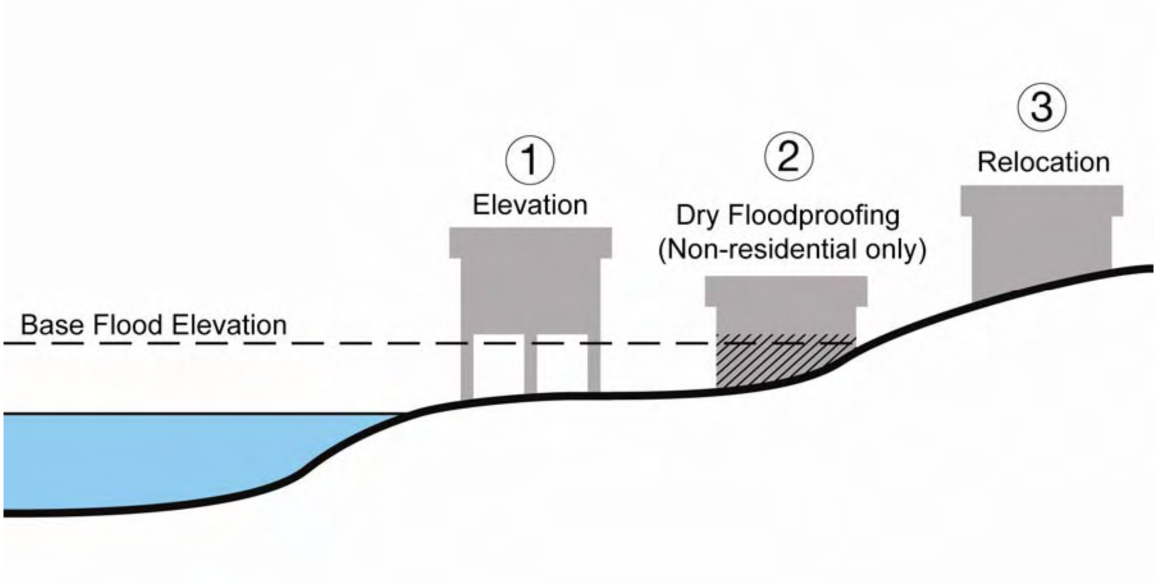


Fig. 3.1. DIAGRAM: Basic flood mitigation strategies.

Relocation poses the greatest threat to neighborhood commercial viability because it displaces neighborhood businesses and their associated benefits. Rather than providing relief to distressed neighborhood commercial areas with vacant and underutilized land, relocation shifts the benefits of small business to communities outside of the floodplain. This strategy may be more cost-effective for the business owner, but does not serve the greater purpose of rebuilding flood-prone communities.

Elevation involves raising the FFE of a building through the use of piers, piles, or structural fill. This mitigation strategy is problematic because it is less physically and visually accessible than at-grade construction, and tends to be out of context in existing commercial neighborhoods. Fig. 3.2 demonstrates poor physical access associated with a typically elevated commercial structure on the Gulf Coast.

Fig. 3.2. PHOTO: Physical access problems associated with an elevated structure.

Non-residential structures have ADA accessibility requirements, such as long ramps or costly elevators that make elevation less desirable. Elevated commercial buildings may have to develop costly and complex loading and unloading systems. Figure 3.3 illustrates the visual inaccessibility of elevated structures to pedestrians and street-level users.

Fig. 3.3. PHOTO: Visual access problems associated with an elevated structure.

In the example shown in Fig. 3.3, even the stairwell is hidden from view from the street. Elevated windows make it difficult for potential customers to see inside the building from street level. Finally, Fig. 3.4 shows how elevated structures appear out of context when sited next to existing structures that are at-grade. This is a particularly important consideration in older established neighborhood commercial corridors, where an elevated building would detract from the fabric of the historic streetscape.

Fig. 3.4. PHOTO: Out-of-context elevated structure.

In contrast to the design problems associated with elevation, dry floodproofing allows businesses to develop within an existing neighborhood commercial area while maintaining accessibility and the continuity of the streetscape, as shown in Figure 3.5 below. Dry floodproofing offers a potentially affordable alternative to relocating a commercial structure outside of existing neighborhood commercial corridors.

Fig. 3.5. PHOTO: Dry floodproofed structure in East Biloxi.

3.2.2 Combining Flood Risk Mitigation Strategies

Dry floodproof certification allows mitigation for up to three feet below the BFE. (*City of Biloxi 2011*) Many coastal commercial districts are located in areas where the BFE is greater than three feet above the existing ground plane. In these situations, combining dry floodproofing with other flood risk mitigation strategies reduces the total height to which a structure must be elevated.

Fig. 3.6 illustrates three flood risk scenarios categorized by required mitigation heights and recommended strategies: dry floodproofing, dry floodproofing in addition to elevating the FFE, and dry floodproofing in addition to elevating the FFE and elevating the exterior entryway. The diagram shows the relationship between the type of flood mitigation strategy, the BFE and user accessibility.

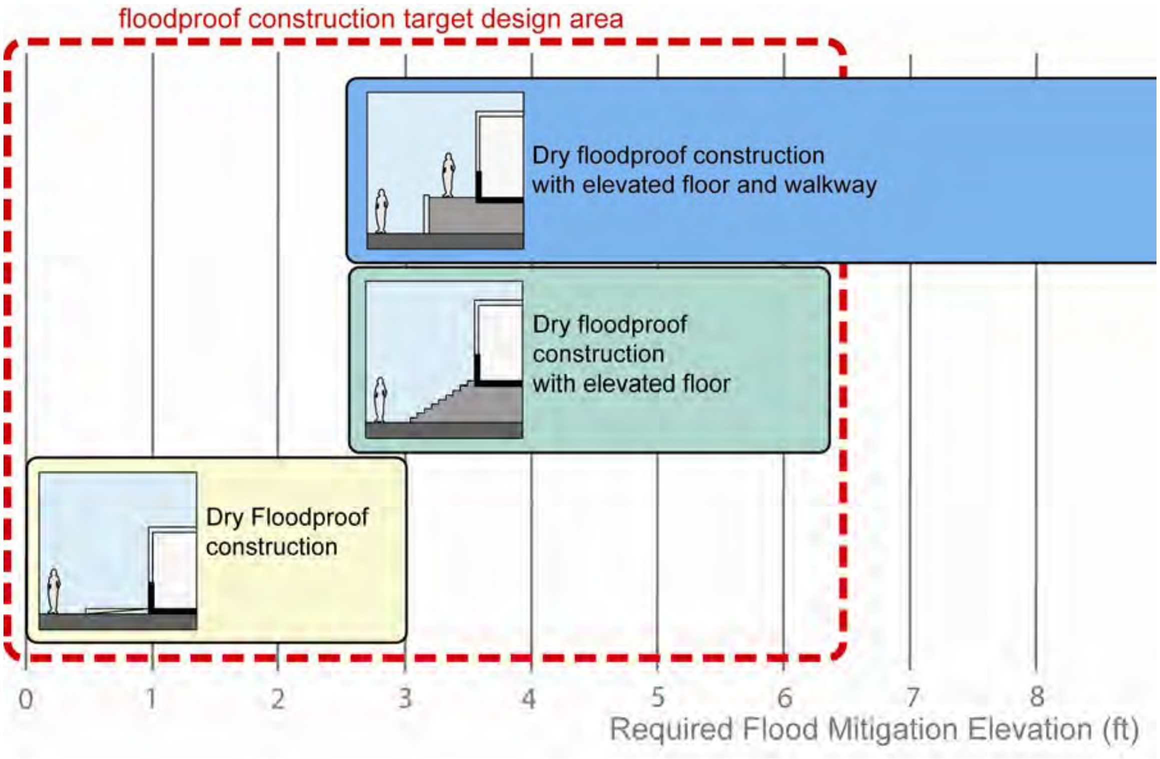


Fig. 3.6. DIAGRAM: Flood risk mitigation and dry floodproofing suitability.

3.2.2.1 Scenario 1: dry floodproofing

A site with a BFE of less than three feet above the existing grade can be wholly mitigated using dry floodproofing construction techniques, allowing the FFE of commercial buildings to remain with street level access. Physical accessibility, visual access, and street presence benefit from this situation. It is logical that all commercial properties with flood risk heights up to three feet should use dry floodproofing for mitigation, because regulatory dry floodproofing is limited to three feet below the BFE.

3.2.2.2 Scenario 2: dry floodproofing and elevation

For a site having between three and five feet of flood risk, dry floodproofing can be combined with elevation, usually by raising the finished floor over a plinth or chainwall supported with structural fill. For example, a flood risk of five feet above existing grade could be mitigated by elevating the finished floor two feet above grade and floodproofing the structure for the remaining three feet above the floor. The use of dry floodproofing reduces the height of elevation needed to meet mitigation requirements. The combination of the two flood risk mitigation strategies increases the range of sites in a Special Flood Hazard Zone that can be mitigated through the use of dry floodproofing, while continuing to prioritize building characteristics such as accessibility and street presence.

To gauge the effects of these height differences, the following comparison is helpful. A commercial space with a finished floor two feet above grade requires three to four stairs to enter, versus eight or nine stairs required by a space elevated five feet above grade. Combining the two flood risk mitigation strategies reduces the number of stairs required to access the structure. Similarly, a ramp to provide access two feet above grade would need to be 24 feet in length, while a ramp to provide access to five feet above grade for the same site would require over sixty feet of length.

Dry floodproofing provides opportunities for accessible structures. Therefore, it is preferable to use dry floodproofing in combination with elevation to achieve flood risk mitigation in areas with three to five feet of flood risk, rather than using elevation as the sole mitigation strategy.

3.2.2.3 Scenario 3: Dry floodproofing, elevation, and elevated walkways

In commercial areas with consistently high flood risk mitigation height requirements, larger or adjacent sites could also share elevated walkways to reduce the total number of trips pedestrians must take up and down stairs and ramps. Fig. 3.7 shows an example of a shared, elevated walkway in a neighborhood commercial district.

Fig. 3.7. PHOTO: Shared, elevated walkway with ramp and stair access.

This system allows pedestrians to move between commercial spaces without negotiating floor height changes. Pedestrians can access several shops or community spaces with a single trip up stairs or a ramp. The shared walkways help achieve a clear means of physical access, unobstructed sightlines between the sidewalk and the elevated space, and a contextual connection to the surrounding natural and built environment.

Shared, elevated walkways have the potential to reduce the cost burden of flood risk mitigation by enabling business owners to share in the cost of accessibility items like elevators and ramps.

The addition of dry floodproofing helps to bring elevated walkways as close to street level as possible, making them more visually and physically accessible from the street.

3.2.3 Diminishing Benefits of Dry Floodproof Construction

After a certain threshold of risk, dry floodproofing no longer makes sense, either functionally or financially. This threshold will depend on the specifics of the project and the cost of construction. For example, if a site has a flood risk of ten feet, and is elevated fully to meet the BFE requirements, a person may be able to comfortably stand under the building and the space beneath the building can take on alternative, yet limited uses, such as parking or outdoor space. Lowering the elevated floor to seven feet with the addition of three feet of floodproofing prohibits the ground plane as a usable space.

3.3 Regulatory Framework

Dry floodproofing has the potential to create accessible infill opportunities that corroborate with the existing street fabric along commercial corridors. However, the local regulatory framework that enables dry floodproofing as a flood risk mitigation strategy, alone or in combination with, other mitigation methods will influence the extent to which dry floodproof construction is successfully implemented.

3.3.1 Land Use Designations

Land use designations and requirements can encourage contextual integration of new buildings into the existing street fabric, making use of dry floodproofing strategies where applicable. If dry floodproofing is only permitted in non-residential zones, city planners should consider the zoning designations along the neighborhood commercial corridors that fall within the floodplain. For example, vacant residential parcels within a neighborhood commercial corridor could be re-zoned for commercial or mixed-use so that development is viable with dry floodproof construction techniques.

For this to occur, it is essential that residential and non-residential uses are clearly defined within the local zoning ordinance. Residential uses include houses, apartments and any spaces meant for human habitation. Non-residential uses include those that are zoned for commercial, industrial use, and mixed use. In order for dry floodproofing to be used as a mitigation strategy on a mixed-use site, the ground floor of the structure must be strictly used for commercial space. Any residential uses within a dry floodproofed mixed-use structure must be located at or above the BFE, as shown in Fig. 3.8. Municipalities can provide clarity within the zoning code so that developers and property owners better understand which non-residential uses are eligible for dry floodproof construction and which zones allow those uses.

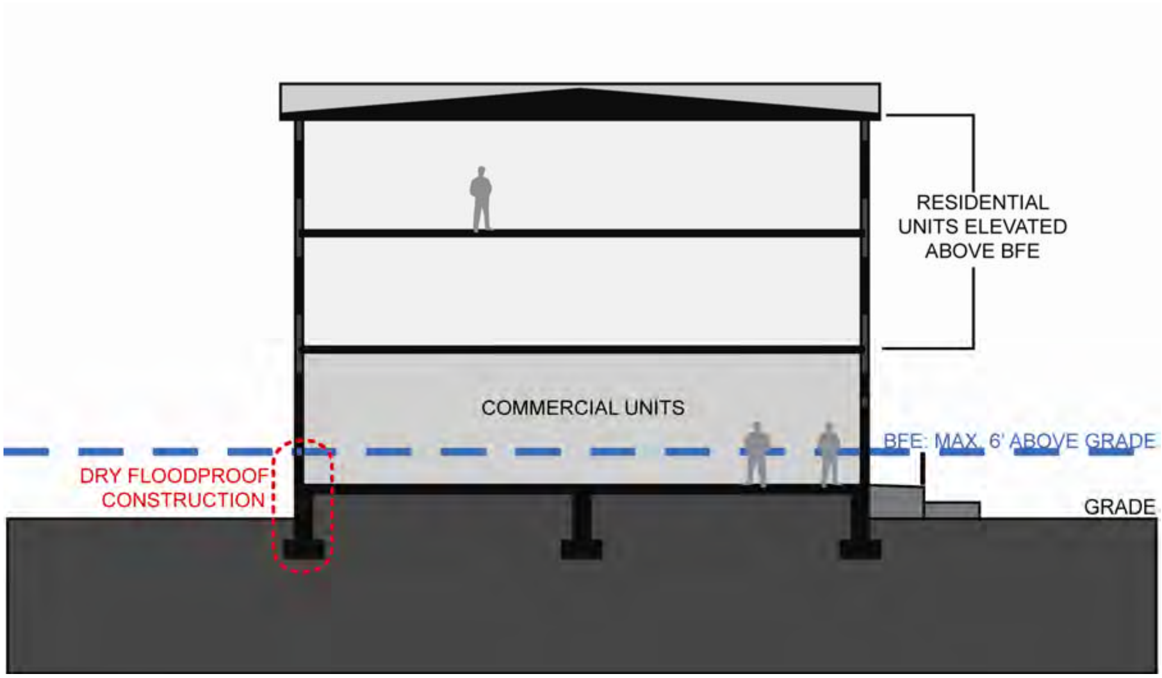


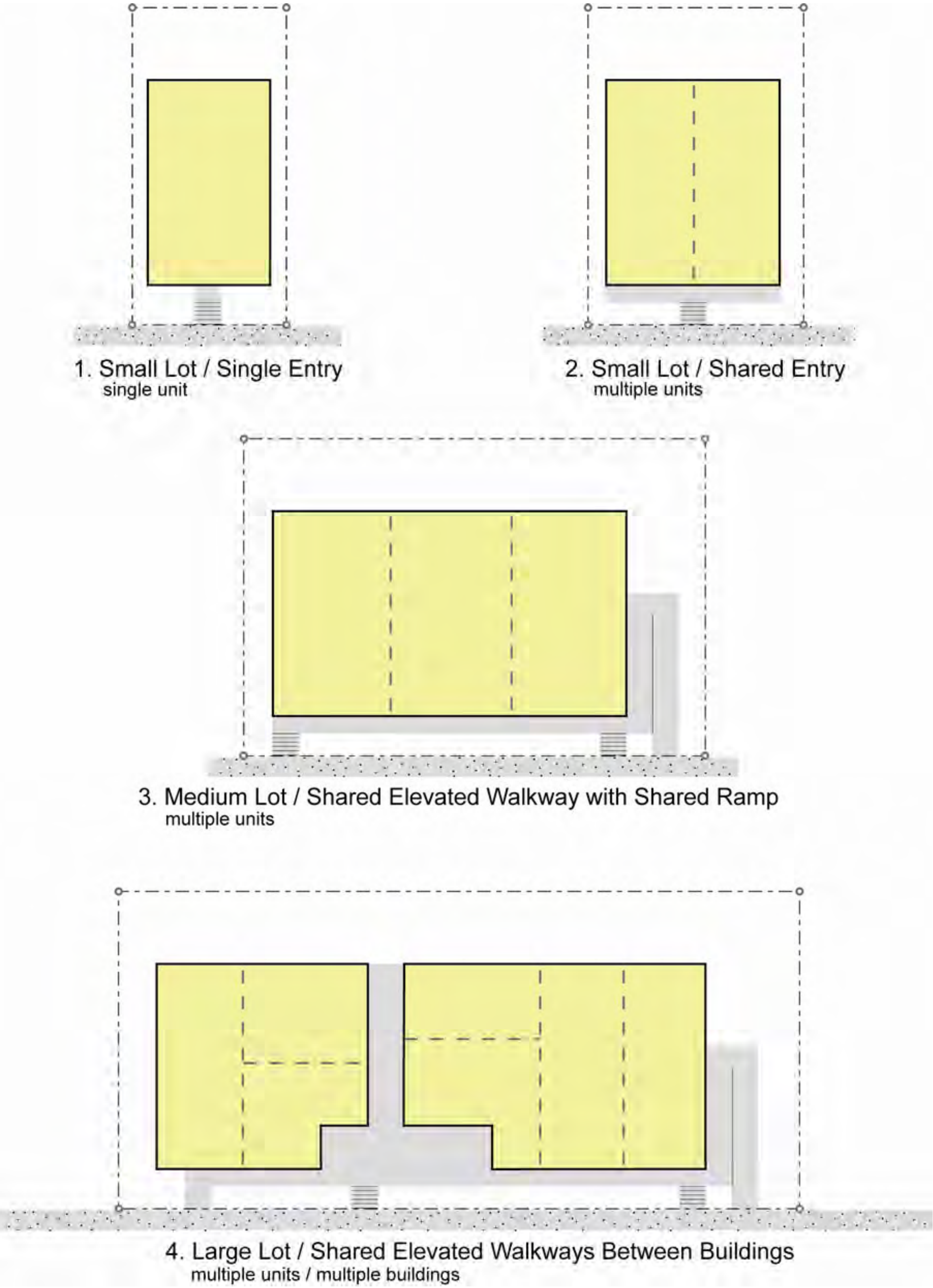
Fig. 3.8. DIAGRAM: Mixed-use building with floodproof construction.

Front and side building setback requirements are also important issues affecting the feasibility of dry floodproofing. Setbacks are requirements within the zoning code that dictate how far buildings must be situated from the property lines. In commercial districts with high elevation flood risks, dry floodproofing can be combined with elevated walkways for improved accessibility. However, in order for the elevated walkways to connect between buildings and work as a coherent system, buildings should have similar front setbacks. For optimum connectivity, these buildings should also have minimal side setbacks, or have zero-lot lines. Municipal zoning codes can encourage the implementation of these strategies by dictating setbacks on properties in neighborhood commercial corridors.

3.3.2 Design Guidelines

Design guidelines are a regulatory tool used by municipal planning commissions or design review boards to ensure that new developments or new buildings corroborate with existing neighborhoods. Dry floodproof construction should assist those working in historic districts, as it enables buildings to be constructed at-grade or at a lower elevation, which is generally more historically accurate. Design guidelines can help encourage best site practices and design techniques for structures that make use of dry floodproof construction in combination with other mitigation strategies.

For example, large development projects that are both dry floodproofed and elevated can be encouraged to use shared, elevated walkways through prescriptive design guidelines in neighborhood commercial corridors. Figure 3.9 illustrates recommended design guidelines for commercial structures built on small, medium, and large lots.



1. Small Lot / Single Entry
single unit

2. Small Lot / Shared Entry
multiple units

3. Medium Lot / Shared Elevated Walkway with Shared Ramp
multiple units

4. Large Lot / Shared Elevated Walkways Between Buildings
multiple units / multiple buildings

Fig. 3.9. DIAGRAM: Guidelines for dry floodproof/elevated structures, by lot size.

3.4 East Biloxi Case Study

The application of land use and planning issues related to dry floodproofing can be understood by looking at a case study from the Gulf Coast. East Biloxi, Mississippi is a Gulf Coast community with several neighborhood commercial corridors that sustained extensive damage during Hurricane Katrina. These neighborhoods are now plagued by a surplus of vacant and underutilized lots.

Fig. 3.10 shows how the floodplain in East Biloxi changed before and after Hurricane Katrina. Four main neighborhood commercial corridors are demarcated: Division Street, Oak Street, Howard Avenue, and Main Street.

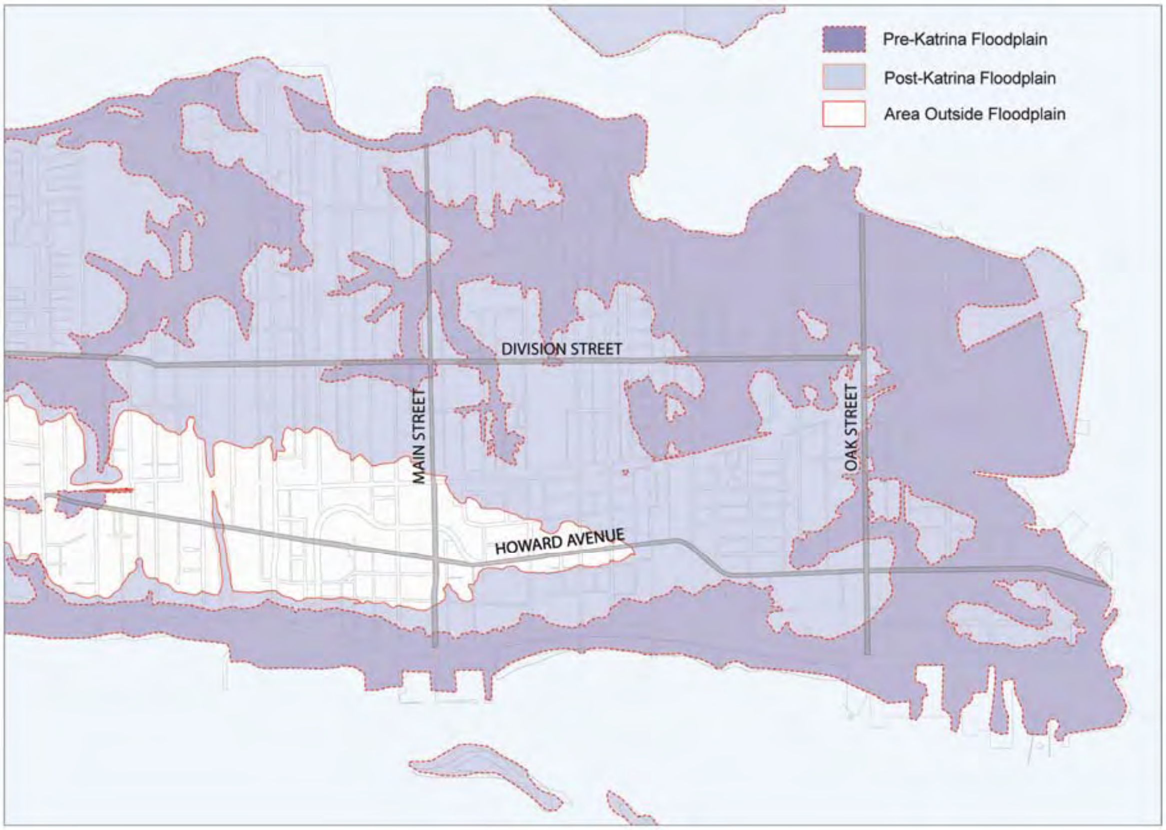


Fig. 3.10. MAP: Floodplain change pre- and post-Katrina, East Biloxi.

The dark shaded area marks the area within the floodplain prior to Hurricane Katrina. The lightly shaded areas are floodplain areas that were added in the revised floodplain after Hurricane Katrina. The small, white area on the map is the only remaining land outside of the floodplain in East Biloxi. This map clearly demonstrates the large amount of properties that have been brought into the floodplain since Hurricane Katrina, which now must cope with stricter building standards and increased flood risk heights for new construction projects in order to meet floodplain ordinances and insurance requirements.

Dry floodproofing presents an opportunity to mitigate flood risk in a way that is sensitive to the existing communities on the Gulf Coast, like East Biloxi. The GCCDS created a series of maps to better understand how the different combinations of flood risk mitigation strategies could be distributed within the East Biloxi study area.

Figure 3.11 shows suitable opportunities for floodproof construction throughout the study area. This map was created by overlaying a Digital Elevation Model (DEM) with Digital Flood Insurance Rate Map (DFIRM) data provided by FEMA. All Coastal A, V, and VE flood zones have been represented in gray, regardless of the flood elevation requirement, because these areas are not eligible for dry floodproof construction as a flood risk mitigation strategy. Figure 3.12 shows opportunities for floodproof construction along the neighborhood commercial corridors identified for the case study area in East Biloxi.

These maps illustrate the challenges of building back East Biloxi communities, as well as the opportunity for rebuilding with dry floodproof construction or a combination of dry floodproof construction and elevation. Each of the four neighborhood commercial corridors contains land within flood risk height ranges that allow for dry floodproof construction. Dry floodproofing is feasible to help these neighborhoods rebuild in an accessible and locally appropriate way.

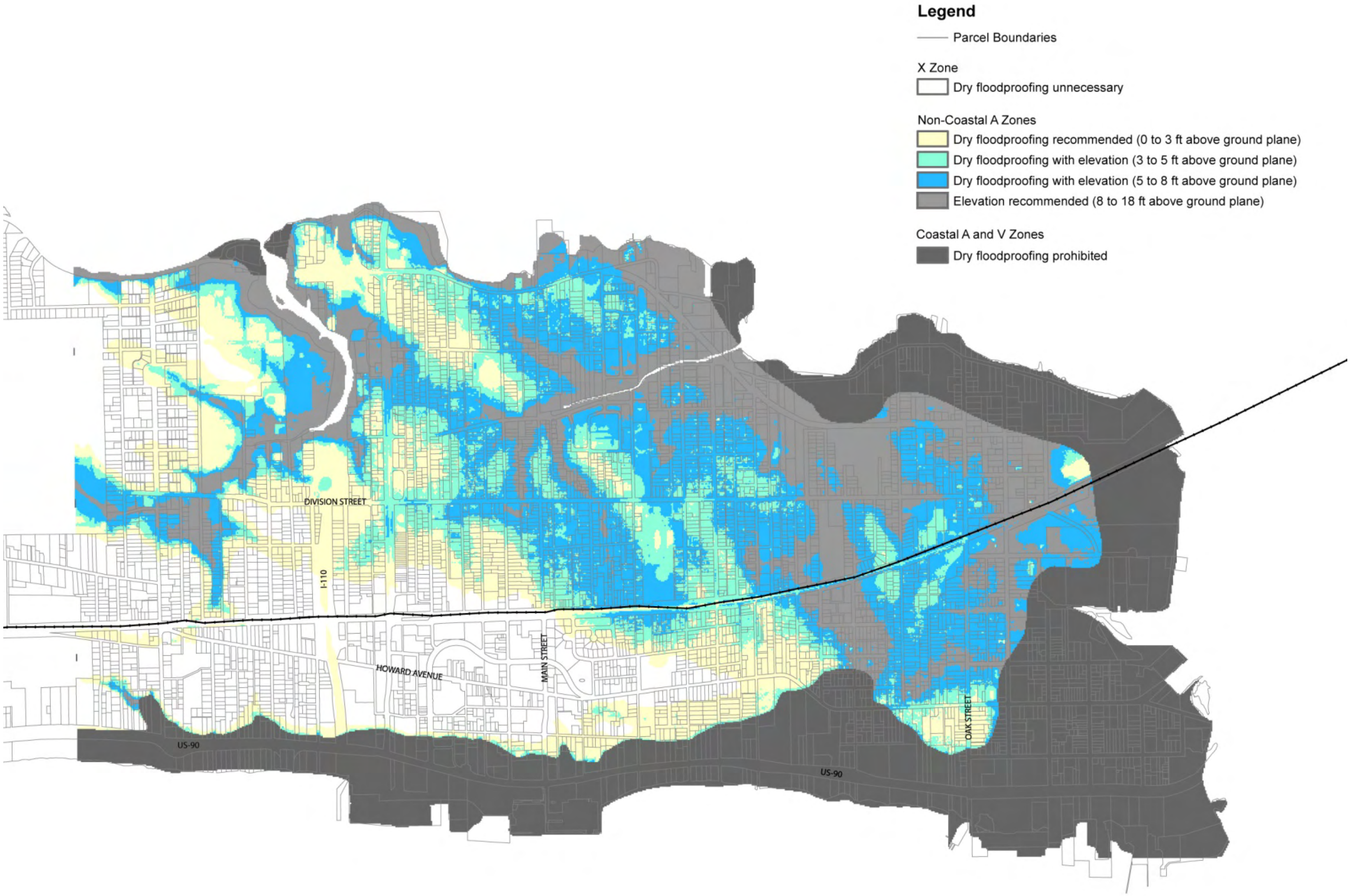


Figure 3.11. MAP: Suitability of dry floodproofing in East Biloxi.

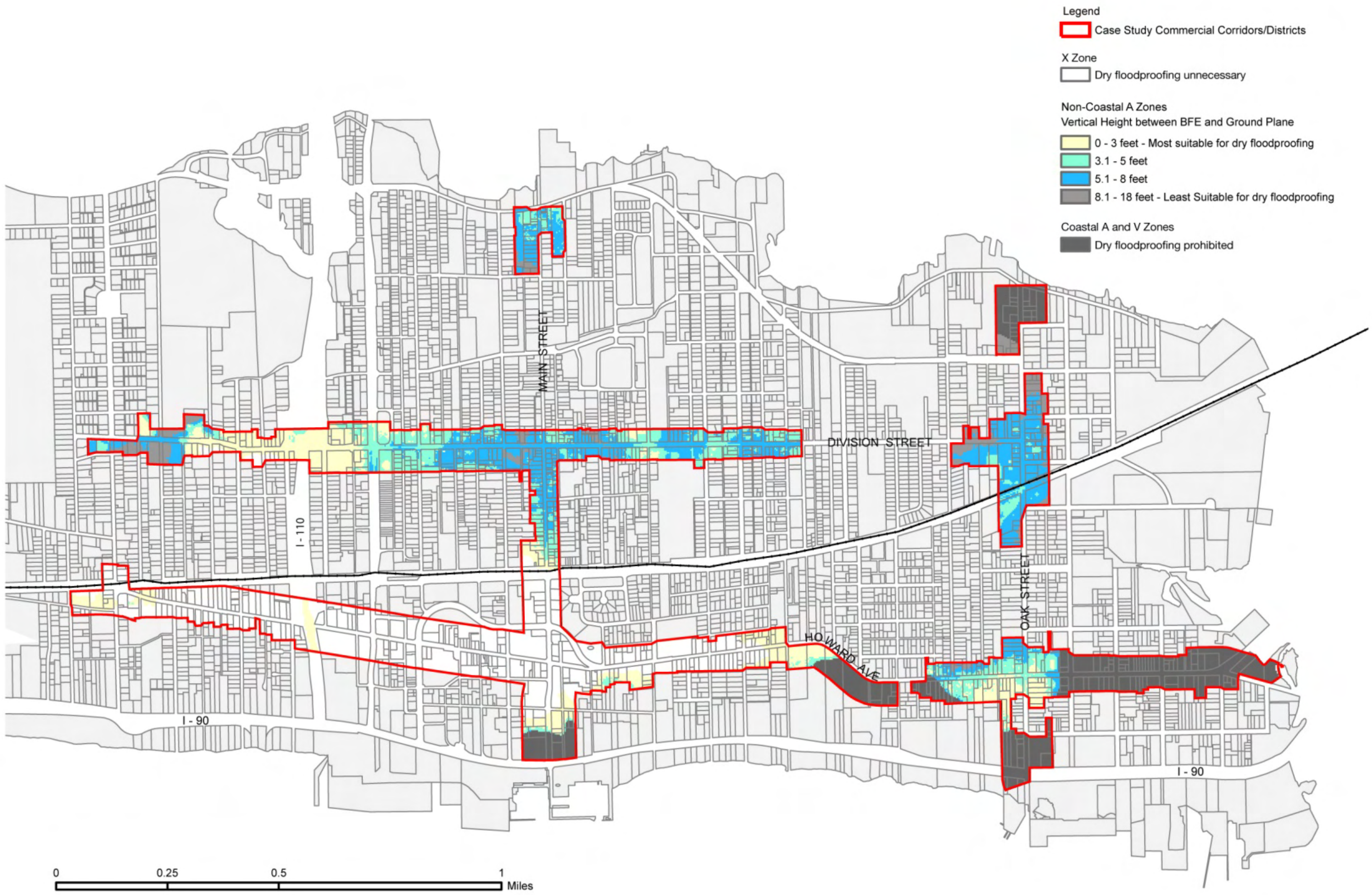


Figure 3.12. MAP: Suitability of dry floodproofing in commercial corridors in, East Biloxi.

A 2008 land use survey of Division Street in East Biloxi reveals a high number of vacant and underutilized properties, shown in Fig. 3.13.

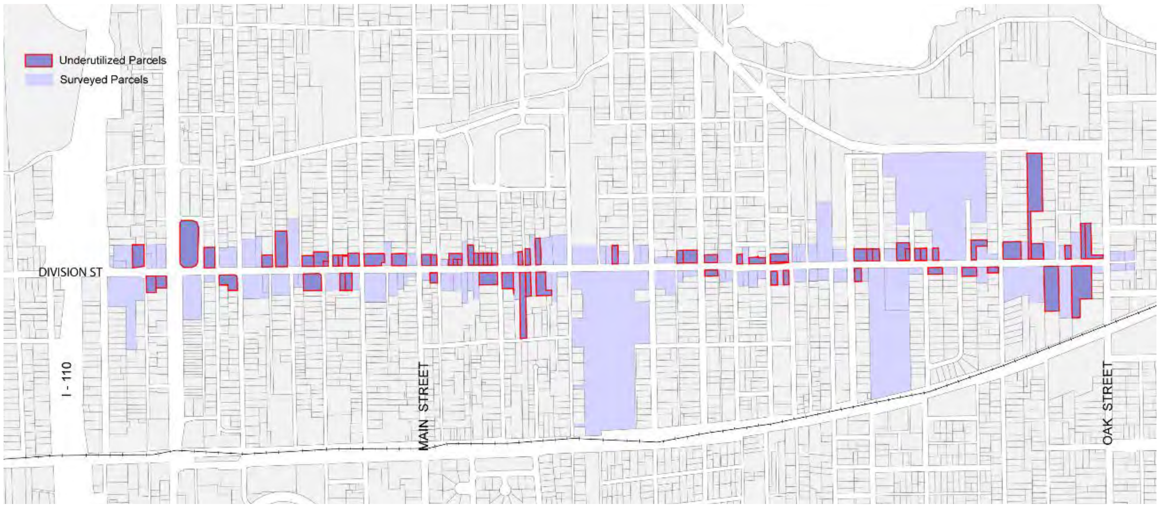


Fig. 3.13. MAP: Underutilized properties, Division St., 2008.

All of the vacant and underutilized properties shown above fall within the floodplain. However, overlaying flood risk mitigation heights with the 2008 land use survey in Fig. 3.14 shows that many of these underutilized parcels fall within the five-foot flood risk height range. Opportunities for these property owners to build on or use their properties could arise through the appropriate use of dry floodproofing mitigation strategies.

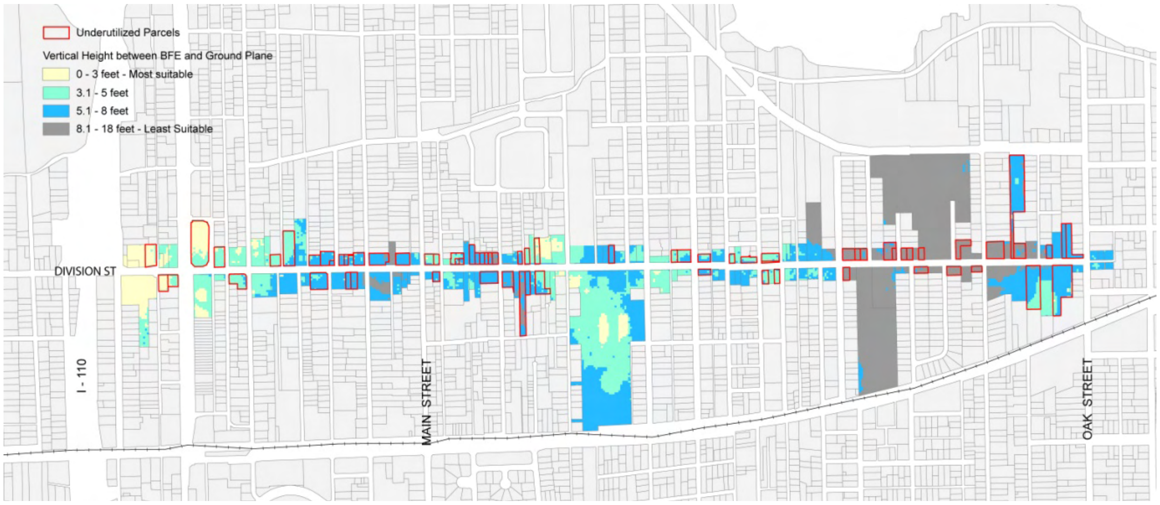


Fig. 3.14. MAP: Dry floodproofing suitability on underutilized properties, Division St.

These maps show over forty underutilized parcels on Division Street that could make use of dry floodproof construction or a combination of dry floodproof construction and elevation techniques for development. Over twenty underutilized parcels could be developed with more accessible, visible and contextually appropriate structures through a combination of mitigation strategies described earlier in this chapter. On adjacent, narrow parcels concentrated between Main Street and Elmer Street on Division Street, developers could make use of lot assembly and shared elevated walkways to create more viable development proposals that fit within the existing streetscape.

Though these maps cannot replace site specific design, they demonstrate more broadly the scope of opportunity for implementing dry floodproof mitigation strategies in East Biloxi. The maps translate complicated floodplain information into useful information for policymakers within the East Biloxi community, and can serve as an example for a suitability analysis in other communities and municipalities on the Coast.

3.5 Applicability to Other Communities

The neighborhood commercial corridors in the East Biloxi study area are representative of a common condition along the Mississippi Gulf Coast. After Katrina, neighborhood commercial corridors throughout the three coastal counties were reassigned to Special Flood Hazard Areas requiring additional flood risk mitigation. Similar to East Biloxi, business owners in other commercial corridors have had difficulty rebuilding and developing since Katrina, due to the new floodplain requirements and the uncertain risk surrounding them.

Streets in these types of neighborhoods fill important roles in the economic and social lives of communities and this research aims to facilitate the rebuilding process by demonstrating opportunities for a variety of flood risk areas and situations. The research in East Biloxi can serve as a case study to be modified and applied to other neighborhood commercial corridors along the Coast. (See Fig. 3.15)

The GCCDS focused this research on highly local conditions to produce information that would be most useful for the communities along the Mississippi Gulf Coast. The research was informed by familiarity with challenges facing Gulf Coast communities and applicable local floodplain management ordinances.

There are many types of flood risk that this research could be applied to elsewhere. However, flood risk characteristics of a particular place would need to be examined, including but not limited to: flood duration, water currents and ground saturation.

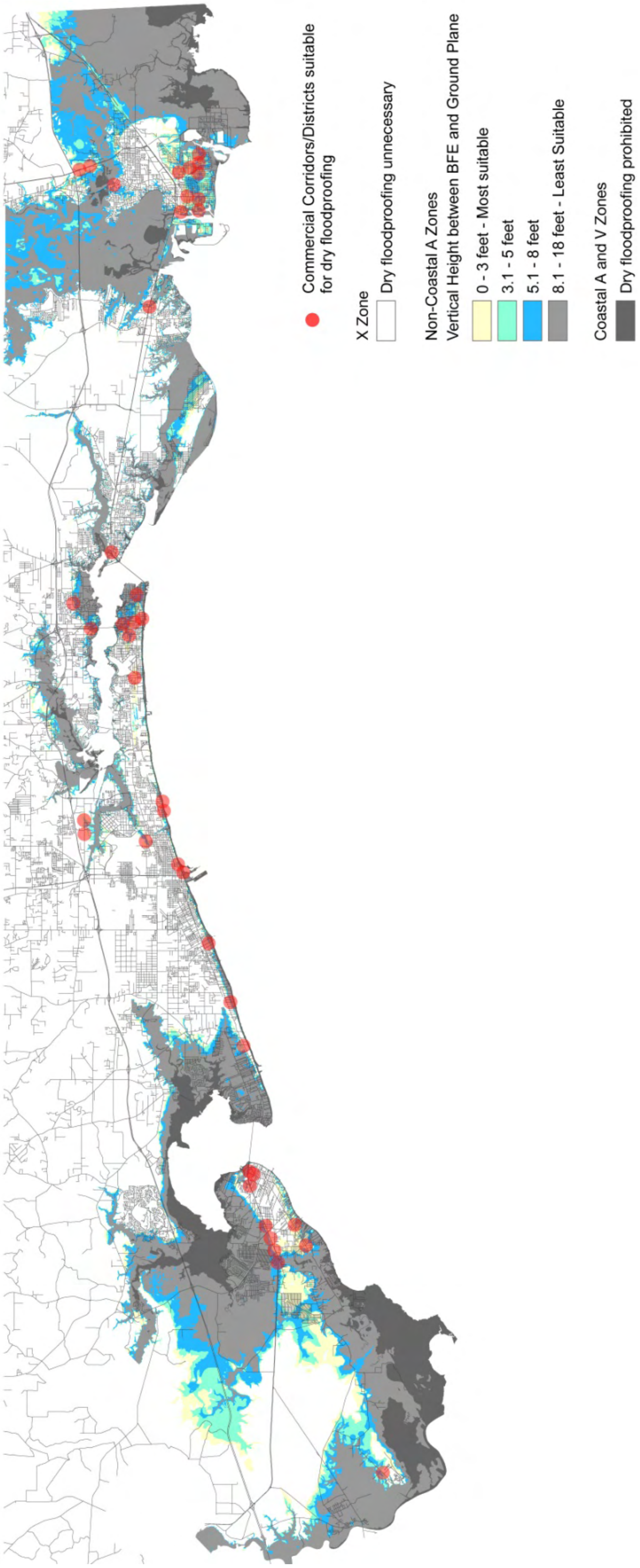


Fig. 3.15. MAP: Commercial corridors and districts suitable for dry floodproofing.

4. MATERIALS AND ASSEMBLIES

4.1 Methodology

To investigate the performance of different materials and wall assemblies under hydrostatic forces, full-scale wall assemblies were constructed and tested for this research. Referred to as test pods within this document, each wall assembly was different, and built within an outdoor flood tank. Eleven test pods were observed during two separate flood simulations with water depths of 36" for a 24-hour period of time. Water penetration measurements, visual observations and electronic moisture content readings were collected during flood simulations. The data collected from the first flood simulation was used to inform new iterations of wall assemblies tested during the second flood simulation.

The flood tank was filled a total of three times during the research: one test fill followed by two monitored flood simulations. During the test fill, the tank was filled with the purpose of testing the performance of the flood tank and the effectiveness of the moisture sensors, along with other methods of observation. This was followed by flood simulation 1, where six uniquely constructed test pods were observed for a 24-hour period of time. After this simulation, test pods were left to dry for two weeks, during which time moisture levels were measured and documented, using embedded sensors. A few months later, the second flood simulation tested five test pods that were revised or retrofitted based on knowledge gained from flood simulation 1. Fig. 4.1 below chronicles the flood testing timeline from January 19th, 2011 through June 29th, 2011.

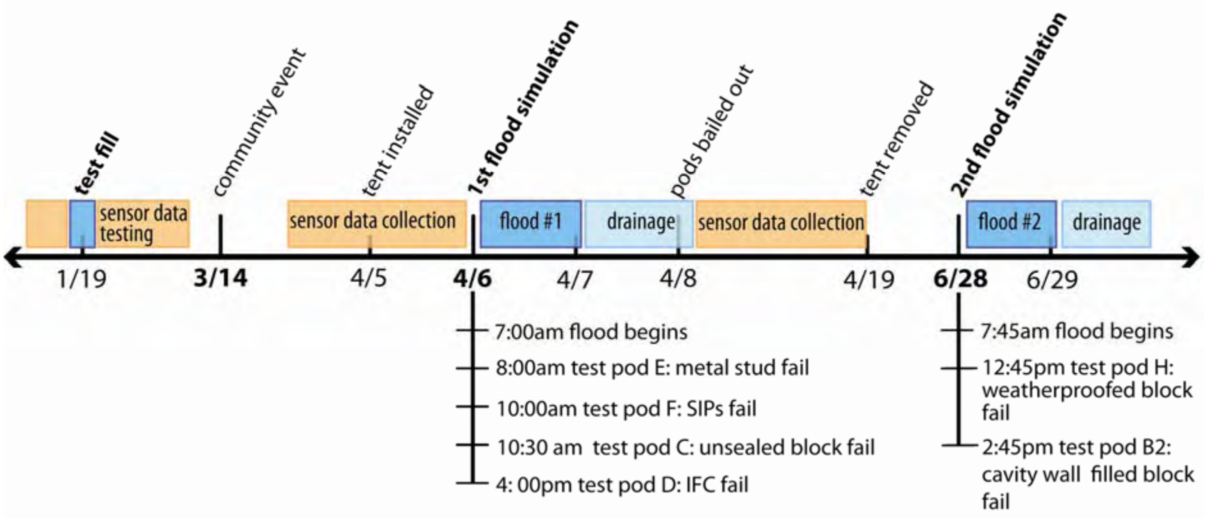


Fig. 4.1. DIAGRAM: Chronology of flood testing, 2011.

Efforts to minimize cost and complexity were made throughout the selection and testing of materials and wall assemblies. Material choices were often made with input from local developers, builders, designers and officials. This was an important way to keep dry floodproofing methods applicable to the groups affected by Hurricane Katrina and subsequent BFE changes.

It was important to create a depth of knowledge about a variety of materials and assemblies. Developing a variety of strategies was important to this research because dry floodproofing techniques need to be flexible in order to be combined with a variety of other challenges involved in the design of a building. Potential designers would be best served by having access to a variety of dry floodproof methods with different characteristics. Therefore within the context of research, it was more helpful to consider several methods of dry floodproofing, rather than a singular solution.

4.1.1 Test Facility Description

The flood tank (see Fig. 4.2) was constructed using Hesco Bastion Containers, otherwise referred to as Hesco boxes. Hesco boxes are welded wire mesh boxes with a geotextile lining for sand or gravel fill. Each box has a 3′ by 3′ base and is 4′ tall, linked together to create a 4′ tall 40′ by 40′ test tank. After the test fill, the tank was lined with heavy plastic sheets to increase its ability to hold water. A walkway was installed for easy access and observation of the test pods. A large open air tent was installed over the tank (see Fig. 4.3) during the flood simulation and drying period.

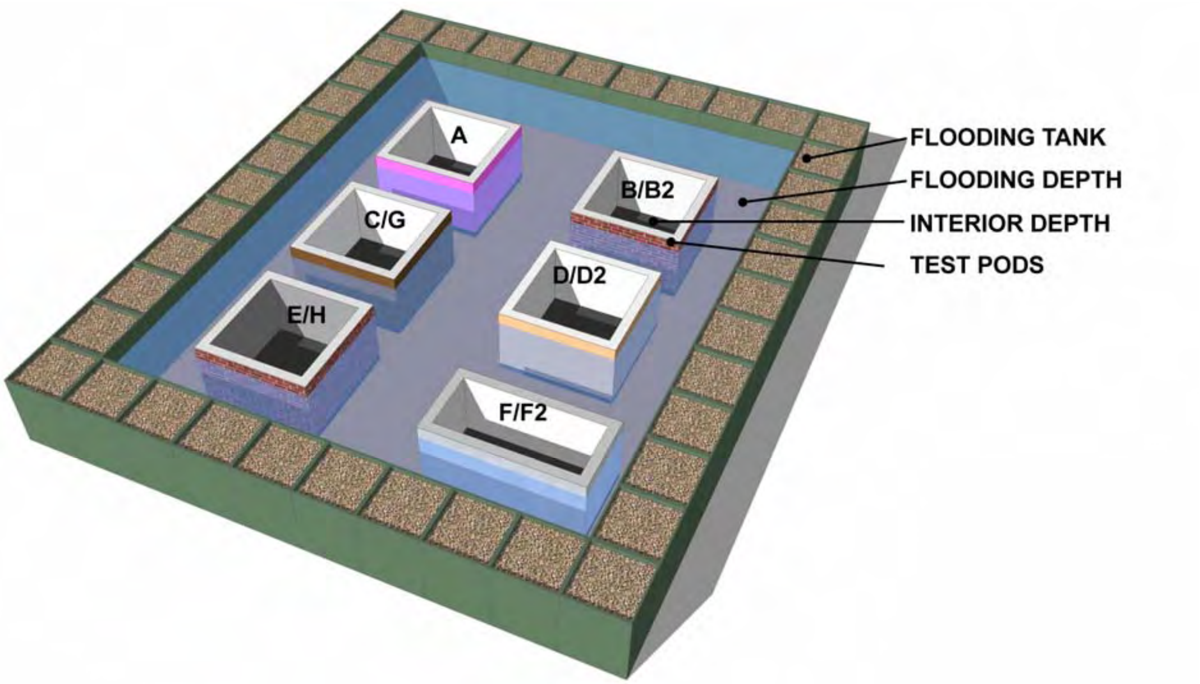


Fig. 4.2. DIAGRAM: Flood tank.

Working outside had several advantages. The size of the testing tank accommodated up to six pods to be tested at once, allowing for direct comparison between the results. Full scale mock-ups built outdoors approximated the construction quality that could be expected during construction of an actual dry floodproof building. Because actual construction can be inconsistent, it was important to work with full scale mock-ups to test the assembly's redundancies to flood resistance.

Fig. 4.3. PHOTO: Flood tank prior to flood simulation 1.

4.1.2 Test Pod Description

Each test pod was built by a local contractor with the exception of the Structurally Insulated Panels (SIPs) assembly. The construction was intended to simulate practices which could be achieved during the construction of an entire building. The standard of construction quality was an important issue for this architectural research. Critical performance systems, such as dry floodproofing, have to be designed to be redundant to mitigate inconstancies in field construction, which often has greater tolerances than laboratory assemblies.

Each pod was built on a concrete slab inside the flood tank. Each concrete slab measured 6′ x 6′, except for the slab which attached to the SIPs, which was 4′ x 8′ at the manufacture's request. Several concrete pads had block or brick ledges, to accommodate the construction type above.

4.1.3 Testing Protocols

During each flood simulation, a flood depth of 36″ above the finished floor was maintained for a period of 24 hours. The length of the flood during Hurricane Katrina along the Mississippi Gulf Coast lasted hours not days. This in combination with the precedent of the USACE criteria led the research team to use a 24-hour period for flood simulation. In *Flood Proofing Regulations*, dry floodproofing is defined in the following statement:

"Type B waterproofing construction shall be substantially impermeable but may pass water vapor and seep slightly during flooding to the RFD [Regulatory Flood Datum] … In no case shall there be permitted the accumulation of more than four inches of water depth in such as space during a 24-hour period if there are no devices provided for its removal.(502.1)"

By using a 24-hour test period GCCDS staff was able to simply measure the depth of the water on the interior of the test pods to ascertain if the assembled materials had preformed to the USACE's criteria for Type B dry floodproof construction. (See Fig.4.4)

Fig. 4.4. PHOTO: Data collection during flood simulation 1.

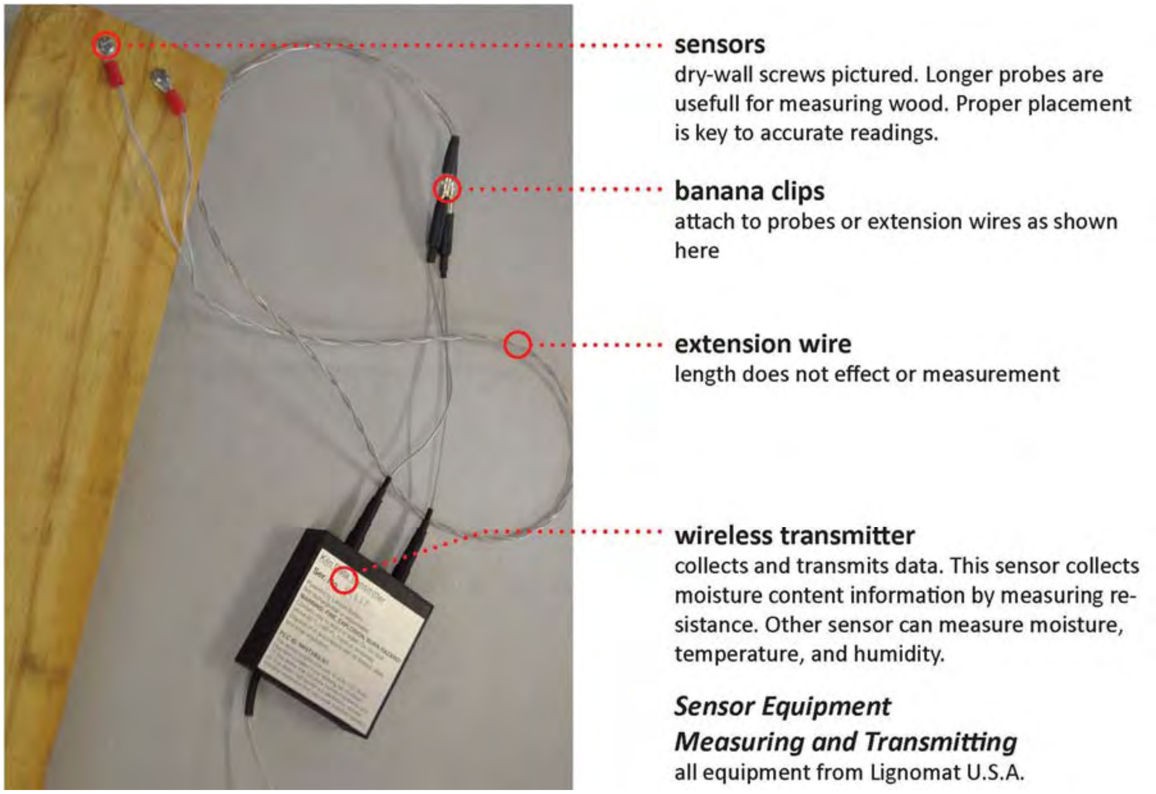
During flood simulations, GCCDS staff members were able to monitor results through measuring water depths inside the test pods, through photographing and videotaping the flood simulations, and through creating a written record of changes in test pod performances. Observations continued as the tank was emptied and water from inside the test pods drained out of the assembly. A two-week drying period followed the first simulation during which moisture content sensors and relative humidity sensors were embedded at various points and depths in the test pods. The final step of the observation protocol was to disassemble several portions of the test pods to look for possible moisture points of intrusion (Fig. 4.5).

Fig. 4.5. PHOTO: Partial demolition of test pod after flood simulation.

4.1.4 Instrumentation

Moisture content and relative humidity sensors (Fig. 4.6) were installed in the test pods both before and after the first flood simulation (Fig. 4.7). The use of automated sensors to record moisture over time created an accurate record of how water infiltrated and later dried out of the wall assemblies. Moisture content sensors measure the amount of water held within wood and gypsum products, by measuring the time it takes an electrode to move between two metal contacts. Once calibrated to the specific material, the data collection software can calculate the amount of water in the material as a ratio of the maximum moisture that material can hold. The amount of water soaked into materials during the flood simulation could be estimated by comparing pre-flood and post-flood moisture content measured from the sensors imbedded before and after the flood simulation.

To measure the amount of moisture in concrete, a relative humidity sensor is placed into a small hole which creates a sealed environment from which the sensor can measure the amount of moisture in the air. The data collection software calibrates for temperature and is able to calculate the amount of moisture in the air relative to the maximum capacity of the air to hold moisture. The moisture in the materials which surround the trapped air can be inferred based on this information. All sensor readings are contextualized by climate data gathered from a weather station on Kessler Air Force Base, located two miles from the test site. In order to keep the wireless equipment from becoming damaged during the flood simulations, the equipment was removed from the test pods just prior to the flood simulation, and subsequently returned to the same locations after the flood simulation was completed.



sensors
dry-wall screws pictured. Longer probes are usefull for measuring wood. Proper placement is key to accurate readings.

banana clips
attach to probes or extension wires as shown here

extension wire
length does not effect or measurement

wireless transmitter
collects and transmits data. This sensor collects moisture content information by measuring resistance. Other sensor can measure moisture, temperature, and humidity.

Sensor Equipment
Measuring and Transmitting
all equipment from Lignomat U.S.A.

Fig. 4.6. DIAGRAM: Sensor equipment.

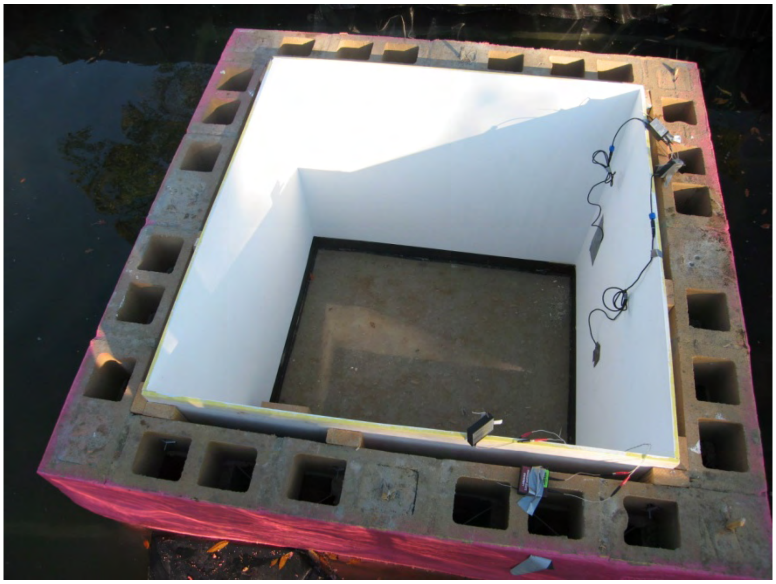


Fig. 4.7 PHOTO: Placement of sensor equipment within test pod assembly.

4.1.5 Documentation

The flood simulations were documented with video, still photography, written reports and digital data collected through the wireless sensors. Written reports were made on log sheets. Water depth inside the tank was referred to as "flood depth". Water depth inside the test pods due to infiltration through the wall assemblies was referred to as "interior depth." Measurements of water depths and photographs of the test pods were taken hourly during the filling of the tank, and the first half (first 12 hours) of the 24-hour flood simulation. Additional reports were made during the early stages of the flood simulation due to the high amount of change in the interior depths. After the first 12 hours of the flood simulation, reports were made every 2 hours without significant loss of data due to the relatively slow rate of change. After the test simulations, graphs, logs and presentations were created from analyzed data. A portion of this gathered data is highlighted in this section under section "3.3 Dry Floodproof Testing Under Flood Simulations" and "3.4 Summary of Results". A more detailed set of results can be found in Appendix A: Observations and Data From Flood Simulations.

4.2 Wall Sections and Material Choices

For the propose of understanding the difference in walls of each test pod, it is best to focus on the four elements which most effect dry floodproof performance in walls: the structure, the flood (bulk water) resistive layer, the thermal resistive layer and the exterior finish. The structure supports all the materials and is able to resist or distribute the hydrodynamic, hydrostatic and all other loads. The flood resistive layer consists of a water proofing membrane or other resistive element and must retain its integrity under hydrostatic loads despite possible inconsistencies. The flood resistive layer separates the portion of the wall intended to be exposed to water and the portion of the wall intended to stay dry. The exterior finish is the exposed face of the building, generally an attractive material, which protects the flood resistive layer from degradation from the sun or other environmental factors, while accommodating inspection and repair of the flood resistive layer.

The flood resistive layer is often but not always placed between the exterior finish and the structure. The exterior finish often needs attachments to the structure; these attachments often must penetrate through the flood resistive layer, thereby causing difficulties with floodproofing efforts. Also critically important for dry floodproof performance is the quality of the attachment between the membranes and the surface of the structure. Some test pods did not have an exterior finish installed during flood simulations, although exterior finish connectors were installed, in order to accurately observe the performance of the flood resistive layer with punctures through it. Alternative modular or panelized systems such as SIPs or ICFs can integrate more than one of the four elements discussed above within the same material or component.

A total of eleven unique wall assemblies were tested. The test fill was conducted with test pod A: sealed block installed. The first flood simulation was conducted with test pods A through F installed and observed. The second flood simulation was conducted with test pods A, B2, G, D2, H and F2. Detailed architectural drawings of each pod can be found in Appendix B. Table 2 shows the order in which pods were tested during three flood simulations.

Table 2. Testing order.

Test Fill	Flood 1	Flood 2
A: sealed block	A: sealed block	A: sealed block
	B: cavity wall	B2: cavity wall filled block
	C: unsealed block (control)	G: sheet membrane block
	D: ICF	D2: ICF
	E: metal stud (control)	H: weatherproofed block
	F: metal SIPs	F2: metal SIPs

4.2.1 Test Pod A: Sealed Block

Test pod A: sealed block was a concrete masonry unit (CMU) wall structure with a layered polymer membrane exterior coating (Fig. 4.8).

- First course (8″ in height) of CMU cells filled with grout with water resistant additive.
- Fully grouted CMU cells located at corners and at the middle of each wall.
- Three-layered multi-component sealant system most often used in industrial or infrastructure applications.
- Wall assembly did not have exterior finish façade although one would be required for actual installation.

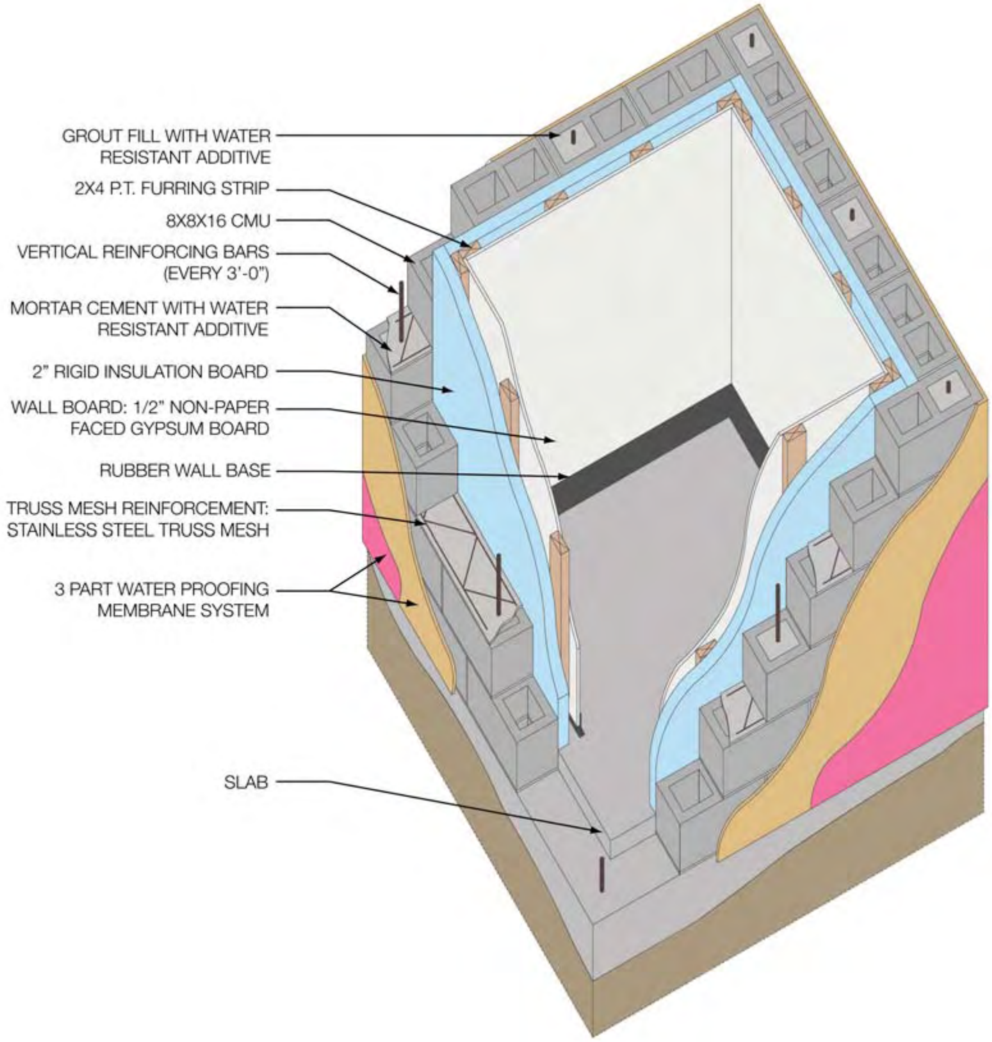


Fig. 4.8. DIAGRAM: test pod A: sealed block.

4.2.2 Test Pod B: Cavity Wall

Test pod B: cavity wall (Fig. 4.9) was a CMU wall structure with a fluid-applied rubberized asphaltic emulsion coating between the exterior of the CMU face and the brick exterior finish.

- First course (8″ in height) of CMU cells filled with grout with water resistant additive.
- Fully grouted CMU cells located at corners and at the middle of each wall.
- Brick was connected to CMU; asphaltic membrane was painted on CMUs around metal connectors.
- A 2″ cavity between the bricks and the rubberized asphalt. This cavity contained the thermal barrier and allowed for good drainage during normal use.

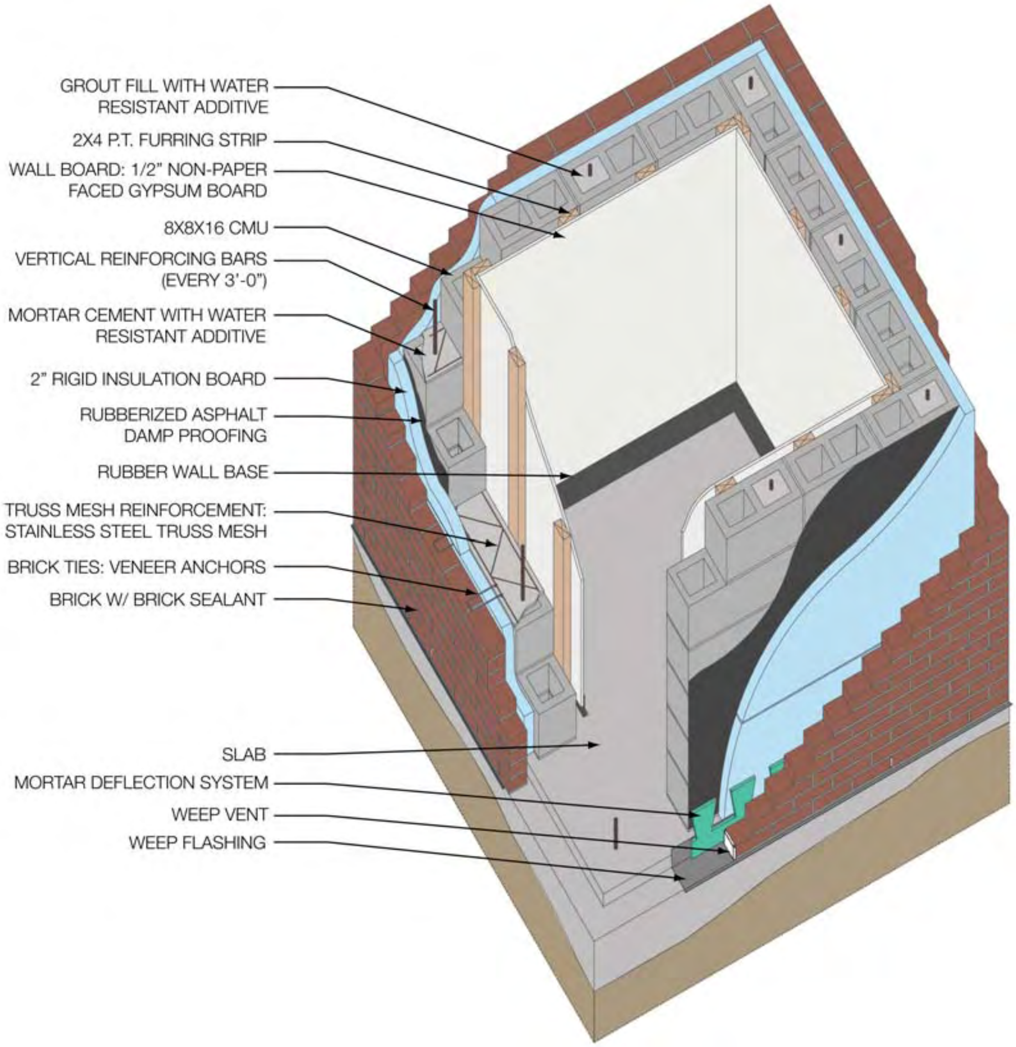


Fig. 4.9. DIAGRAM: test pod B: cavity wall.

4.2.3 Test Pod C: Unsealed Block

Test pod C: unsealed block (Fig. 4.10) was a CMU wall structure with a non-adhesive weather barrier wrapped around the block under fiber cement panels.

- First course (8″ in height) of CMU cells filled with mortar.
- Fully grouted CMU cells located at corners and in at the middle of each wall.
- A non-adhesive weather barrier was wrapped around the wall. This provides little protection against flood waters.
- A plastic drainage mat was placed between the insulation and the membrane to keep water from getting trapped in the assembly.
- Vertical furring strips connect the exterior panels to structure via masonry screws which penetrate the membrane.

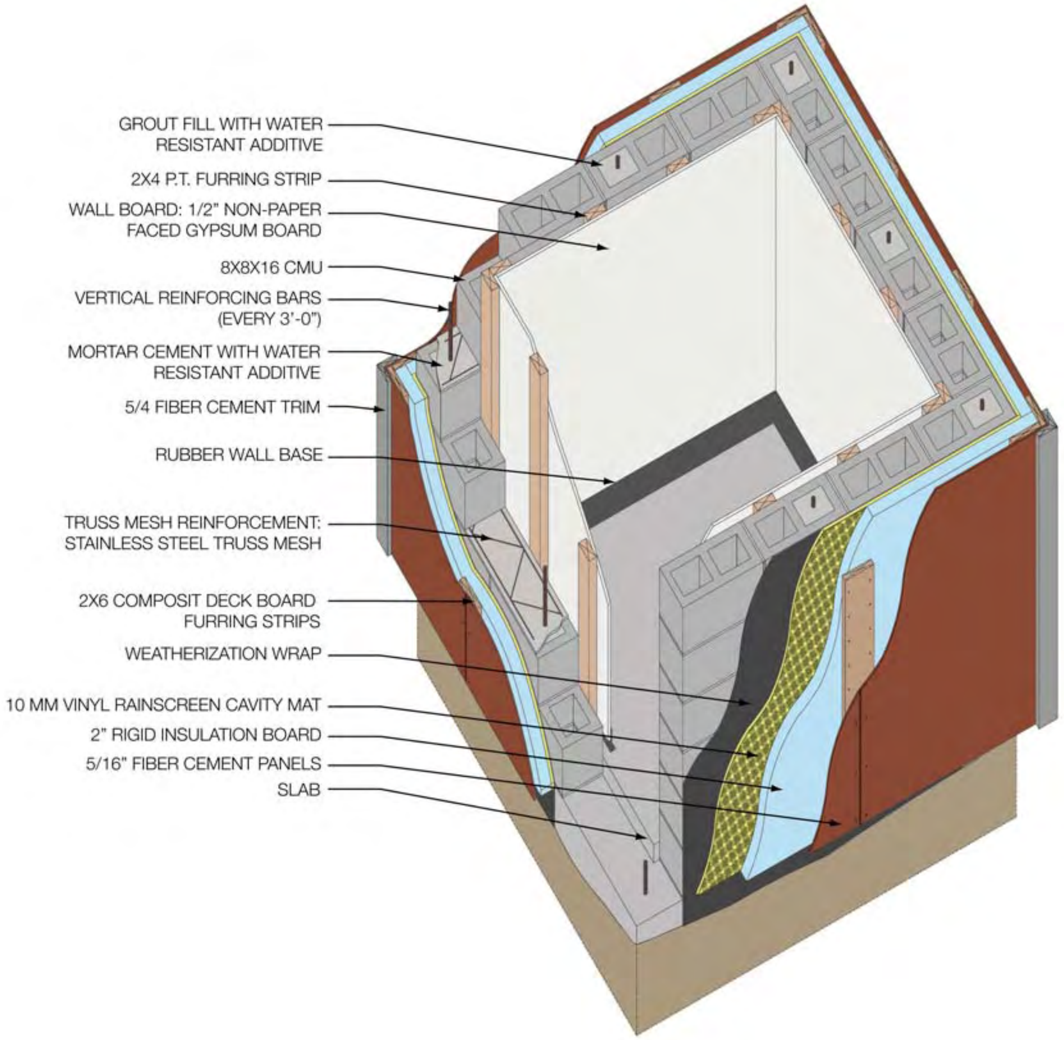


Fig. 4.10. DIAGRAM: test pod C: unsealed block.

4.2.4 Test Pod D: ICF

Test pod D: ICF (Fig. 4.11) was constructed using ICF with a stucco exterior finish.

- ICF is a system of formwork for concrete that stays in place as a permanent thermal resistive layer.
- ICF was made from polystyrene foam.
- A channel in the foundation slab was used to "key" the wall into the slab.
- The joint between the concrete slab and the concrete core of the wall was filled with a rubberized asphaltic emulsion.
- Stucco finish is water permeable.

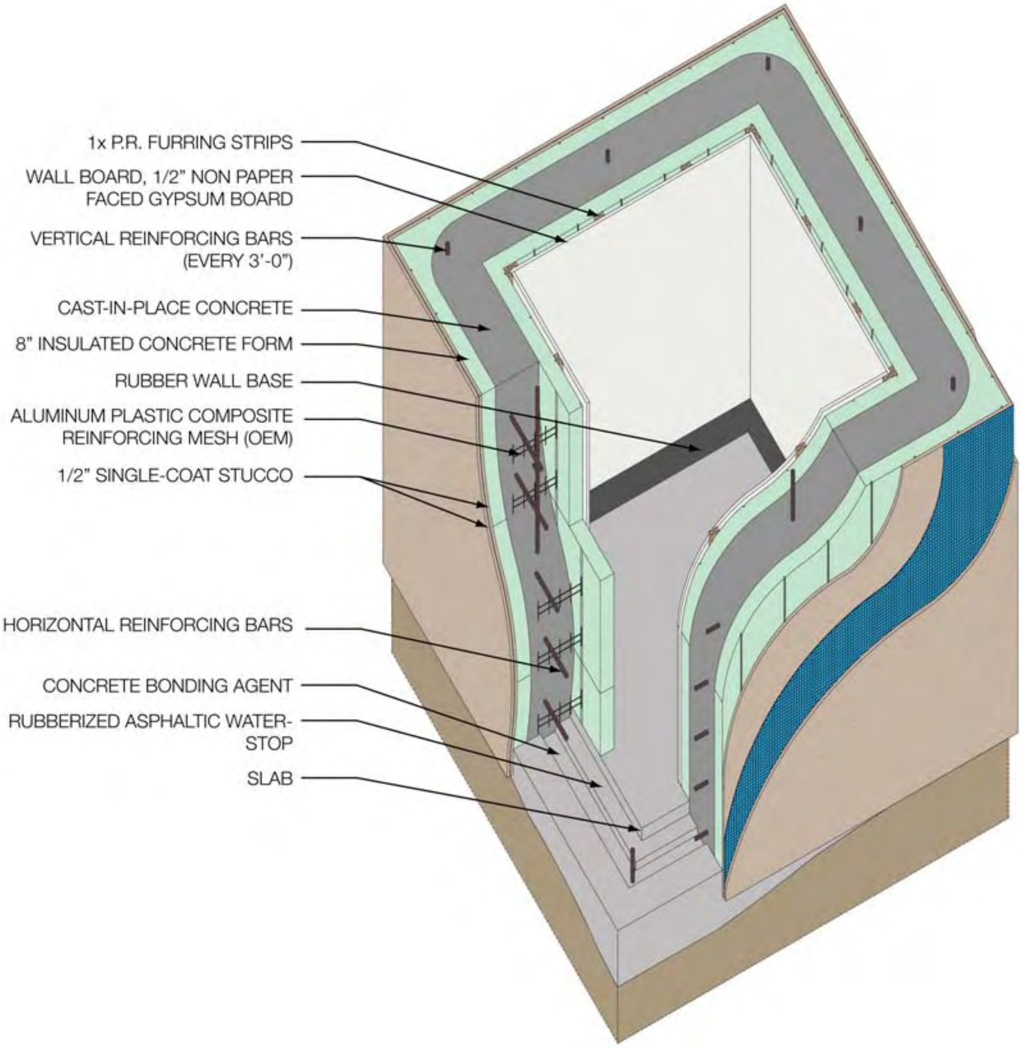


Fig. 4.11. DIAGRAM: test pod D: ICF.

4.2.5 Test Pod E: Metal Stud

Test pod E: metal stud (Fig. 4.12) was a metal stud structure with a non-adhesive weather barrier wrapped around the sheathing beneath the brick façade.

- Same weather barrier as test pod C.
- Built as a "Control Pod" to observe how local building might perform during a flood event.
- This assembly is an example of commercial construction common in the Mississippi Gulf Coast.

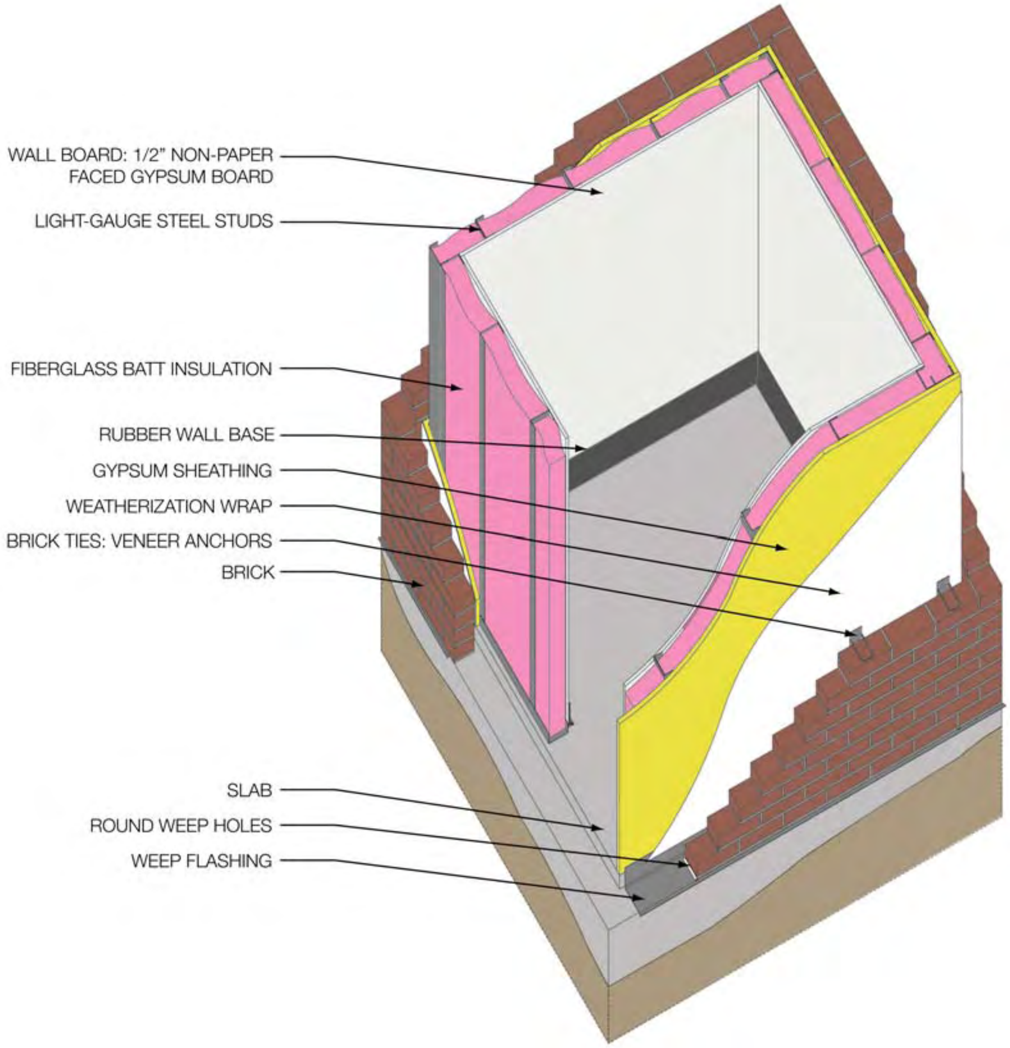


Fig. 4.12. DIAGRAM: test pod E: metal stud.

4.2.6 Test Pod F: Metal SIPs

Test Pod F: metal SIPs (Fig. 4.13) was constructed using metal SIPs set in a steel channel, which had been bolted to the concrete slab.

- Metal SIPs were made by sandwiching a core of rigid foam insulation between two metal panels.
- Joints were covered with metal flashing and caulked.
- No exterior finish or water resistive layer was used. It was intended that the SIPs would be the structure, water resistive layer, thermal layer and exterior finish.

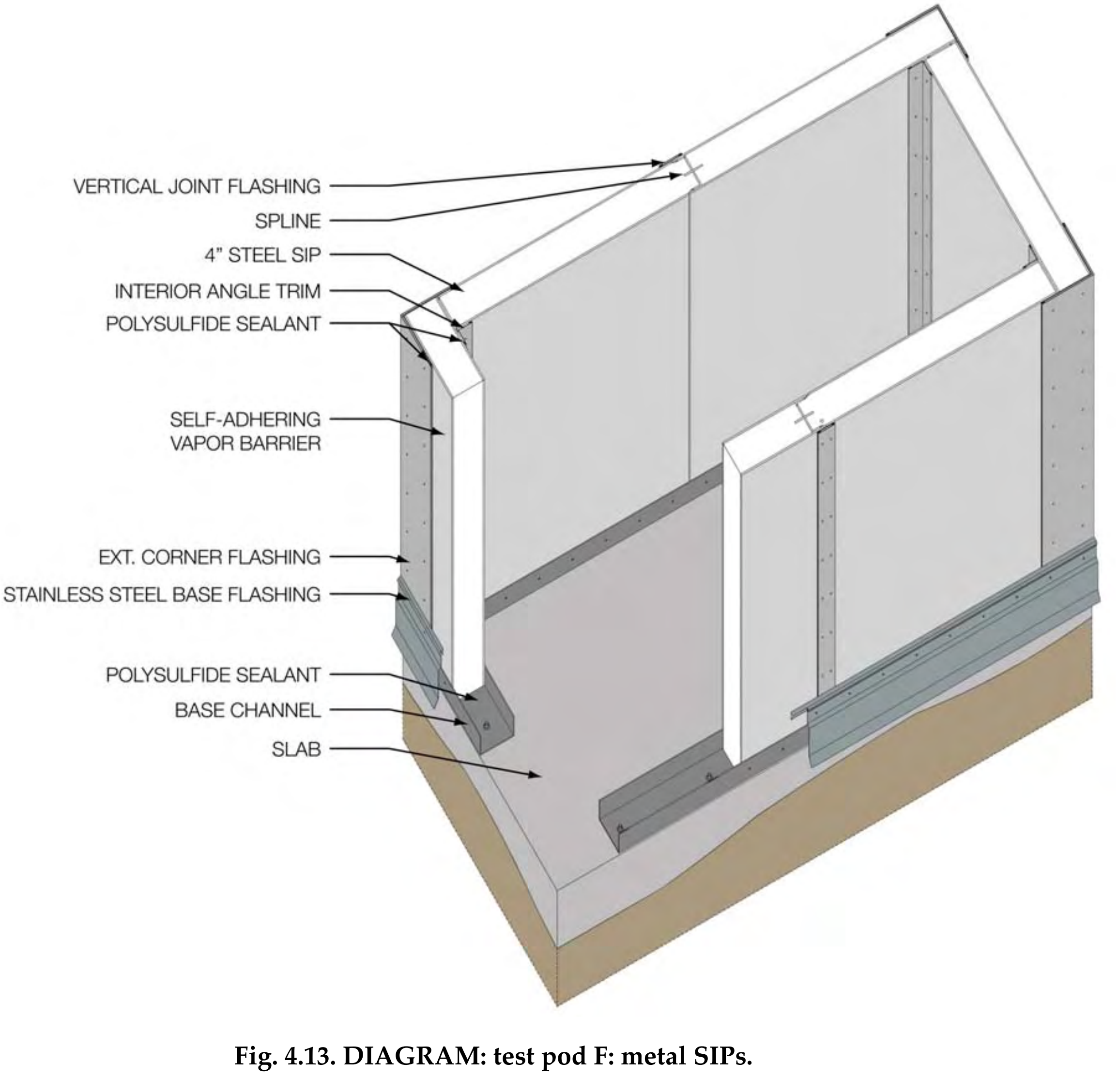


Fig. 4.13. DIAGRAM: test pod F: metal SIPs.

4.2.7 Test Pod G: Sheet Membrane Block

Test Pod G: sheet membrane block (Fig. 4.14) was a retrofit of test pod C: unsealed block with a self-adhering rubberized asphalt/polyethylene membrane sheet applied to the exterior face of the CMU.

- Sheet applied directly to CMU.
- The self-adhering sheet is covered with 1mm (.04″) of rubberized asphalt/polyethylene.
- Sheets overlap 2″.
- For structure description see test pod C.

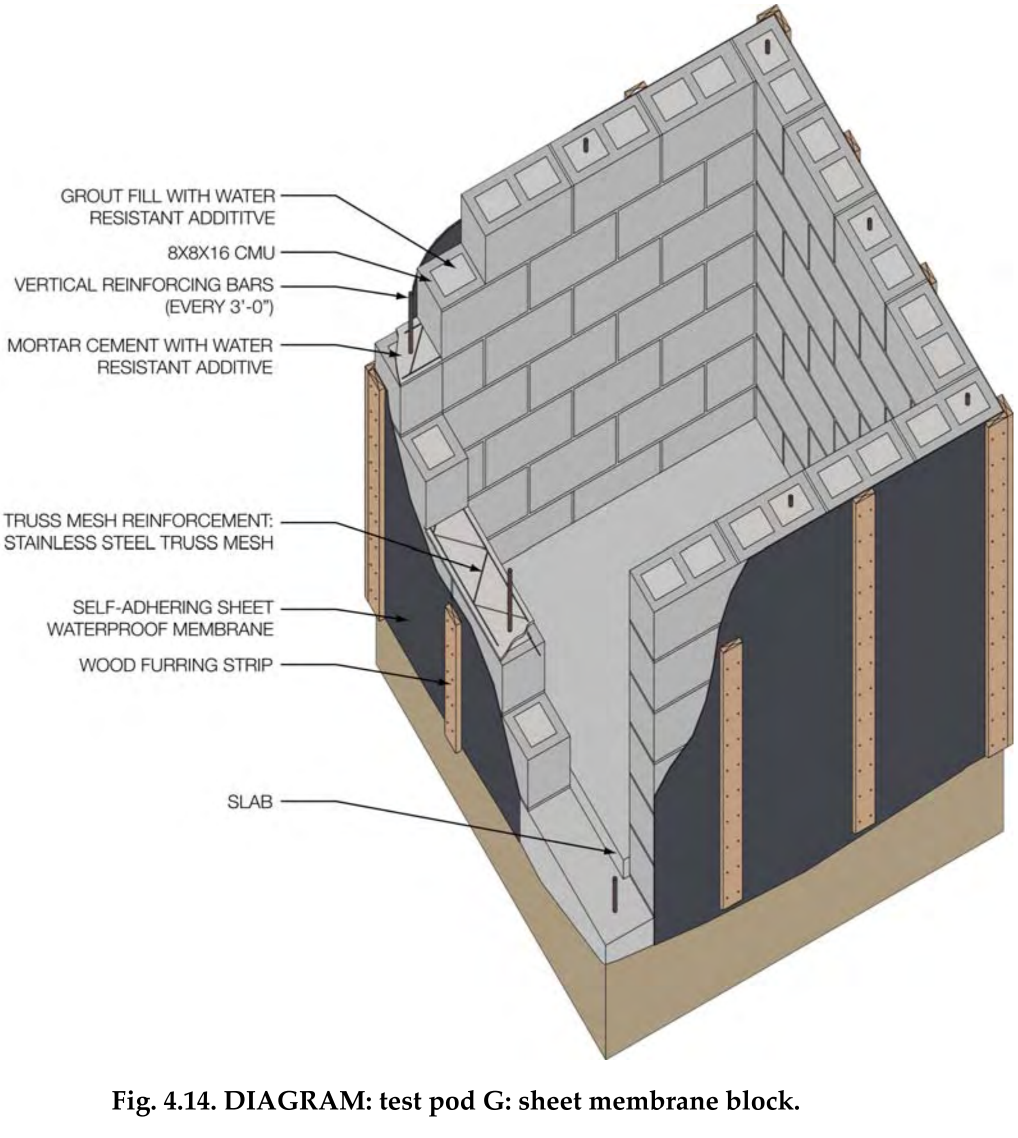


Fig. 4.14. DIAGRAM: test pod G: sheet membrane block.

4.2.8 Test Pod H: Weatherproofed Block

Test pod H: weatherproofed block (Fig. 4.15) was a CMU block structure with a liquid membrane sprayed onto the exterior of the CMU face.

- First course (8″ in height) of CMU cells filled with mortar.
- Fully grouted CMU cells located at corners and at the middle of each wall.
- The flood resistive layer was an elastomeric waterproofing coating for masonry and concrete, applied in four thick coats.
- Design was developed as an inexpensive alternative to test pod A: sealed block which performed well with a high-end spray-applied water resistive layer.
- Elastomeric coating was applied with a residential sprayer.

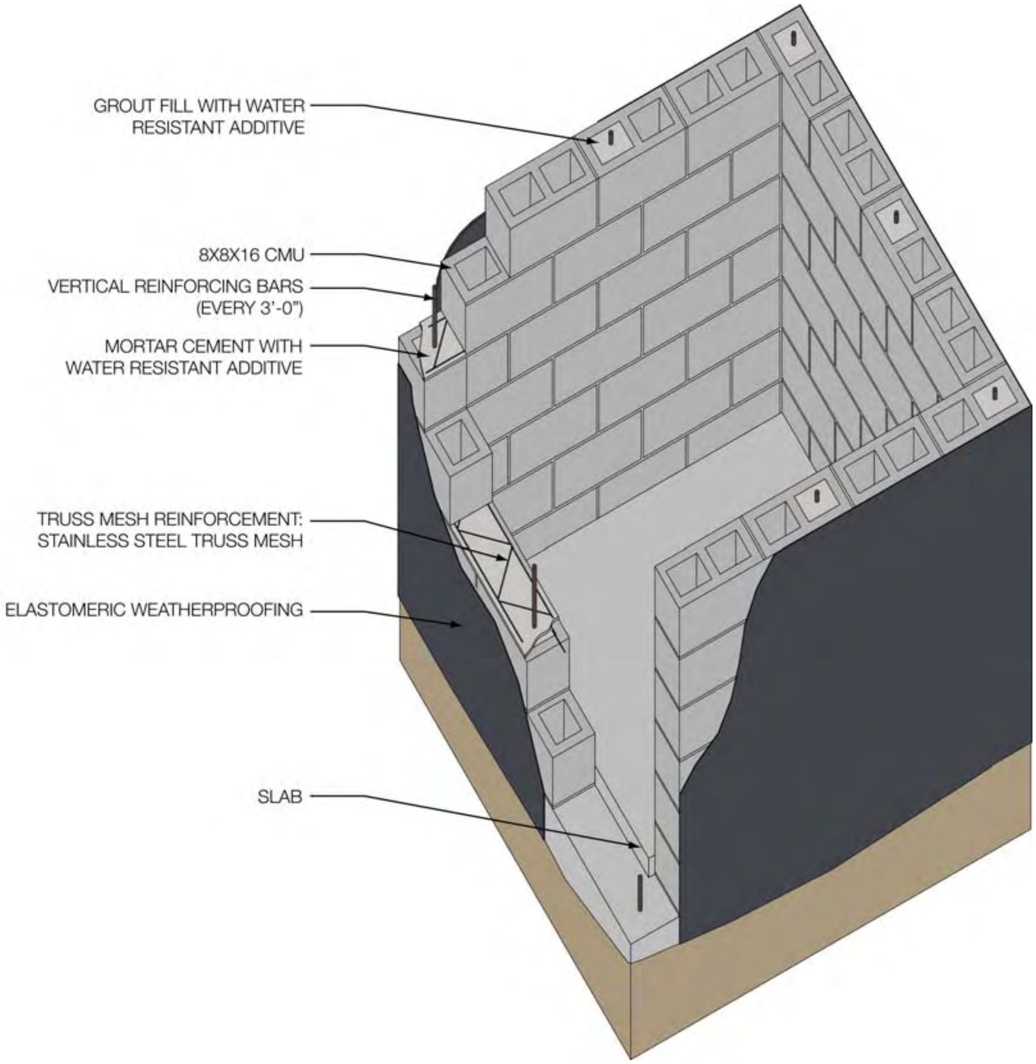


Fig. 4.15. DIAGRAM: test pod H: weatherproofed block.

4.2.9 Test Pod B2: Cavity Wall Filled Block

Test pod B2: cavity wall filled block (Fig. 4.16) was a retrofit of test pod B: cavity wall.

- Each cell of the CMU was completely filled with grout for the entire height of the wall.
- For a description of the rest of the construction of the wall, see test pod B: cavity wall description.

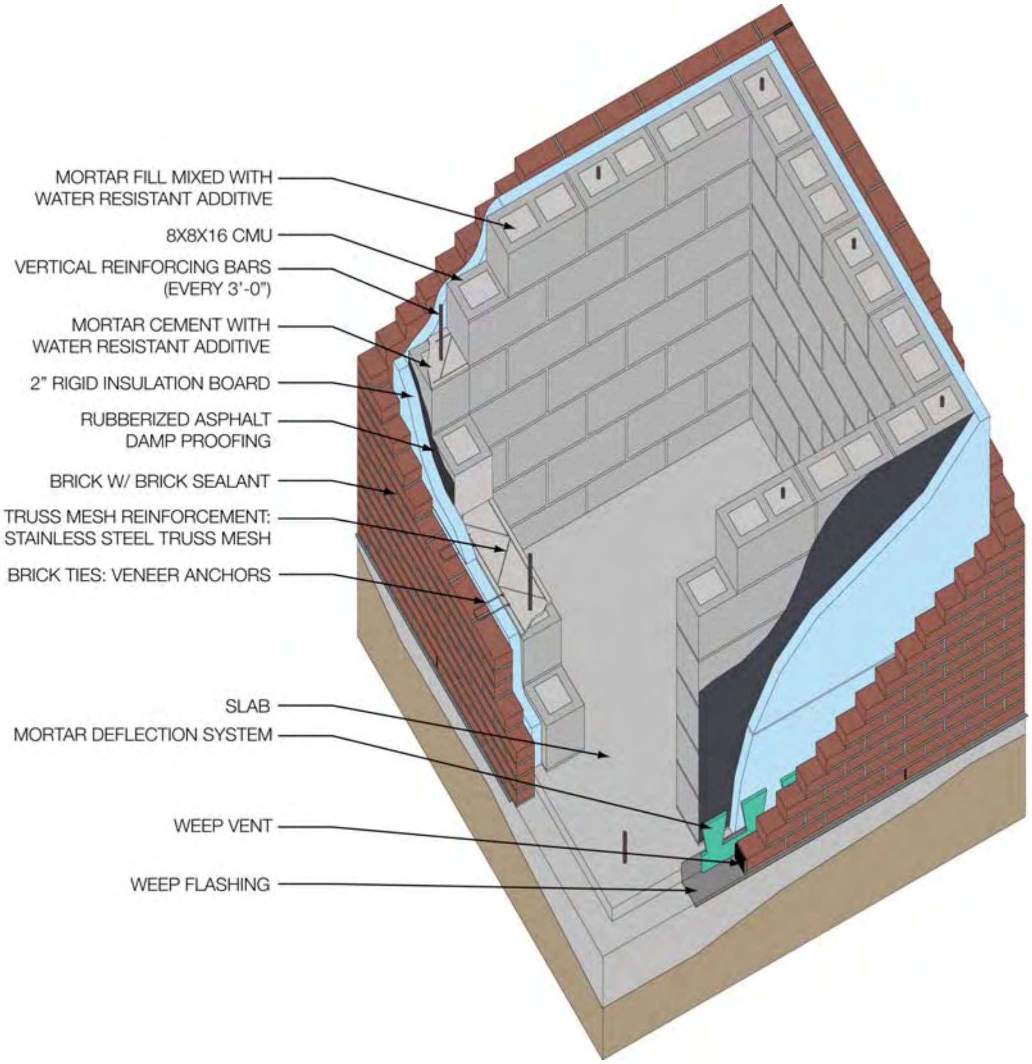


Fig. 4.16. DIAGRAM: test pod B2: cavity wall filled block.

4.2.10 Test Pod D2: ICF

Test pod D2: ICF (Fig. 4.17) was a retrofit of test pod D: ICF with an elastomeric paint applied to the exterior of the stucco.

- The elastomeric paint is partially impermeable to water
- For a description of the rest of the construction of the wall see test pod E: ICF description.

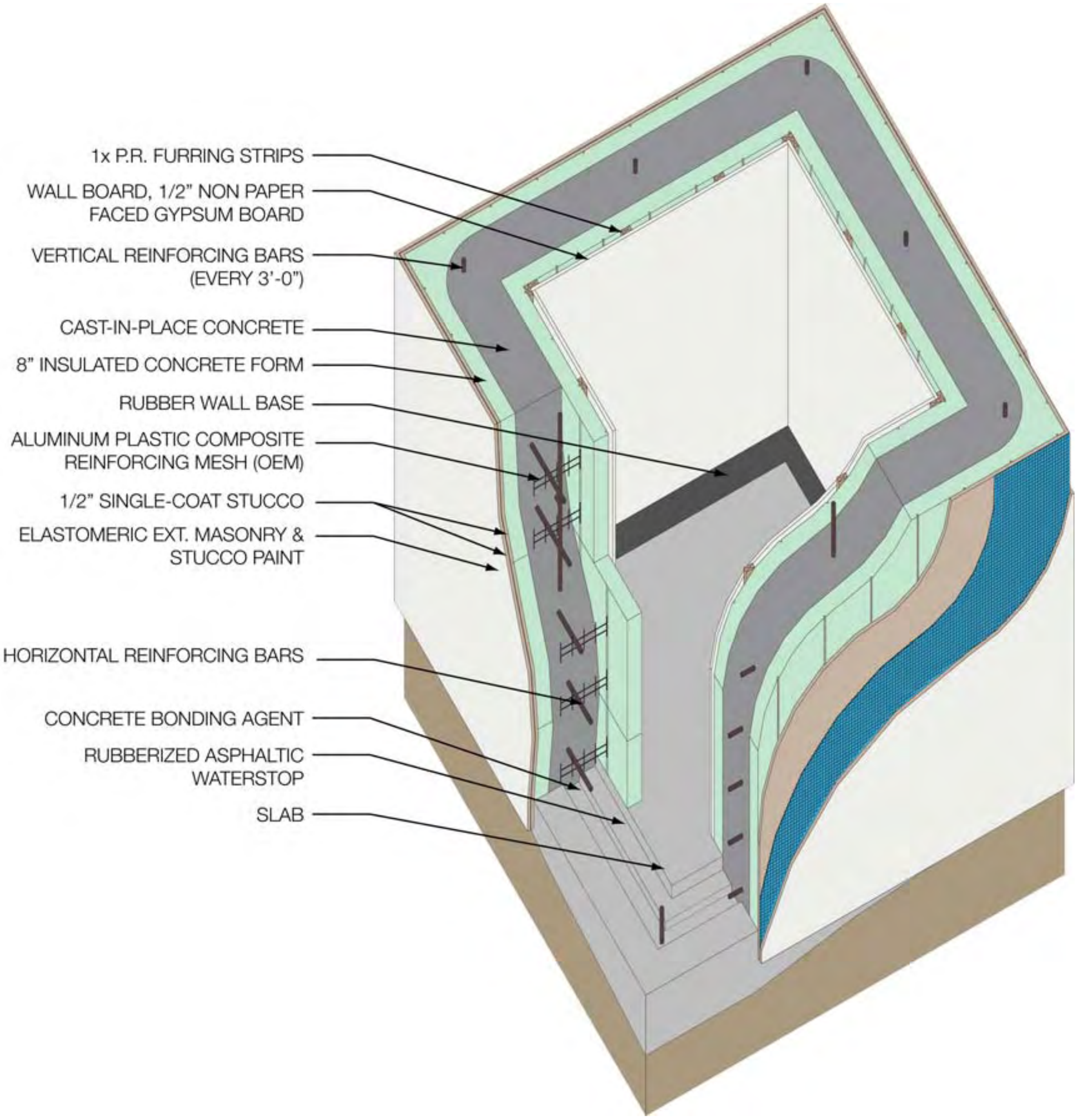


Fig. 4.17. DIAGRAM: test pod D2: ICF.

4.2.11 Test Pod F2: Metal SIPs

Test pod F2: metal SIPs (Fig. 4.18) was a retrofit of test pod F: metal SIPs with an updated SIP-to-foundation detail that created a more robust seal between the panels and the slab.

- A much larger amount of sealant was placed into the base channel before the SIPs were set into it.
- Butyl tape was used to seal the vertical and horizontal joints.
- For a description of the other aspects of the wall see test pod F: metal SIPs description.

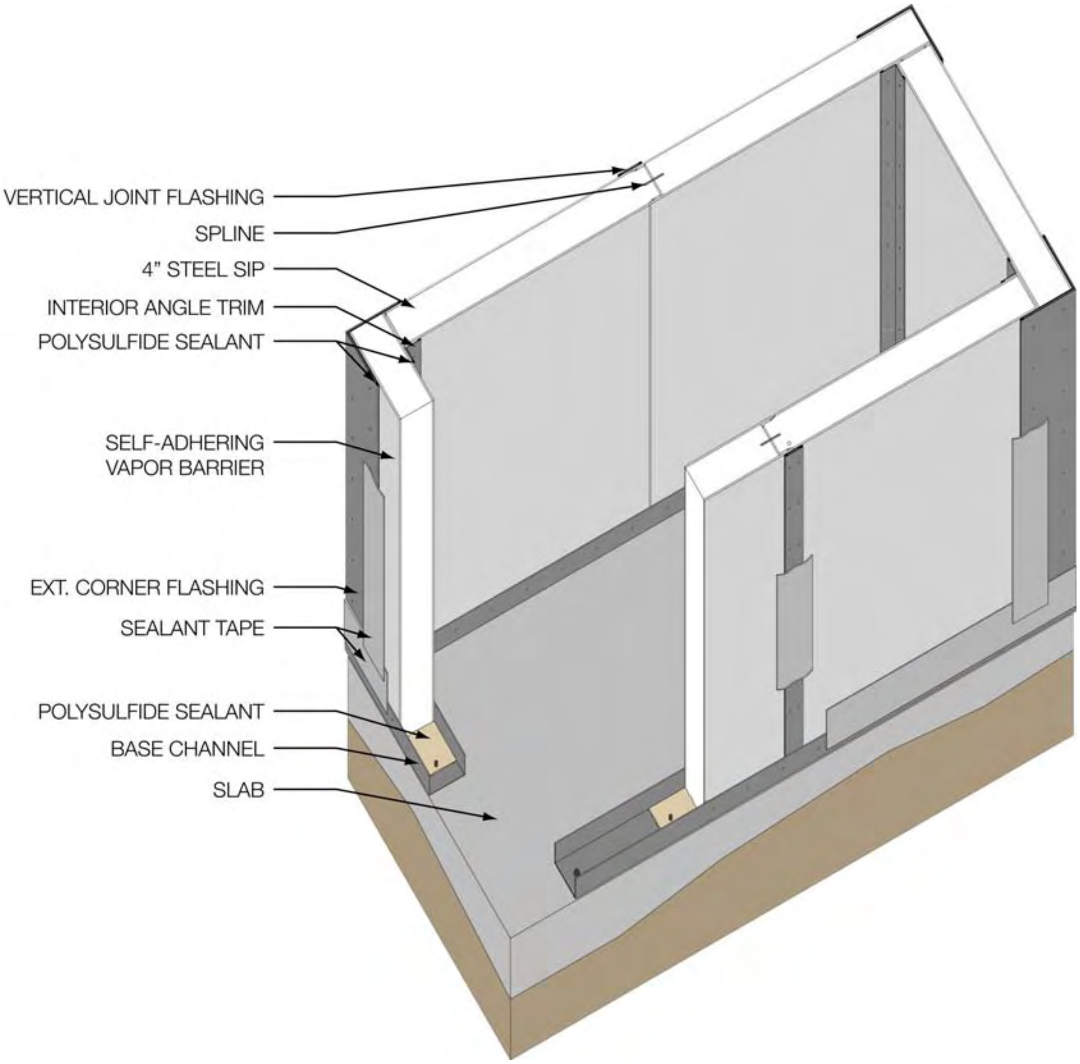


Fig. 4.18. DIAGRAM: test pod F2: metal SIPs.

4.3 Dry Floodproof Testing Under Flood Simulations

The test fill, which was a test for the facility, equipment and protocols, took place on January 19th 2011. The sensors were installed into the test pods to collect pre-flood data on March 15th 2011. Flood simulation 1 began on April 6th, 2011. On April 8th any remaining water in the test pods were completely drained and the sensors were placed back in the walls. Flood simulation 2 took place on June 28th and 29th 2011. There was not a drying period measured with sensors after the second flood simulation. (See Fig. 4.1 for timeline)

4.3.1 Test Fill Results

During the test fill a water depth of 36" within the tank could not be maintained for an entire 24 hour period. Water leak through the tank lining and Hesco boxes at a high rate making it too difficult to maintain proper depth. Only pod A: sealed block had been installed at the time of the test fill. The interior water depth in the test pod was 2" after 20 hours of flood simulation at water depths ranging from 24" to 40". After the flood tank had been evacuated an inspection of the exterior coating of test pod A: sealed block revealed that a 6"x 2" strip of the layered polymer membrane had broken off the wall near the bottom (Fig. 4.19). This hole in the sealant material was patched using the same liquid-applied asphaltic sealant used in test pod B: cavity wall, prior to the next flood simulation.

Fig. 4.19. PHOTO: Damage to test pod A: sealed block during the test fill.

4.3.2 Flood Simulation 1 Results

The following is a condensed version of the report from flood simulation 1, which highlights the significant events during the simulation. For a more complete report of the simulation see Appendix A: Observations and Data From Flood Simulations.

April 6th, 2011

7:30am - The flood simulation began. The approximate rate of water entering the flood tank was 200 gallons per minute. Two hoses were used to fill the flood tank and were positioned to avoid creating hydrodynamic forces on the test pods.

7:55am - The interior depth in test pod E: metal stud surpassed the 4″ mark. The flood depth in the tank was 10″ at that time.

*9:*53am – Test pod F: metal SIPs interior depth reached 4″. The flood depth was 28″ at this time.

10:25am – The interior depth in test pod C: unsealed block rose to 6 ½″, surpassing the 4″ mark. The flood depth in the flood tank had risen to 33″.

10:50am – The flood depth reached the targeted 36″ depth. At this time, the test pod A: sealed block had no measurable interior depth; only a small amount of seepage could be seen. Test pod B: cavity wall had 4″ of interior depth. Test pod C: unsealed block had 9.5″ of interior depth. The interior depth for test pod E: metal stud had equalized with the flood depth at 36″. Test pod D: ICF had 1.75″ of measurable interior depth. Test pod F: metal SIPs had an interior depth of 7″.

3:33pm – The water inside test pod D: ICF reached a depth of 4.25″, passing the dry floodproof threshold.

6:00pm - Test pod F: metal SIPs floated free of the metal base channel which remained connected to the concrete slab. Test pod F: metal SIPs had at least 33″ of interior water depth when this happened.

April 7th, 2011

1:00am to 3:00am – Test pod B: cavity wall and test pod C: unsealed block had equal interior depth and flood depth at 36″.

7:00am - The contractor began to empty the tank. The flood tank emptied at an average rate of 5″ to 5.5″ inches an hour.

11:00am - The interior water depth in the test pod A: sealed block reached a level of ¼″. This was the maximum interior depth for this test pod.

1:16pm – Test pod D: ICF reached an interior depth of 10 ½″. This was the maximum interior depth for this test pod.

4:00pm –The flood tank was almost completely empty.

April 8th, 2011

12:01pm – GCCDS staff bailed out the remaining water in all six test pods and placed the moisture content and relative humidity sensors back into the wall assemblies. The remaining interior depths prior to bailing were .25″ in test pod A: sealed block, 17.75″ in test pod B: cavity wall, 13.25″ in test pod C: unsealed block, 7.25″ in test pod D: ICF. Test pods E: metal stud and test pod F: metal SIPs were not holding standing water at this time.

April 19th, 2011

The tent was removed after two weeks of observation.

Below (Fig. 4.20), a graph shows the interior depths that infiltrated the test pods during the flood simulation 1.

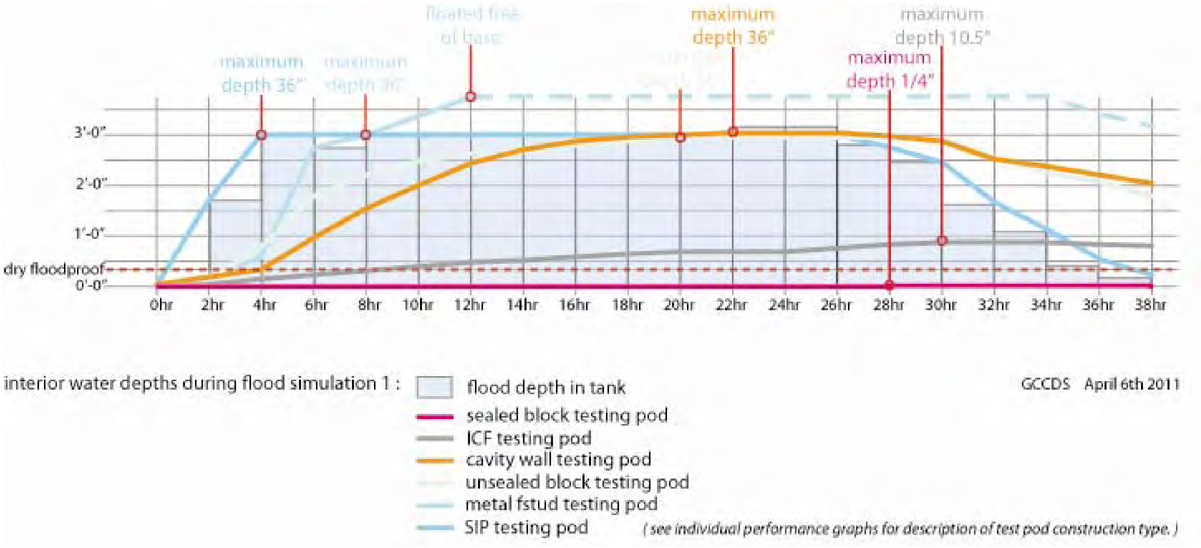


Fig. 4.20. GRAPH: Interior depths: flood simulation 1.

4.3.2.1 Test pod A: sealed block

Test pod A: sealed block never had an interior depth of more than ¼″ of water at any point during flood simulation 1 (Fig. 4.21). The water that did seep into this test pod did so at a continuous rate starting from the middle of the west wall of the pod. This location corresponds with the 6″ x 2″ section of the layered polymer membrane which had been damaged and repaired prior to flood simulation 1.

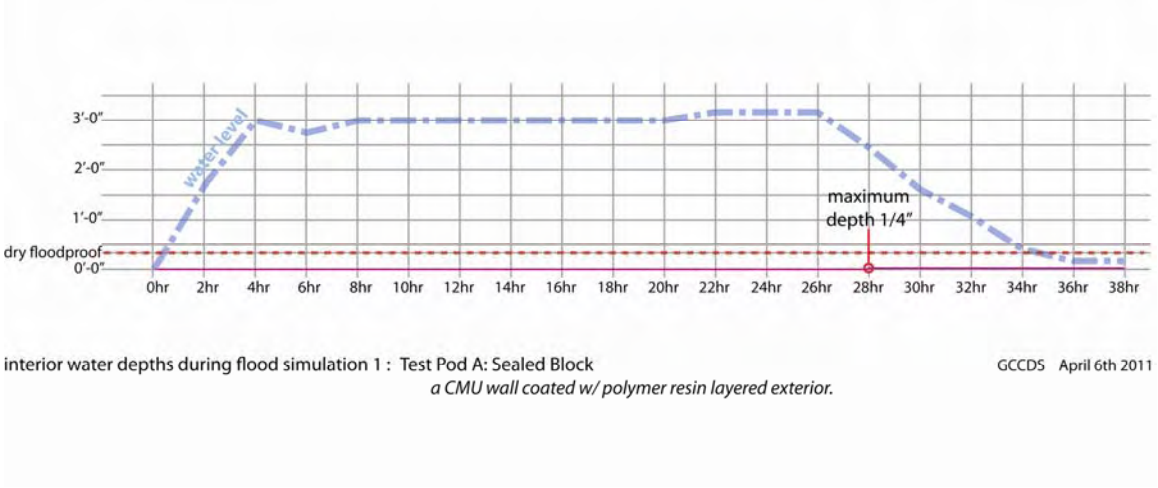
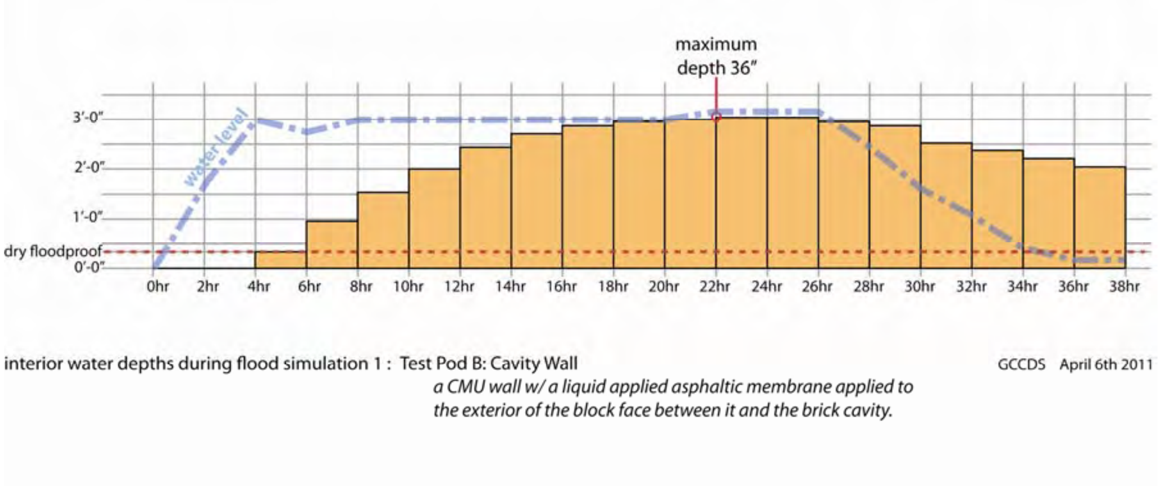


Fig. 4.21. GRAPH: Interior depths: test pod A: sealed block, flood simulation 1.

4.3.2.2 Test pod B: cavity wall

Test pod B: cavity wall maintained 4" or less of interior depth for the first 6 hours, eventually equalizing with the flood depth after 18 hours (Fig. 4.22). Water was observed filling different CMU cells at different rates during the test. A CMU block is 8" tall; 8" was often the difference between the depths of water in neighboring CMU cells. Because of this observation, it was concluded that penetration of water between CMU cells happened through the joints rather than the blocks themselves.



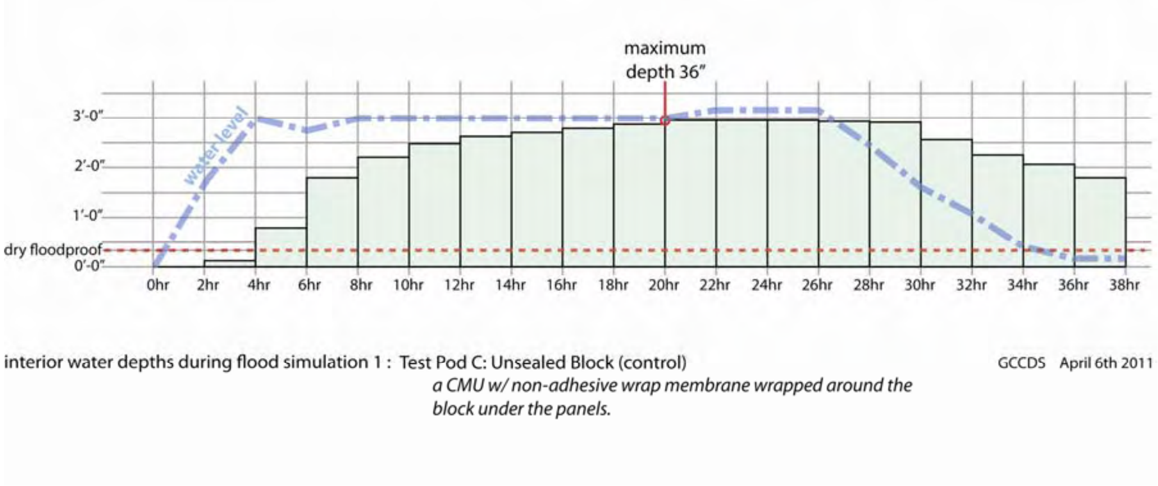
interior water depths during flood simulation 1 : Test Pod B: Cavity Wall GCCDS April 6th 2011

a CMU wall w/ a liquid applied asphaltic membrane applied to the exterior of the block face between it and the brick cavity.

Fig. 4.22. GRAPH: Interior depths: test pod B: cavity wall, flood simulation 1.

4.3.2.3 Test pod C: unsealed block

Overall, test pod C: unsealed block had similar performance to the test pod B: cavity wall, but filled at a quicker rate (Fig. 4.23).



interior water depths during flood simulation 1 : Test Pod C: Unsealed Block (control) GCCDS April 6th 2011

a CMU w/ non-adhesive wrap membrane wrapped around the block under the panels.

Fig. 4.23. GRAPH: Interior depths: test pod C: unsealed block, flood simulation 1.

The difference in performance between the two test pods can be attributed to the difference in membranes used in the test pods, as represented by the darker shaded areas in Fig. 4.24. Test pod C: unsealed block was a CMU wall without a membrane.

When compared to test pod B: cavity wall, the results show that the presence of the asphaltic membrane in test pod B made little headway towards floodproof performance. The comparison of test pods B and C led the GCCDS research team to conclude that the asphaltic liquid membrane applied with a brush was not a viable option for investigation of dry floodproofing.

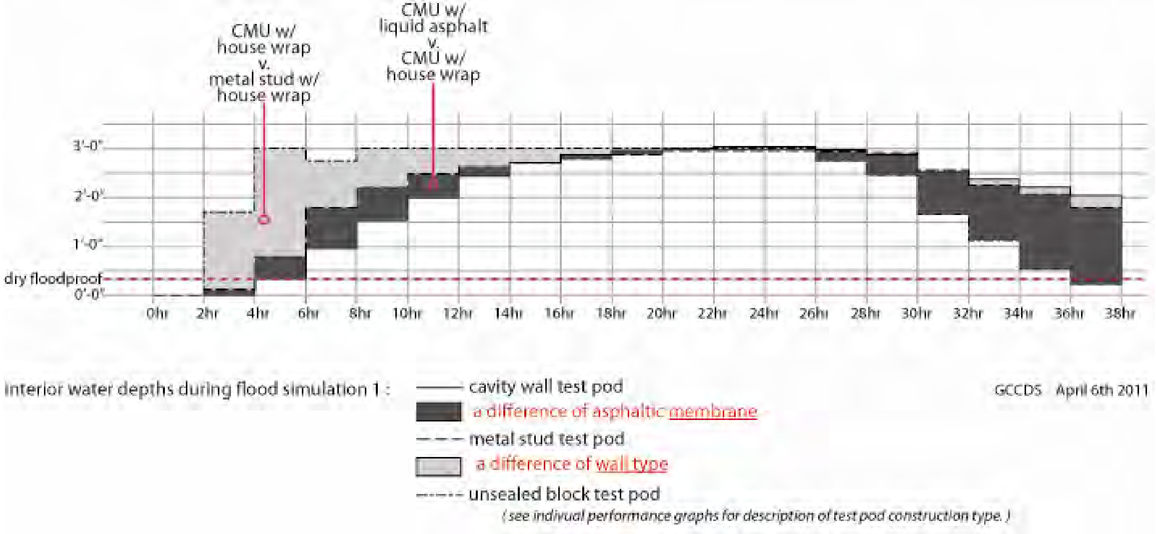


Fig. 4.24. GRAPH: Int. depths: differences between membranes and wall assemblies.

4.3.2.4 Test pod E: metal stud

Test pod E: metal stud provided the least resistance to the penetration of water into the interior (Fig. 4.25). The interior depth of test pod E: metal stud was nearly constant and equal to the flood depth throughout flood simulation 1. The interior depth was higher than the flood depth during the evacuation of the flood tank. Likely, this was a result of the external hydrostatic pressure slowing the drainage of the water from inside the test pod. This observation led GCCDS staff to conclude that the majority of water was penetrating the assembly along the base of the test pod, where hydrostatic forces were strongest, causing quick filling and slow draining of the test pod.

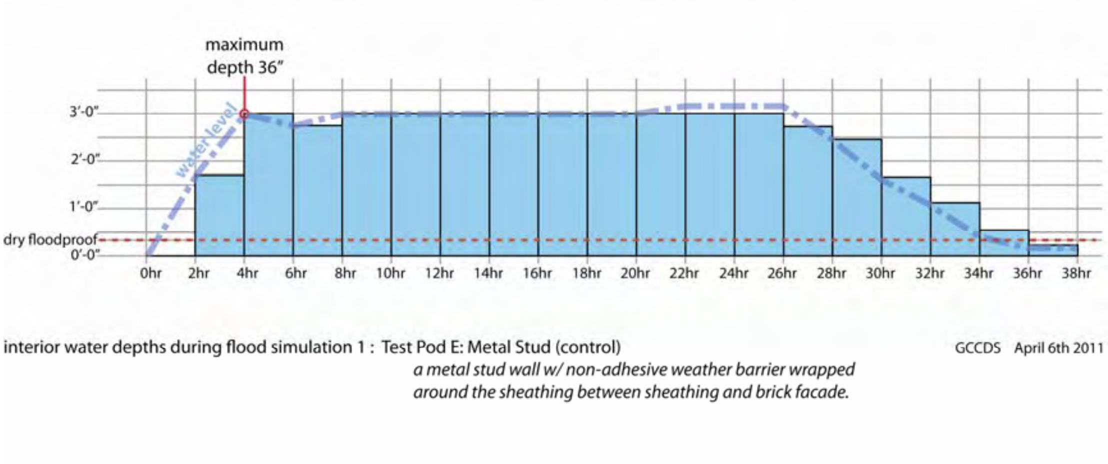
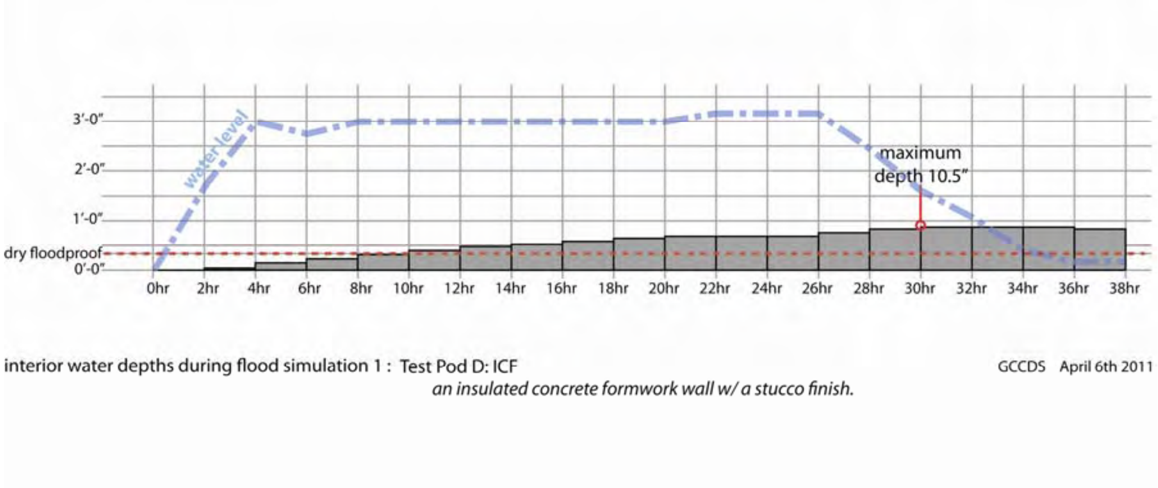


Fig. 4.25 GRAPH: Interior depths: test pod E: metal stud, flood simulation 1.

4.3.2.5 Test pod D: ICF

Test pod D: ICF displayed a constant rate of water penetration into the assembly system, even after flood depths began to drop (Fig. 4.26). The interior depth surpassed the 4″ dry floodproof threshold at approximately 4.5 hours after the 36″ flood depth was reached. The maximum interior depth for test pod D: ICF was 10.5″, 26 hours after the flood simulation began. The final interior depth was much lower than systems which obviously failed, implying that the assembly continuously maintained some resistance to flood waters throughout the test. The slow rate of change in the interior depth suggested that the accumulated water was likely due to seepage through material rather than leakage through gaps in connections.



interior water depths during flood simulation 1 : Test Pod D: ICF

GCCDS April 6th 2011

an insulated concrete formwork wall w/ a stucco finish.

Fig. 4.26. GRAPH: Interior depths: test pod D: ICF, flood simulation 1.

4.3.2.6 Test pod F: metal Structural Insulated Panels (SIPs)

Test pod F: metal SIPs was unable to resist both vertical and horizontal hydrostatic forces during the first flood simulation. Once the flood depth reached 36″, the test pod quickly filled up with water (Fig 4.27). Water could be seen flowing to the interior along a path which followed the connection between the U-shaped channel and panel. Water was not seen passing through the vertical seams between panels. By the 12th hour of the test, the entire test pod floated free from the foundation slab. The vertical hydrostatic (buoyant) forces acting on the wall were too great for the caulk, which was the sole component in the assembly connecting the channel to the SIPs. Likely, the buoyant forces stressed the caulk early in the simulation, to where the caulk was no longer an effective barrier against the passage of water.

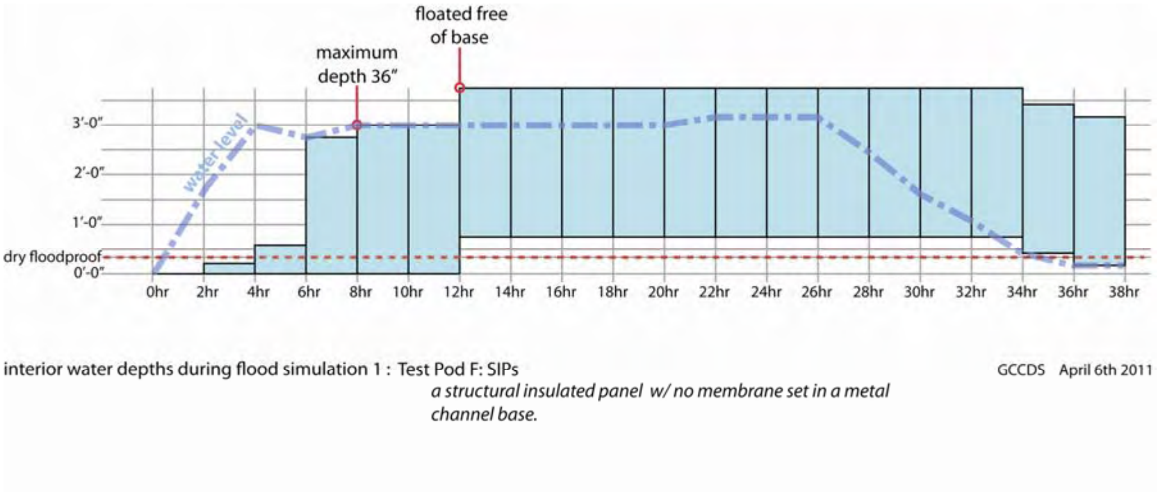


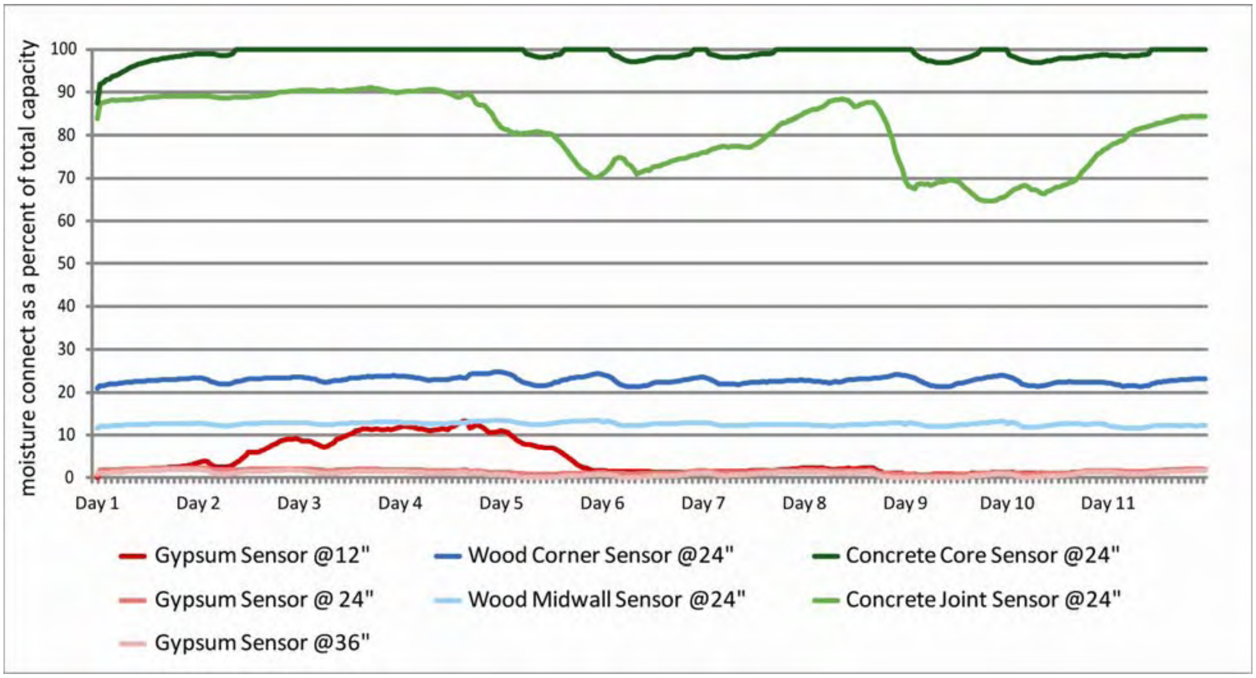
Fig. 4.27 GRAPH: Interior depths: test pod F: metal SIPs, flood simulation 1.

4.3.3 Two-Week Drying Period

After flood simulation 1 was complete, and all water had been evacuated from both the flood tank and the test pods, the wireless sensors were placed back into the test pods at the same locations as before the simulation. Each sensor recorded moisture content for a two-week drying period. During this time the flood tank was covered with a tent to keep out the weather, but allowed air flow. Four data sets are presented in this chapter: the drying period of a wall classified as dry floodproof, the drying period of a wall not classified as dry floodproof, a comparison of the mortar joints 24 hours before and after the flood simulation, and a comparison of drywall within all of the test pods. For more sensor graphs and analysis, refer to Appendix A.

4.3.3.1 Drying period of a wall classified as dry floodproof

The sensor readings for test pod A: sealed block are exemplary of the moisture levels within an assembly classified as dry floodproof. The sensor reading data (Fig. 4.28) provides information regarding the moisture collection within an assembly. Fig. 4.28 also shows the location of these sensors within the assembly. The concrete sensors (upper green lines, Fig. 4.28) show that the concrete dried little during the two- week drying period. The fluctuations in the moisture level of the concrete cavity sensor represent daily temperature change. The concrete joint sensor fluctuates similarly, however over a two-day cycle. The cause of this is unclear. The wood sensors were placed between the interior face of the CMU block wall and the backside of the gypsum board, embedded into the wood furring strips. The readings (middle red lines, Fig. 4.28) show that the moisture level within the furring strips hovered around 10% and 20% for the duration of the drying period. However, these post-flood moisture levels match the pre-flood moisture levels, indicating that the moisture content was constant and unrelated to the flood simulation. The average moisture content for all wood products in the test pods prior the flood simulation was 12%.



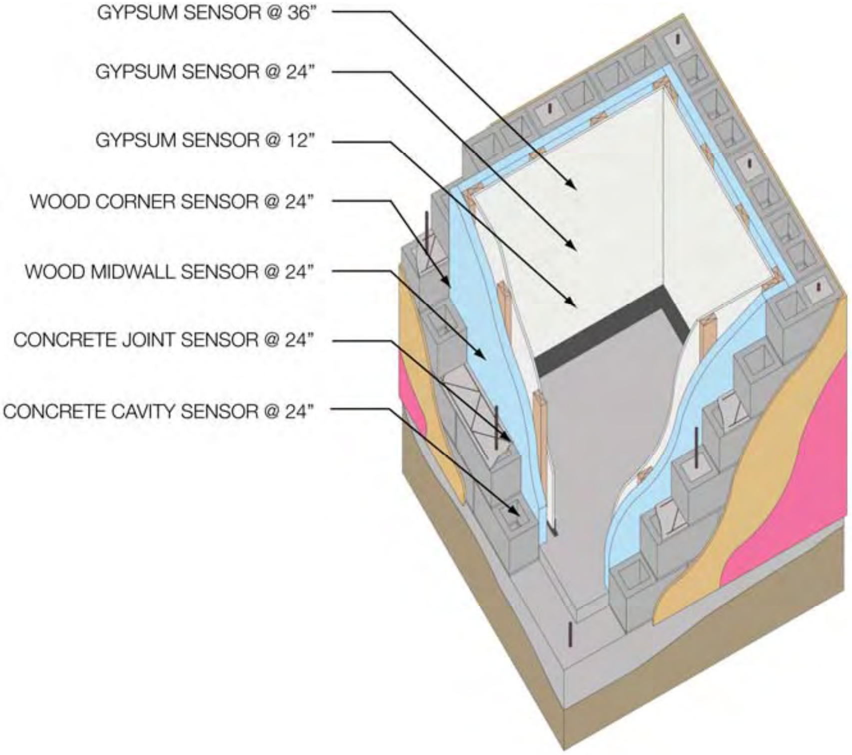


Fig. 4.28. DIAGRAM: Drying period test pod A: sealed block and sensor locations.

The lower blue lines in the graph represent the three moisture sensors embedded at various heights into the gypsum board. Sensors were placed at 12″, 24″ and 36″above the slab, aligned vertically (Fig. 4.28). Since only .25″ of water penetrated the interior of the pod, none of the gypsum sensors were in direct contact with water during the flood simulation. The increase in moisture content reading from the gypsum sensor embedded 12″ above the slab is most likely the result of water wicking, as a result of capillary action, from the base of the gypsum board. Note that it took several days for the moisture to migrate to this height, and subsequently dried out within one week. Moisture was not able to reach the height of sensors at either 24″ or 36″. These results are constant with the gypsum data shown in subsequent readings.

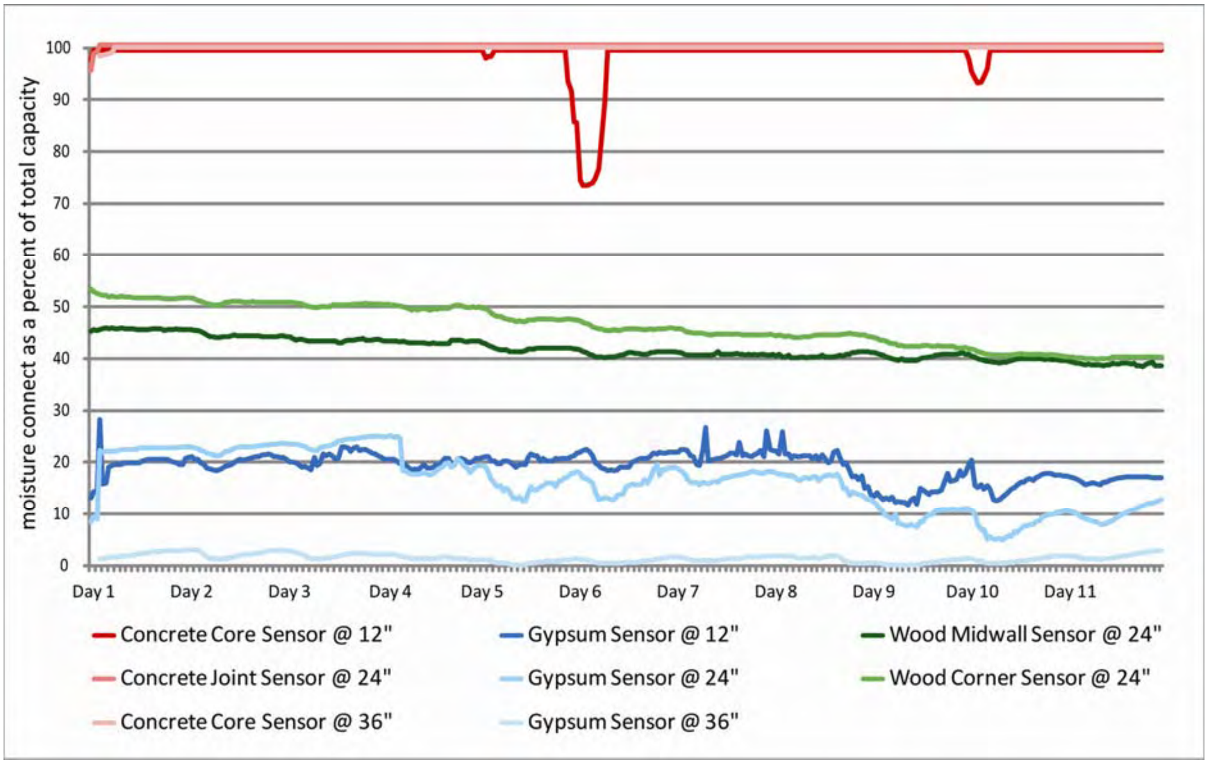
4.3.3.2 Drying period of a wall not classified as dry floodproof

The sensor readings for test pod B: cavity wall are exemplary of moisture levels found within an assembly that completely failed to perform as dry floodproof. During the flood simulation, water filled all cavities within the assembly. The sensor readings shown in Fig. 4.29 provide information regarding the degree of water infiltration, and the drying rate of the materials during the two-week drying period. Fig. 4.29 also shows the sensor locations.

The graph shows that the concrete dried very little during the two-week drying period. The moisture levels in the concrete were similar to the moisture levels found in test pod A: sealed block. Likely, this is because the concrete still had high moisture content from being poured approximately a month before the testing began. However, neither of data sets gathered from the concrete in test pod B fluctuated similar to the data sets gathered from the concrete materials in test pod A: sealed block. An explanation for this difference may be that while the concrete materials in both test pods were holding the maximum amount of moisture the material was capable of (100% reading), the concrete products in test pod B: cavity wall were also surrounded by water, as water was trapped within the assembly. This explanation was supported by evidence of water found within the interior of other CMU block walls during partial demolition (Fig 4.5).

The wood sensor readings shown in the mid-section of the graph represent moisture data collected from the sensors embedded in wood furring strips located behind the gypsum board. Over the drying period, the wood furring strips dried approximately 10 percentage points. At around 40% moisture content, neither wood furring strip came close to returning to pre-flood simulation moisture levels (at around 12%).

The three lower readings represent data collected from moisture sensors embedded in the gypsum board. The two sensors located closest to the slab showed moisture content of around 20 percentage points higher than the sensor located 36″ above the slab. The sensors recorded slight drying in the gypsum during the two-week drying period; they also showed significant variation over that same period. This variation may be the result of moisture trapped within crevices within the wall assembly, which were subject to temperature and vapor level variation during an average day.



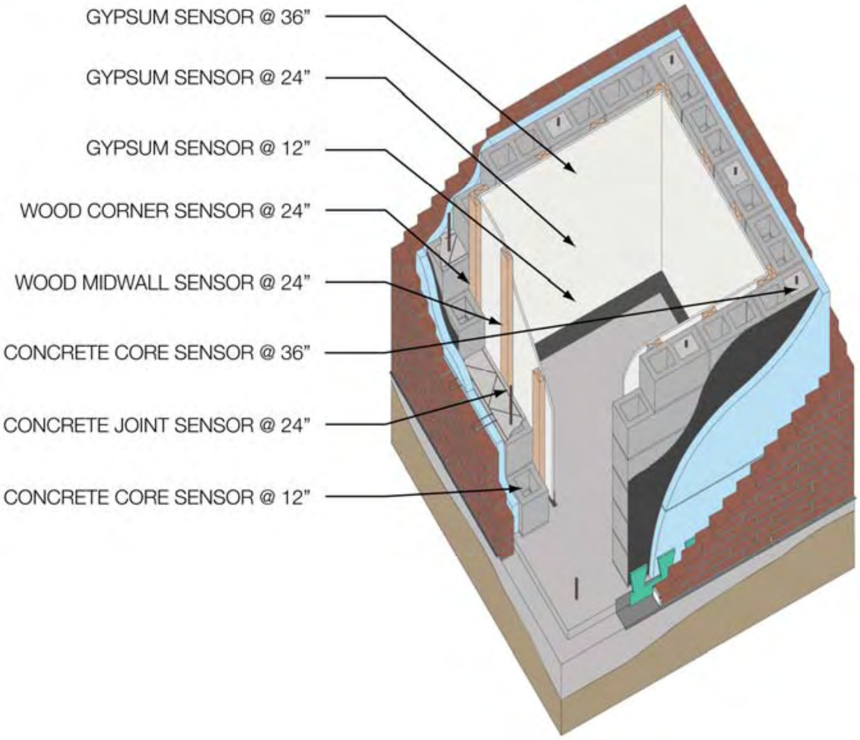


Fig. 4.29. DIAGRAM: Drying period test pod B: cavity wall, and sensor locations.

4.3.3.3 Mortar joints before and after flood simulation

Fig. 4.30 shows the data collected by sensors embedded in the mortar joints of three test pods for 24 hours before and after the flood simulation. The data collected from test pod A: sealed block shows that even though the test pod demonstrated interior depths compatible with dry floodproof construction, the cement-based products in the wall accumulated additional moisture during the flood simulation. Mortar joints in the other two test pods behaved similarly to each other. While in all cases an approximate increase of 15 percentage points is recorded after the flood simulation, in the case of materials which were fully submerged during the flood simulation, the mortar material reached a level of 100% moisture content. Data from sensors embedded in submerged materials showed the mortar material maintaining a 100% moisture content during the entire two-week drying period. It is unclear how long the drying period would have had to continue to record some amount of drying in these materials.

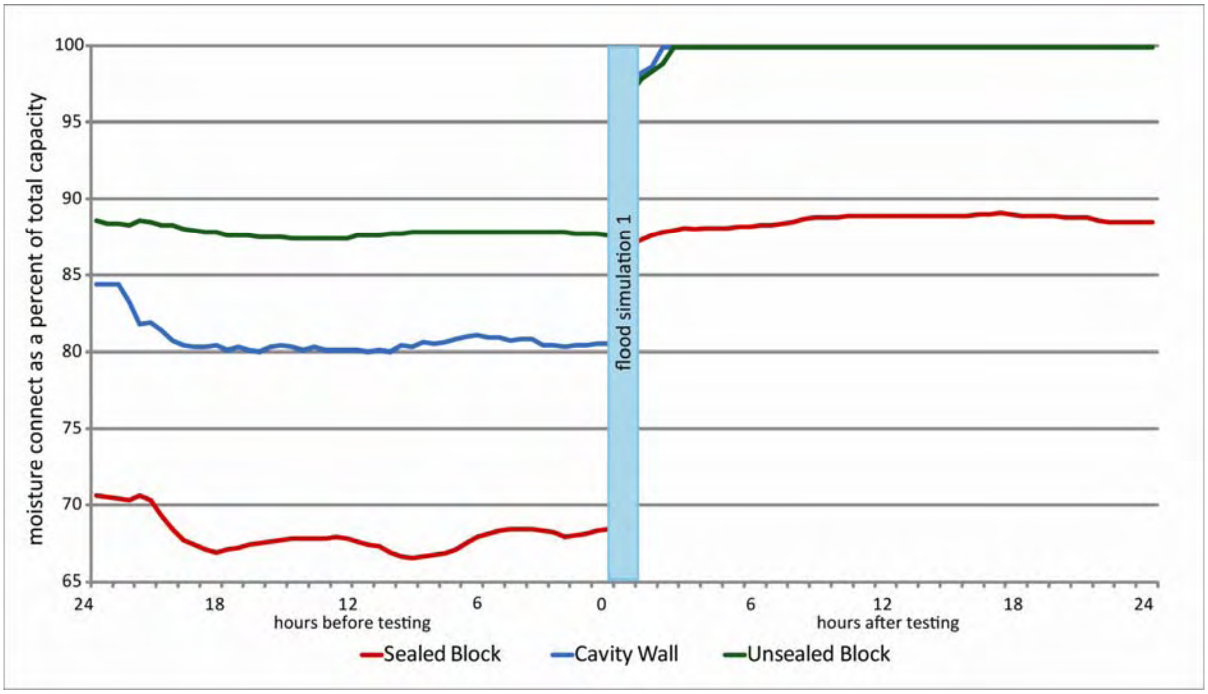


Fig. 4.30 GRAPH: Moisture levels in mortar: before and after flood simulation 1.

4.3.3.4 Drywall in all test pods before and after flood simulation

Data collected from five of the six test pods (test pod F: metal SIPs had no sensors embedded) shows that the gypsum products gained an average of 15% moisture content after flood simulation 1 (Fig. 4.31). Data also showed that the amount of moisture gain was not related to the length of time it took for the assembly to reach an interior depth of 36”. Sensors which recorded more than a 5% increase in moisture content where located below final interior depths. Sensors that reported less than a 5% increase were above the final interior depth. Data collected over the two-week drying period showed no significant drying of the gypsum. Material observations taken on-site indicated that gypsum boards which held 10-20% of moisture content were still intact, but had peeling paint. Test pod E: metal stud had gypsum board installed as the exterior sheathing of the structure. This gypsum board on the exterior had a moisture level of 80% after the flood simulation and had become crumbly and infirm.

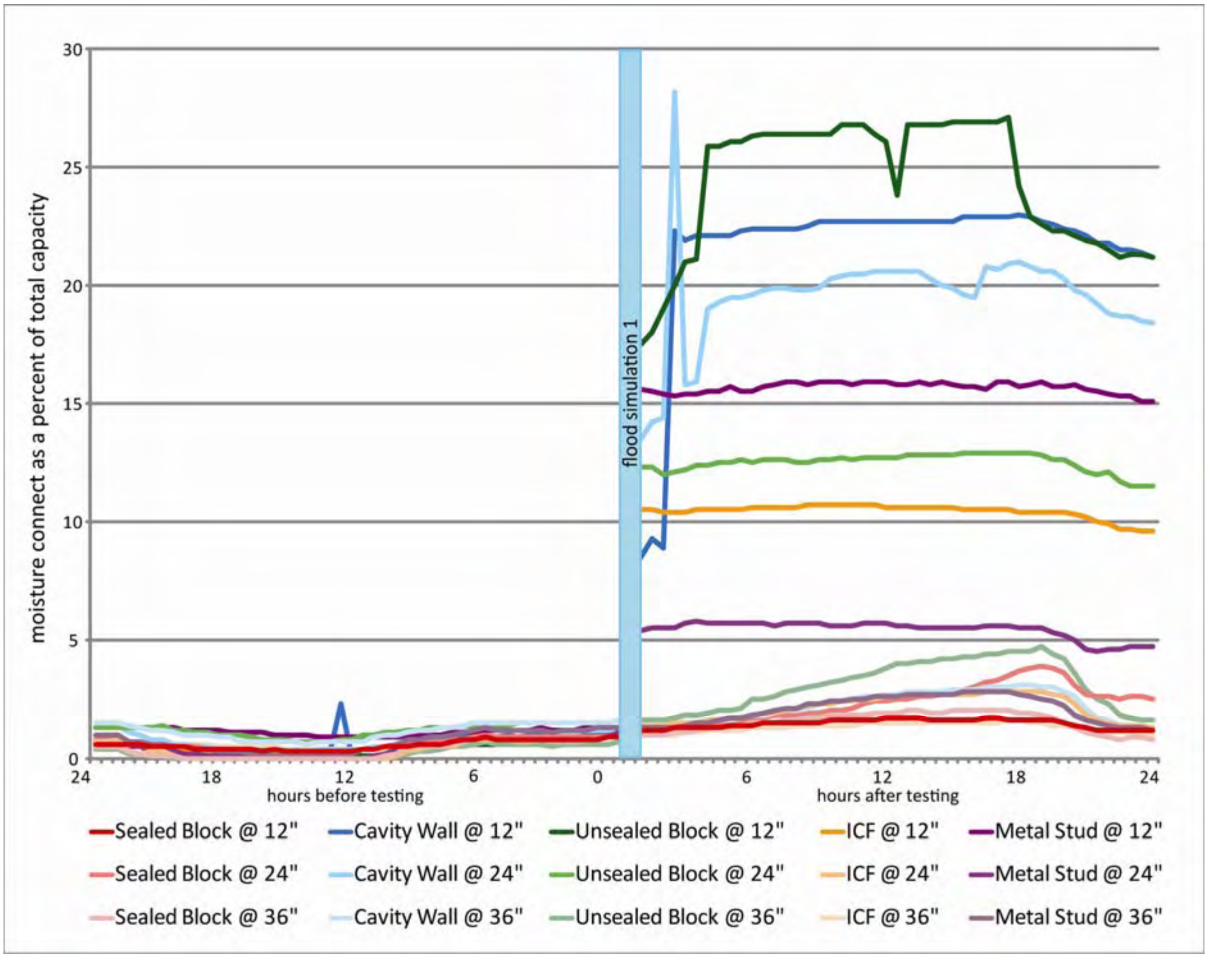


Fig. 4.31. GRAPH: Moisture levels in gypsum: before and after flood simulation 1.

4.3.4 Flood Simulation 2 Results

The following is a report of flood simulation 2, highlighting the significant events during the simulation. For a list of the test pods used in flood simulation 2, see Table 2 on page 48. Descriptions of these test pods can be found in Section 4.4 "Wall Sections and Material Choices". For the second flood simulation, the flood tank and test site were arranged the same as in the first simulation. Observation through the use of wireless sensors of the drying of assemblies was not performed after the second flood simulation; the primary goal of the second flood simulation was to test simple detail changes in the test pod assemblies to achieve dry floodproof performance. The gypsum board was removed from some of the assemblies so that moisture movement could be better observed in test pods B2, C2, and D2. The following is a condensed timeline for flood simulation 2. For a more complete report of the simulation see Appendix A: Observations and Data From Flood Simulations.

June 28th, 2011
7:45am –Flooding began
8:35am – Flood depth at 10", some seepage was observed in test pod G: sheet membrane block, test pod D2: ICF and test pod F: metal SIPs.
10:45am - Flood depth at 36", observations for 24 hour dry floodproof testing began. Test pod H: weatherproofed block had an interior depth of 1.5". Test pod B2: cavity wall filled block and test pod D2: ICF both had interior depths of 0.5". Test pod G: sheet membrane block and test pod F2: metal SIPs both had interior depths of .25". Test pod A: sealed block and test pod B2: cavity wall filled block had no measurable interior depths of water.
12:45pm – Test pod H: weatherproofed block had an interior depth of 6" (this is 2" above the 4" dry floodproof threshold). Test pod B2: cavity wall filled block had an interior depth of 2.25". All other test pods had interior depths of less than 1".
2:45pm – Test Pod B2: cavity wall filled block had 4" of interior depth.
3:45pm – Due to the consistent interior water depth in the test pods, observations were changed to two-hour time intervals.

June 29th, 2011
10:45am – After more than 24 hours of exposure to a 36" simulated flood, four of the test pods had maintained an interior depth low enough to be considered dry floodproof. Test pod A: sealed block had an interior depth of 0.25". Test pod G: sheet membrane block and test pod D2: ICF both had interior depths of 3.75". Test pod F2: metal SIPs had 0.5" of interior depth. At this time evacuation of the flood tank began.
1:45pm – 12" of flood depth remained. Interior depths of the test pods had remained the same as the previous log entry, except for test pod B2: cavity wall filled block and test pod H: weatherproofed block, which had slightly increased interior depths.
4:45pm – The flood tank was completely emptied. No changes were observed in flood depths from the previous log entry in any of the test pods.

Fig. 4.32 below shows the interior depths of water infiltration during the second flood simulation.

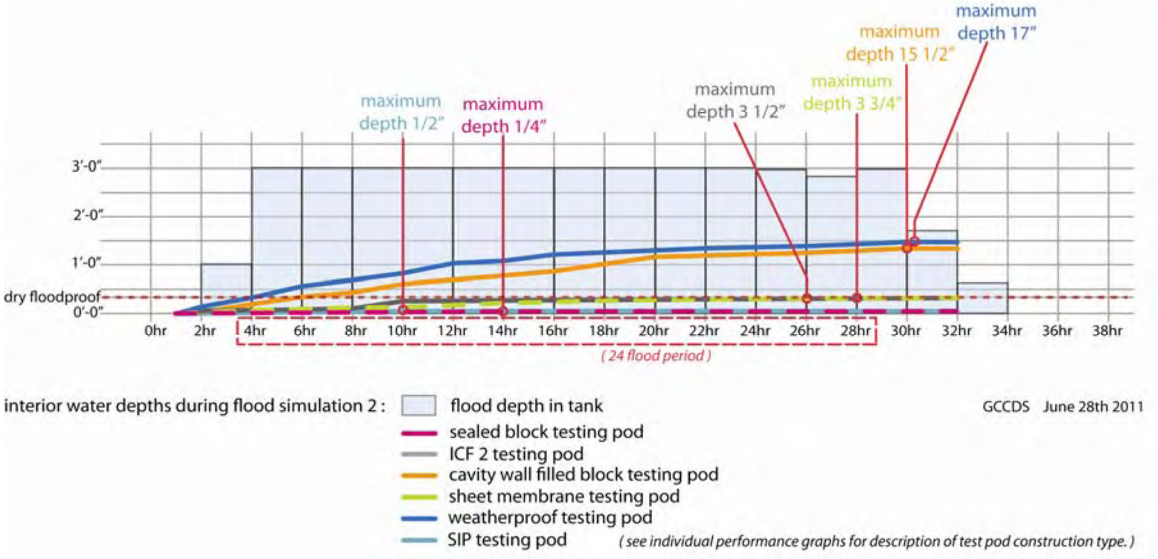


Fig. 4.32. GRAPH: Interior water depths, flood simulation 2.

4.3.4.1 Test pod A: sealed block

Test pod A: sealed block performed as well during the second flood simulation as it did during the first simulation (Fig. 4.33). The assembly of this pod was exactly the same during both flood simulations. The layered polymer membrane of the exterior coating was beginning to show bubbling and discoloration prior to flood simulation 2, likely due to prolonged exposure to ultraviolet light between flood simulations. However, this did not seem to affect performance of the assembly.

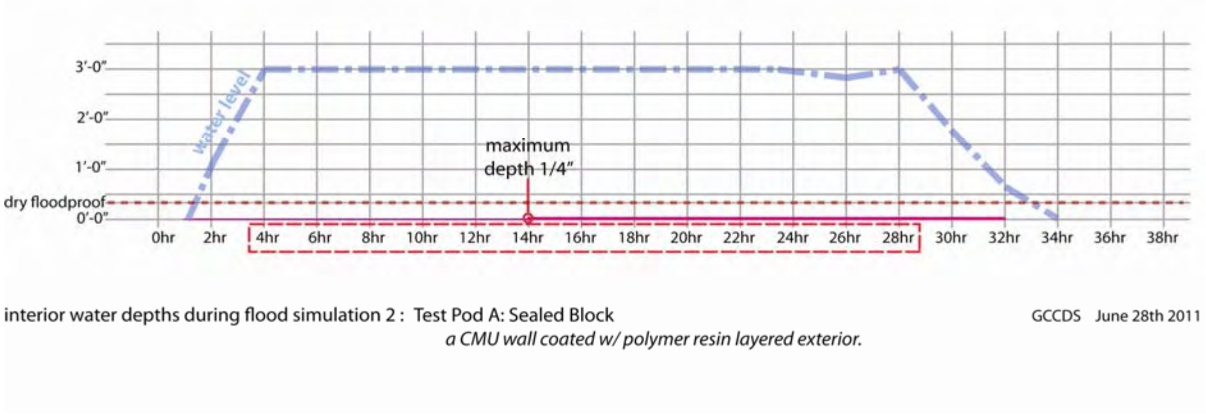


Fig. 4.33. GRAPH: Interior depths: test pod A: sealed block, flood simulation 2.

4.3.4.2 Test pod G: sheet membrane block

Test pod G performed well enough during flood simulation 2 to be considered a viable option for dry floodproofing, as shown in Fig. 4.34. The increase in dry floodproof performance can be attributed to the impermeability and consistent coverage of the self-adhering rubberized asphalt/polyethylene membrane sheet.

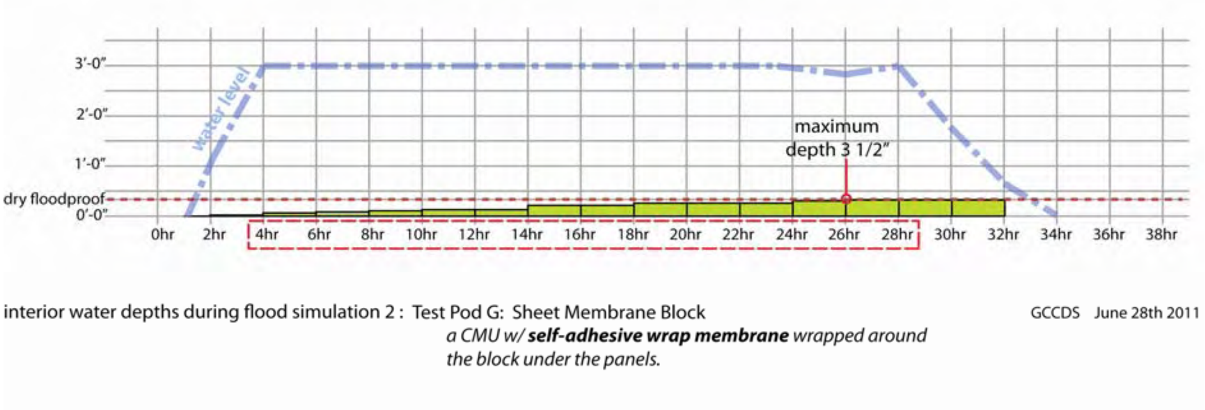


Fig. 4.34. GRAPH: Interior depths: test pod G: sheet membrane block, flood sim. 2.

4.3.4.3 Test pod H: weatherproofed block

During the early hours of flood simulation 2, test pod H: weatherproofed block had an interior depth greater than 4" (Fig. 4.35) . While not considered dry floodproof, the test pod did show a degree of resistance to flood water. The maxium interior water depth of 17" was a significant improvement over the previous results of test pod C: unsealed block in flood simulation 1. The two test pods had similar assemblies; however test pod H: weatherproofed block had an elostameric coating sprayed on the exterior.

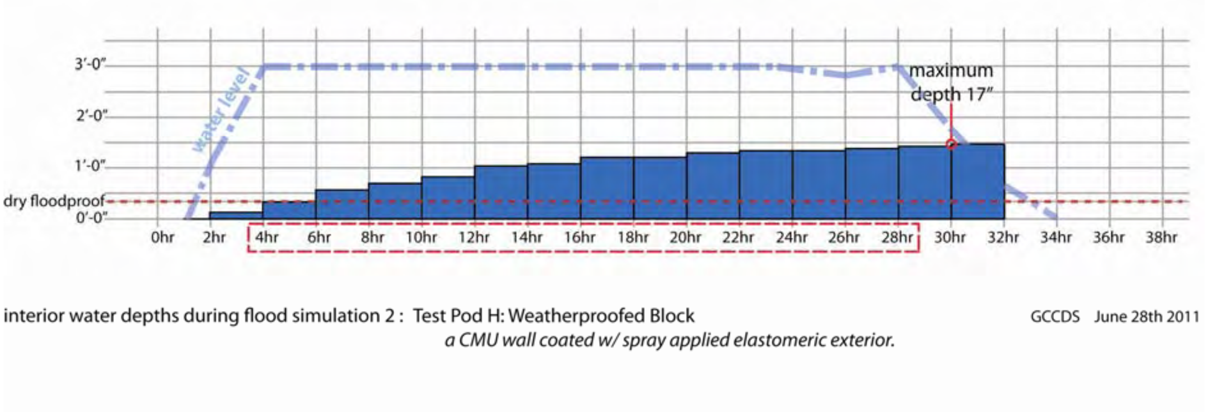


Fig. 4.35. GRAPH: Interior depths: test pod H: weatherproofed block, flood sim. 2.

4.3.4.4 Test pod B2: cavity wall filled block

Test pod B2: cavity wall filled block allowed 13″ of interior depth to accumulate during the 24 hour dry floodproof test period, with a maximum depth of 15.5″ of interior depth that was reached after the flood tank began to drain (Fig. 4.36). These results showed significant improvement over the results of test pod B: cavity wall during the first flood simulation. The only difference between the two assemblies was the addition of continuous grout fill in each CMU cell in test pod B2: cavity wall filled block.

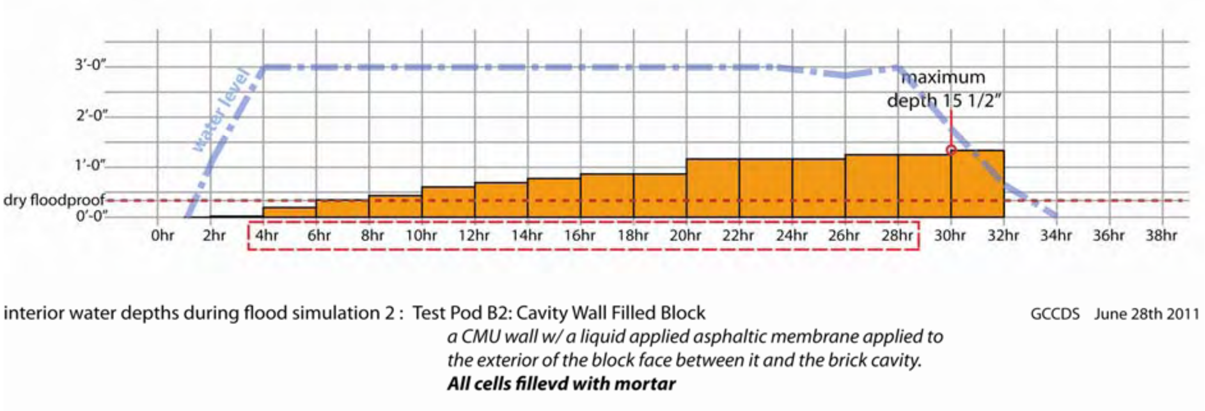


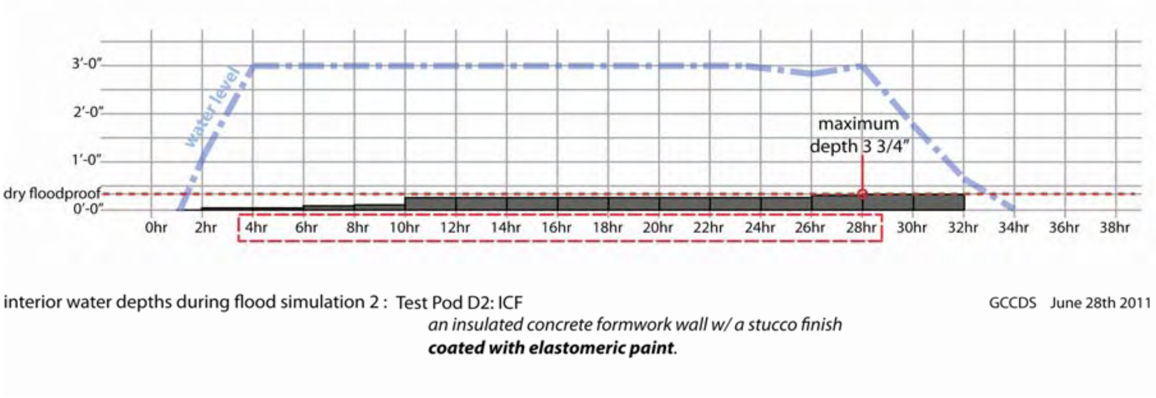
Fig. 4.36. GRAPH: Interior depths: test pod B2: cavity wall filled block, flood sim. 2.

Throughout the second flood simulation, water was observed collecting on several interior faces of the CMU wall, as shown in Fig. 4.37. This accumulation of water was more evident on CMU blocks where cells which had been previously filled for flood simulation 1, rather than those cells which were filled as part of the assembly revisions in flood simulation 2. Despite the improvement in performance in flood simulation 2, this assembly is not a viable option dry floodproofing.

Fig. 4.37. PHOTO: Water seeping into test pod B2: cavity wall filled block, flood sim. 2.

4.3.4.5 Test pod D2: ICF

Test pod D2: ICF resisted water penetration well enough during the 24-hour test period in flood simulation 2 to be considered a viable option for dry floodproof construction (Fig 4.38). With the addition of an elastomeric paint applied to the exterior surface of the assembly, water penetration during the second flood simulation decreased over 50% from the first flood simulation. It is likely that the water which did accumulate on the interior of the test pod during flood simulation 2 was the result of seepage around the base of the wall or through the foundation slab. Further detailing of this joint could potentially reduce the amount of water penetration.



interior water depths during flood simulation 2 : Test Pod D2: ICF

GCCDS June 28th 2011

an insulated concrete formwork wall w/ a stucco finish
coated with elastomeric paint.

Fig. 4.38. GRAPH: Interior depths: test pod D2: ICF, flood simulation 2.

4.3.4.6 Test pod F2: metal SIPs

Test pod F2: metal SIPs was very resistant to the penetration of water during flood simulation 2. By securely fastening the SIPs with screws to the base channel, buoyancy forces were kept from stressing the caulk, maintaining a water-tight seal. With a maximum interior depth of 0.25″ (Fig. 4.39), this wall assembly improved from one of the lesser performing test pods in flood simulation 1 to one of the better performing test pods in flood simulation 2.

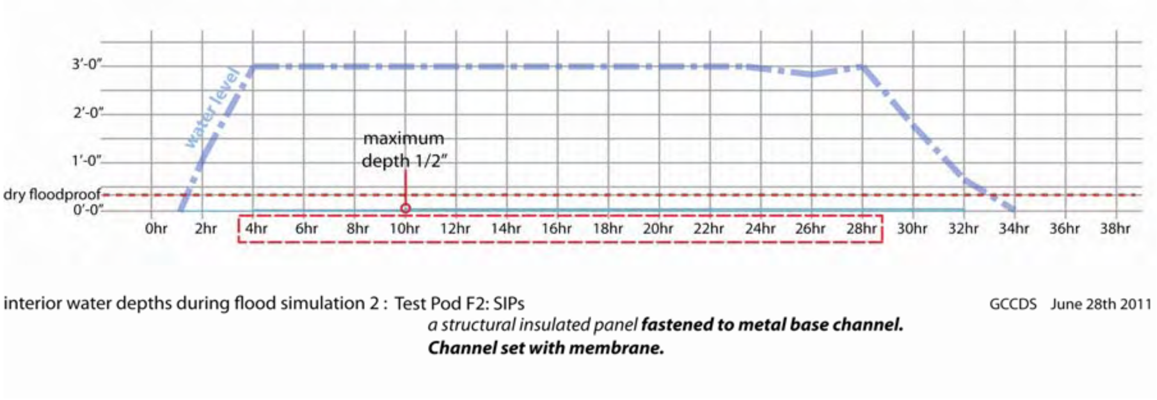


Fig. 4.39. GRAPH: Interior depths: test pod F2: metal SIPs, flood simulation 2.

4.4 Summary of Results

Of the eleven wall assemblies tested, four allowed less than 4″ of water to accumulate over a 24-hour flood simulation. Using the USACE standards referenced in the beginning of this chapter (USACE Document EP1165-2-314 *Flood Proofing Regulations*), these four wall assemblies would be viable options for a dry floodproof building: test pod A: sealed block, test pod D2: ICF, test pod F2: metal SIPs and test pod G: sheet membrane block.

4.4.1 Protection of Joints Between Materials

During flood simulation 1, water was observed and recorded moving within the wall assembly through gaps in the mortar joints. It could not be observed specifically how the water had entered into the CMU wall, but it may have been through the same type of gap on the exterior face of the wall. This water movement was different during the second flood simulation when test pod B2: cavity wall filled block had all CMU cells filled with grout. During the second flood simulation, water was observed seeping through the CMU faces of the wall. It is unclear if this was happening because CMU cells had been filled or if the CMUs had been damaged during the first flood simulation. One conclusion based on these observations is that fewer joints in an assembly lead to better hydrostatic resistance. However wall assemblies with solid concrete fill did not provide enough resistance to hydrostatic pressure without an additional water resistive membrane, as shown in test pod B2: cavity wall filled block and test pod D: ICF.

4.4.2 Consistency of Coverage

When comparing the performances of test pod B: cavity wall and test pod G: sheet membrane block, the importance of a consistent coverage of a membrane becomes apparent. In test pod B: cavity wall, which had a flood resistive material brushed on, the resistance to flood water was marginally better than an unprotected block assembly as observed in test pod C: unsealed block. Test pod G: sheet membrane block was coated in a similar material to test pod B, but with a consistent depth it performed much better. Test pod H: weatherproofed block, which had a sprayed weatherproof coating, did not perform to dry floodproof standards. However, it did perform better than test pod B: cavity wall which was a similar structure to test pod H, but with a different flood resistive membrane material and application.

4.4.3 Designing Redundancy

Within the testing, the difference between critical failure and minor infiltration was the presence of redundancy within an assembly. In the same way that one designs structural redundancy to prevent failure, a good way to mitigate failure due to substandard installation of a product is to design a wall assembly with redundancies. Test pod A: sealed block, test pod D: ICF, and test pod D2: ICF are good examples of a multi-layered assembly. Unfortunately, system redundancy cannot compensate fully for sub-standard construction; as a result it is paramount that quality is controlled through diligent construction administration practiced on site during the installation of dry floodproof systems. The affects of inconsistencies in dry flood proof construction can be more critical than in other construction systems.

5. IMPLICATIONS FOR MIXED-USE BUILDINGS

The GCCDS worked with the BHA to identify a prospective site and program for the development of a sample mixed-use building in Biloxi, Mississippi. Using this identified site and program, the GCCDS designed a sample mixed-use building to fit the parameters of the site, taking into consideration zoning, parking, landscaping, and massing within the neighborhood context. The building was designed to meet the City of Biloxi floodplain management ordinance, along with applicable building code requirements. The process of designing a sample building was used to integrate knowledge gained from earlier research presented in Chapters Two, Three, and Four of this report, regarding regulatory and technical feasibility of dry floodproof construction. Additionally, the process of designing a sample building provided further research of the economic and insurance implications of dry floodproof construction, in areas such as construction methods, cost premiums, insurance coverage and building operations.

5.1 Mixed-Use Buildings

The sample building demonstrates a conventional mixed-use building arrangement with accessible commercial units located on the lowest ground level and residential units located above on the upper floors. The combination of residential and commercial units within the same building creates an opportunity for the developer to offset the added costs of dry floodproof commercial construction by providing supplemental income through the sale or rental of the residential units, which may have lower construction costs (per square foot) than the premium costs for commercial units located within the flood plain. In this design each use (commercial and residential) was given its own entrance to allow the design team to investigate the urban design challenges of integrating a multiple entry dry floodproof building into an existing commercial corridor.

5.2 Site Considerations

The site chosen for the sample mixed-use building is located on Division Street in East Biloxi and was selected for a number of reasons:

a) The site lends itself well to the integration of dry floodproofing with a grade-and-fill strategy to meet the BFE requirements (See Fig. 5.1)
b) The location of the site is within an existing commercial corridor that has been targeted for redevelopment. A mixed-use building would serve as much needed infill development along Division Street.
c) The site is already zoned for both commercial and residential use.
d) The site is large enough to accommodate a building to include dry floodproofing and elevation mitigation strategies, as well as accessible elevated walkways (see Chapter 3.2.2- Combining Flood Risk Mitigation Strategies).

e) The site is currently owned by the BHA, which acts as both a property manager and a developer. The collaboration between the GCCDS and the BHA draws on both agencies' existing partnerships to bring many parties into the conversation surrounding the design and economic feasibility of dry floodproof buildings.

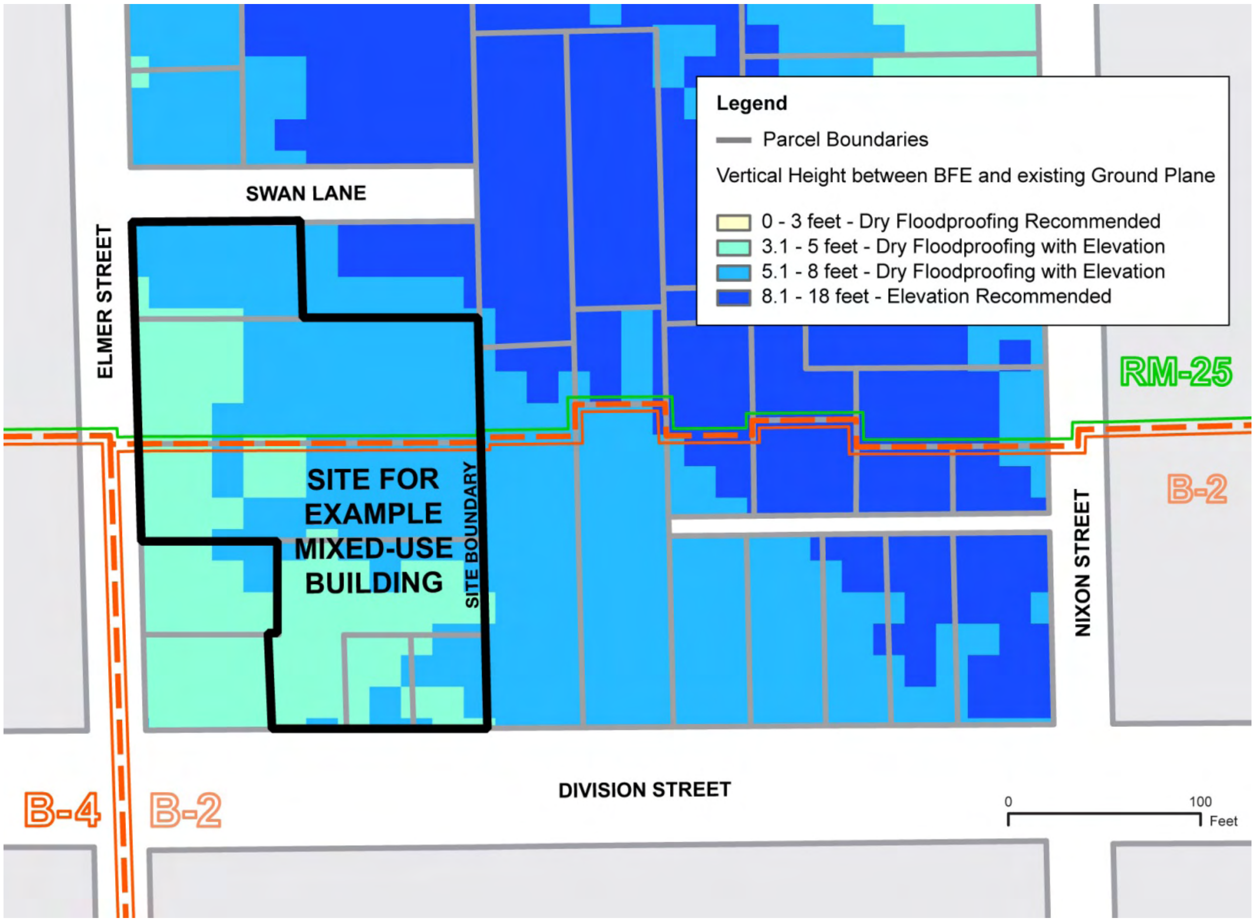


Fig. 5.1. DIAGRAM: Map of sample site with recommended mitigation strategies.

The site plan for the sample mixed-use site (Fig. 5.2) focuses on integrating the street level with all entrances to the building. An at-grade walkway allows for access through the site, connecting the rear parking to the commercial and residential entrances. Residents have a separate entrance from the commercial spaces to make it easier to secure the separate sections of the building during different times of day and night. A special hazard egress was combined with the service entrance in the back of the commercial space to allow emergency exit from the building above the extent of dry floodproofing.

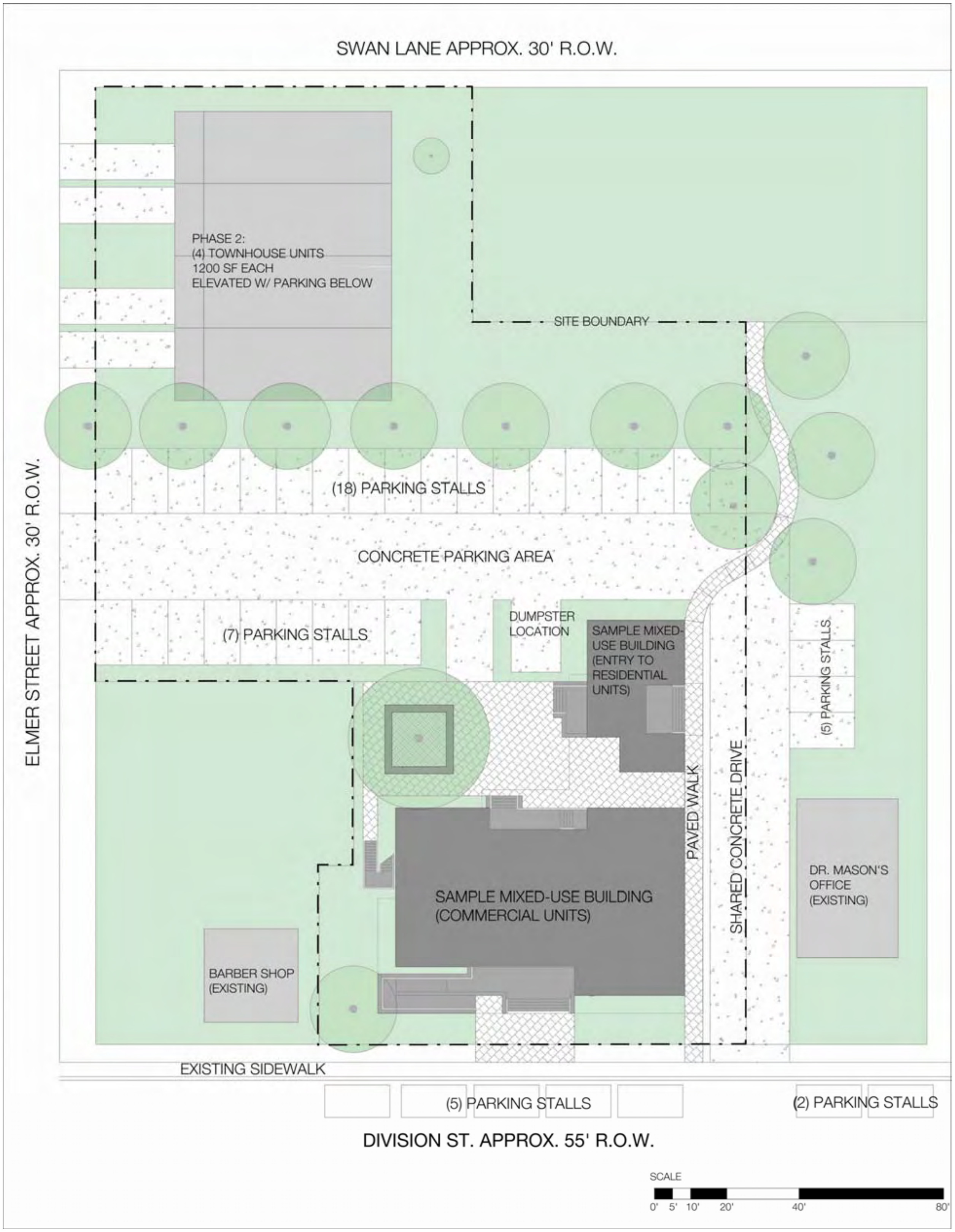


Fig. 5.2. DIAGRAM: Site plan for sample building.

5.3 Programming

The sample building is a three-story mixed-use building. The first floor is made up of three similar commercial units (Fig. 5.3). The upper two floors are occupied by a variety of studio, one- and two-bedroom rental units, with a total of 20 residential units. See Table 3 below for building program.

Table 3. Building program

Division Street Floodproof Construction Mixed-Use Building								
First Floor [Commercial]: 4417 sf	area (sf)	quantity	total area		First Floor [Res. Amenities]: 1182 sf	area (sf)	quantity	total area
Commercial A	744	1	744		Stairwell	164	1	164
Commercial B	542	1	542		Elevator	39	1	39
Commercial C	871	1	871		Lobby	125	1	125
Storage A	129	1	129		Office	145	1	145
Storage B	112	1	112		Laundry	167	1	167
Storage C	198	1	198		Restroom	40	1	40
Restrooms	74	2	148		Corridor	39	1	39
Corridor	193	1	193		Exterior Entrys	131-143	2	274
Exterior Entry North	620	1	620					
Exterior Entry South	195	1	195					
Mechanical Room	245	1	245					
		program area	*3997*				*program area*	*993*
Second Floor [Residential]: 5700 sf	area (sf)	quantity	total area		Third Floor [Residential]: 5700 sf	area (sf)	quantity	total area
Stairwells/Lobby	379	2	379		Stairwells/Lobby	379	2	379
Corridor	465	1	465		Corridor	465	1	465
Studios	269-283	5	1373		Studios	269-283	5	1373
1 Bedrooms	509-580	4	2173		1 Bedrooms	509-580	4	2173
2 Bedroom	696	1	696		2 Bedroom	696	1	696
		program area	*5086*				*program area*	*5086*
Total Floor Area: 17,000 sf								

The front entrances for the three commercial units are located on a raised (3’ above existing grade) patio with direct access to the sidewalk. Interior back entrances from each commercial unit provide access to a set of shared restrooms, storage closets, and an elevated mechanical room with egress elevated above the extent of dry floodproofing. The FFE of the special hazard egress is required to be above the limit of dry floodproof construction, per dry floodproof regulations stated in ASCE 24 Section 6.2.2. Secured residential entrances along with service spaces for the residential units are located on the first floor, although separated by an outdoor breezeway from the commercial units. The program for residential service area does not include any living spaces; only support spaces such as a shared laundry room, a lobby with mailboxes and a leasing office. (Fig. 5.3)

The upper floors of the building were included in the cost estimates, but the layout and design were not substantially influenced by the inclusion of dry floodproof construction in the design of the lower commercial level. However, the upper floors were designed to accommodate affordable rental units, potentially to meet the needs of elderly tenants. The sizes of the residential units were determined by an existing unmet need within the East Biloxi community for affordable studio and one-bedroom multi-family housing units.

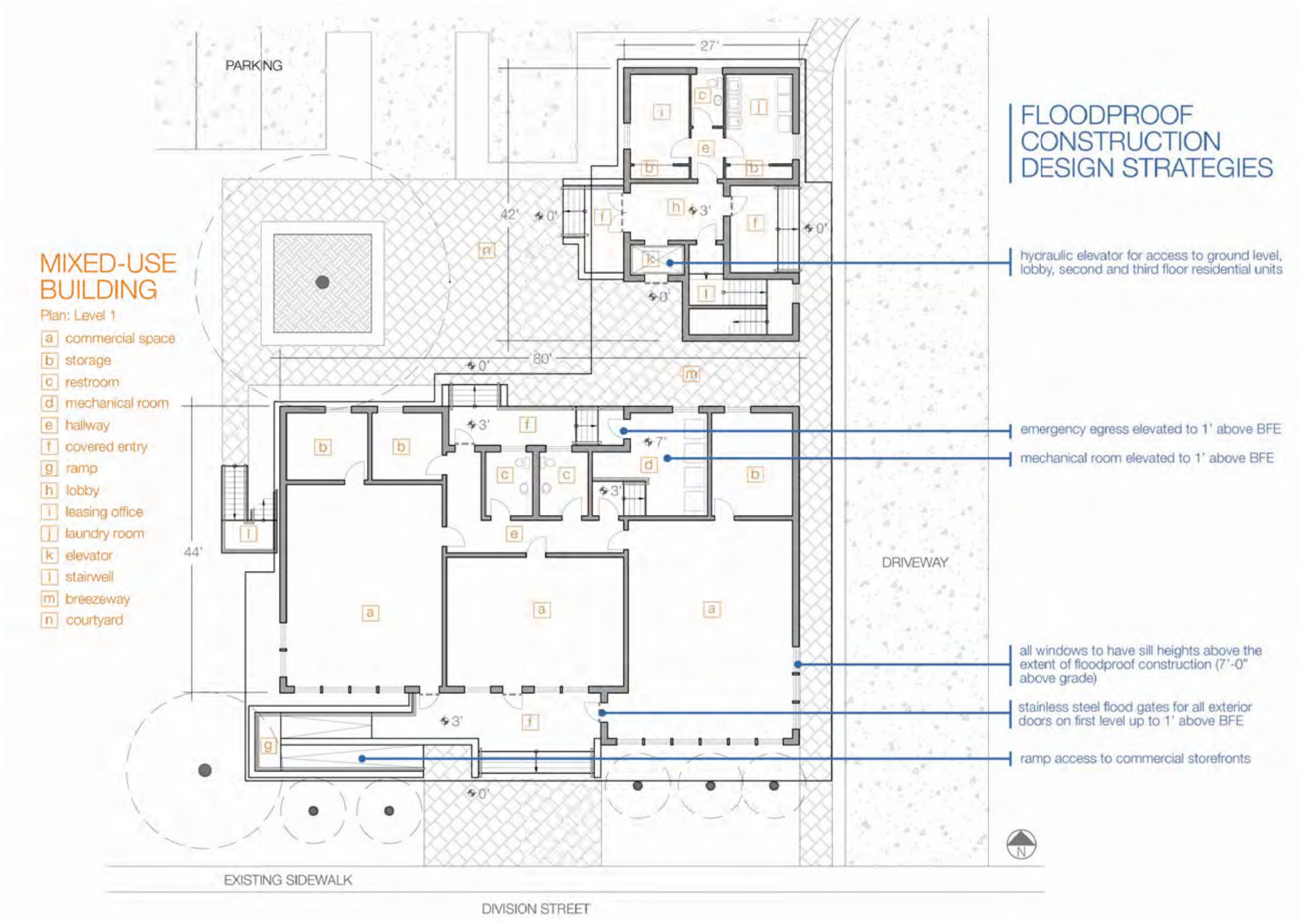


Fig. 5.3. DIAGRAM: First floor plan for sample building.

5.4 Dry Floodproof Construction Details

The construction details designed for the dry floodproof perimeter wall in the sample mixed-use building were determined by synthesizing the demonstrated performances of a variety of test pods observed through the material and assembly research presented in Chapter Four. As shown in Figure 5.4, the dry floodproof perimeter wall extends to 7′ above the existing ground plane, which is 1′ above the BFE. The finished floor of the first level is elevated 3′ above the ground plane on a concrete slab supported by structural fill.

Fig. 5.4. DIAGRAM: Front (south) and side (east) elevations for sample building.

The foundation wall is a reinforced monolithic wall with a continuous footing, protected by a polyethylene vapor barrier. The location of this foundation wall is shown in Fig. 5.5.

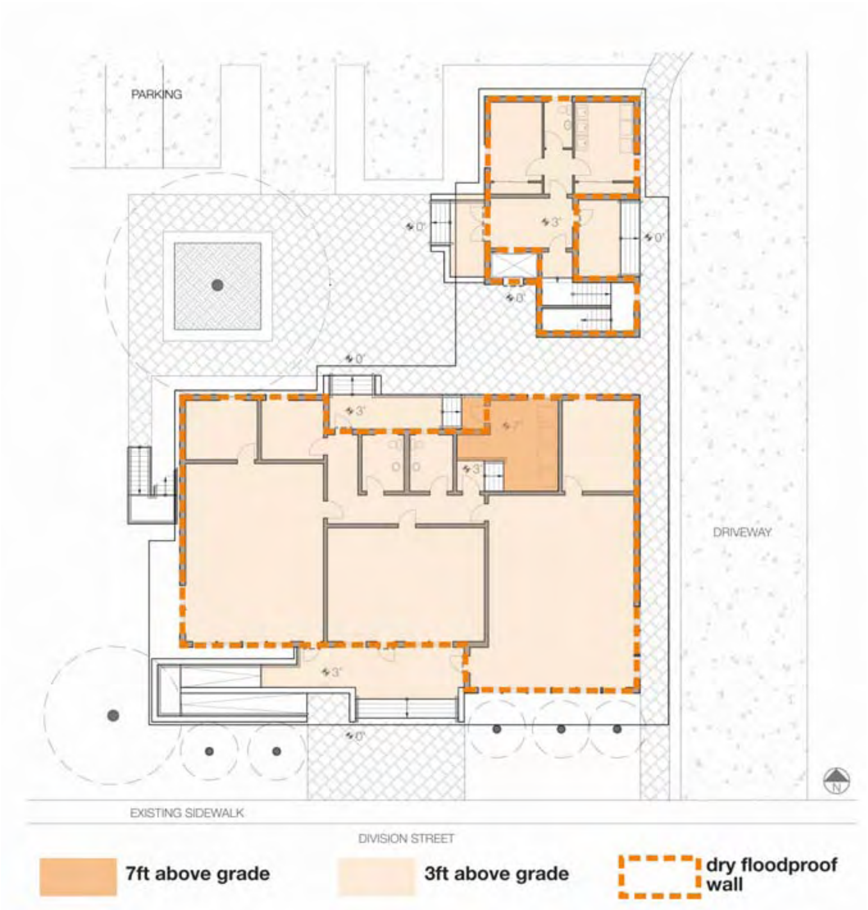


Fig. 5.5. DIAGRAM: Dry floodproof construction, first floor, sample building.

Fig. 5.6 shows the entire cross section of the first floor exterior wall of the building. The exterior wall for both the first level and the upper levels is a reinforced CMU block wall. Up to the extent of dry floodproofing, the wall has a multi-layered polymer membrane coating (two layers of silicone modified polyurea sandwiching 2” of closed-cell spray foam), acting as the waterproofing membrane (as tested with test pod A: sealed block). An air space separates the exterior of this membrane from a brick wall, which is tied back to the CMU wall with truss mesh ties. Similar to test pod B: cavity wall, this wall system has a mortar deflection system and polypropylene weep vents to allow proper drainage at the base of the wall.

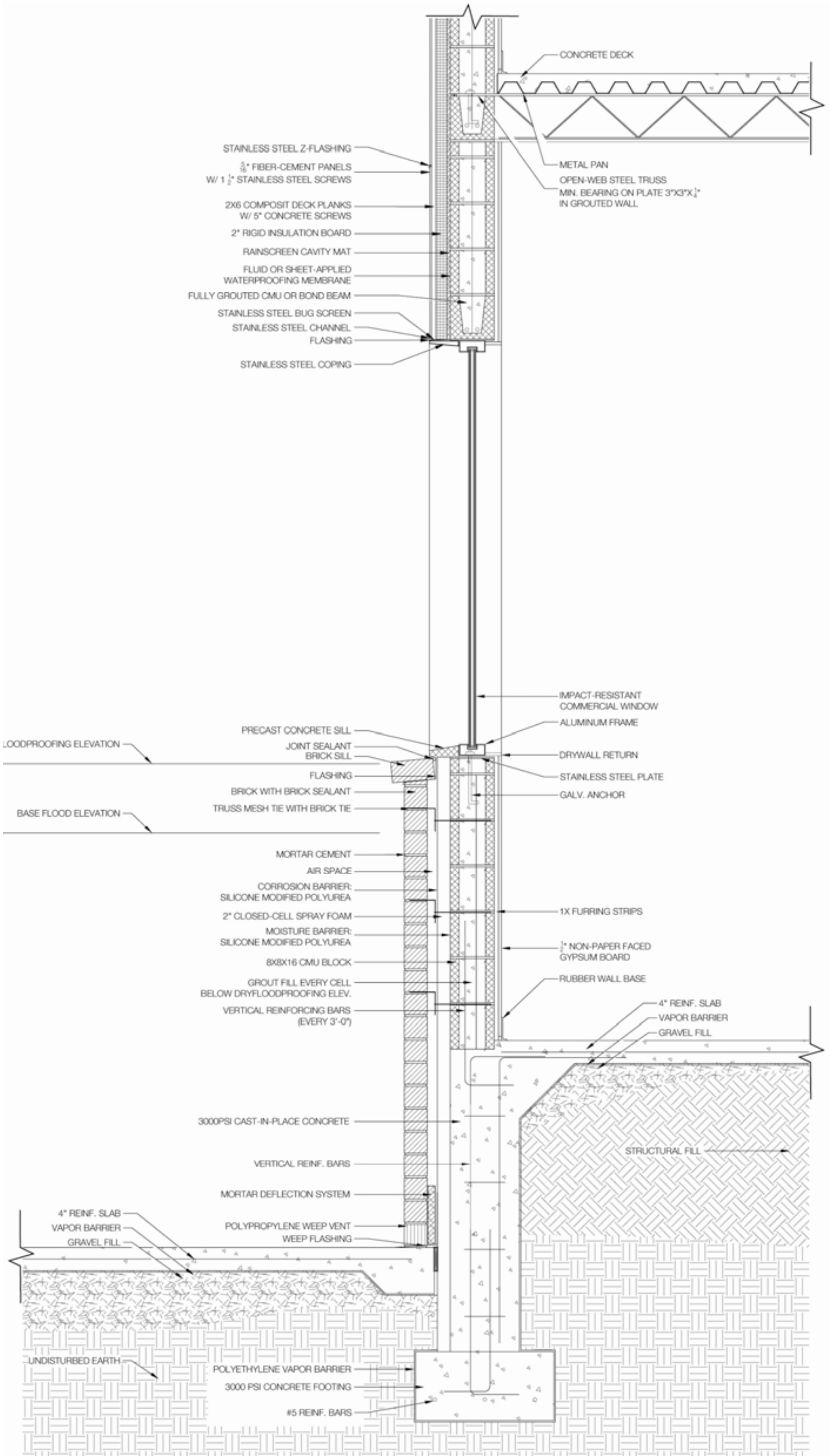


Fig. 5.6. DIAGRAM: Wall section for sample building.

5.5 Building Cost and Premiums

When building a dry floodproof building, there are certain premiums above those found in typical commercial construction. Some, like the cost of the perimeter floodproof wall are more obvious, but there are other considerations that are both dependent and independent of site choice. Dependent factors to consider include insurance and the cost of grade-and-fill to accomplish the necessary elevation. An example that is independent of site conditions would be the added cost of required egress above the dry floodproof elevation.

5.5.1 Dry Floodproofing Costs

The cost estimate of floodproofing the sample building envelope includes additional costs for both the premium wall materials to be used within the flood plain (such as the multi-layered polymer membrane) and flood shields for exterior door openings located below the BFE. In the sample building design, all windows were placed above the BFE to reduce the need for flood shields over window openings. This sample building has seven doors located below the BFE which would each need a flood shield. The additional cost estimate for building the perimeter wall in the sample building to dry floodproof standards would be $150,000. The additional cost estimate for providing flood shields for the exterior door openings in the sample building would be $50,000.

In Table 4, the total cost of meeting dry floodproof construction standards is estimated to be approximately 15% of the total budget for the project.

Table 4. Cost Estimate for sample building.

Mixed-Use Building Cost Estimate						
Name	Base Cost	%Total	Dry Cost	% Total	Total Price	Total %
SUBSTRUCTURE						
Foundation	87,500	14.2%	30,000	4.9%	117,500	19.1%
Dampproofing/Water Proofing	10,000	1.6%			10,000	1.6%
Total SUBSTRUCTURE						
SHELL						
Superstructure	300,000	48.7%			300,000	48.7%
Exterior Enclosure: Unsealed Block	270,000	43.8%			270,000	43.8%
Exterior Enclosure Options: Dry Floodproofing						
Sealed Block			*150,000*	*24.3%*	*150,000*	24.3%
Windows & Doors	200,000	32.4%			200,000	32.4%
Total SHELL						
INTERIORS						
Commercial Interiors	100,000	16.2%	15,000	2.4%	115,000	18.7%
Commercial Finishes	60,000	9.7%	30,000	4.9%	90,000	14.6%
Residential Interiors	200,000	32.4%			200,000	32.4%
Residential Finishes	100,000	16.2%			100,000	16.2%
Total INTERIORS						
SERVICES						
Mechanical	300,000	48.7%	40,000	6.5%	340,000	55.2%
Electrical	250,000	40.6%	20,000	3.2%	270,000	43.8%
Plumbing	200,000	32.4%	50,000	8.1%	250,000	40.6%
Fire Alarm & Supression	30,000	4.9%			30,000	4.9%
Elevator	100,000	16.2%	30,000	4.9%	130,000	21.1%
Total INTERIORS						
EQUIPMENT & FURNISHINGS						
Equipment & Furnishings	100,000	16.2%	10,000	1.6%	110,000	17.8%
Total EQUIPMENT & FURNISHINGS						
SPECIAL CONSTRUCTION						
Stairs & Ramps and Exterior Decks	150,000	24.3%	50,000	8.1%	200,000	32.4%
Flood Shields			50,000	8.1%	50,000	8.1%
Total SPECIAL CONSTRUCTION						
SITEWORK						
Sitework & Improvements	75,000	12.2%	75,000	12.2%	150,000	24.3%
Total SITEWORK						
PROJECT SUBTOTALS	2,532,500	410.8%	550,000	89.2%	3,082,500	500.0%
General Conditions (20%)	616,500				616,500	
		PROJECT TOTAL			**$3,699,000**	

Table 5 shows the costs of construction using other assemblies which performed well during the flood simulations as the dry floodproofing method for the sample mixed-use building. The average cost of the dry floodproofing components across the various assemblies was approximately $455,000, or 12.75% of the total budget for the project.

Table 5. Cost Estimates for sample building using alternative construction types.

PROJECT TOTALS (Dry Floodproofing Options)							
	Base Cost	%Total	Dry Cost	% Total	Subtotal Price	General Conditions	% Total
Sealed Block	2,532,500	68.5%	550,000	14.9%	3,082,500	616,500	20.0%
						PROJECT TOTAL	**$3,699,000**
Sheet Membrane Block	2,532,500	71.2%	430,000	12.1%	2,962,500	592,500	20.0%
						PROJECT TOTAL	**$3,555,000**
ICF	2,487,500	70.9%	435,250	12.4%	2,922,750	584,550	20.0%
						PROJECT TOTAL	**$3,507,300**
SIP	2,487,500	71.7%	404,000	11.6%	2,891,500	578,300	20.0%
						PROJECT TOTAL	**$3,469,800**

Beyond the cost of construction of a dry floodproof wall system and the cost of installation of flood shields, there are several other cost premiums for bringing the entire building up to dry floodproof standards. The additional requirements discussed in the next sections are based on the City of Biloxi floodplain ordinance and may not be directly applicable in other municipal jurisdictions.

5.5.2 Grade-and-Fill Costs

A strategy combining dry floodproofing and grade-and-fill methods is used for the sample mixed-use building on the Division Street site (Fig. 5.6). This combination allows the building to meet the City of Biloxi regulation limiting dry floodproofing to 3′ below the BFE on a site that has an existing grade of 6′ below the BFE. The sample mixed-use building designed on this site required three feet of grading and fill, which accounted for approximately $120,000 (nearly three percent) of the total project budget.

5.5.3 Utility and Egress Costs

In addition to the increased costs of wall and foundation construction, there are cost premiums associated with the egress and utility requirements of a dry floodproof building. ASCE 24-05, *Flood Resistant Design and Construction* contains standards for the construction of these systems. While these costs are not as significant as those associated with the wall and foundation construction, they are important to be aware of because they do not correspond to the size of the building. These additional premiums would be required in any dry floodproof building, regardless of the size or program.

The ASCE regulations outlined in *Flood Resistant Design and Construction* pertaining to egress and utilities are as follow:

> 7.1: "Utilities and attendant equipment shall not be located below the elevation specified [BFE + 1'] unless...designed, constructed, and installed to prevent floodwaters, including any backflow through the system, from entering or accumulating within the components."
>
> 6.2.2: "Dry floodproofed areas of structures shall...have at least one door satisfying building code requirements for an exit door or primary means of escape, above the applicable elevation specified [BFE + 1'] …and capable of providing human ingress and egress during the design flood."

In the sample mixed-use building, the decision was made to keep utilities and equipment above the BFE. The cost reflected in the estimate includes backflow prevention, which does not add significant cost to the overall system. In order to achieve the elevated egress required, $45,000 was added to the cost estimate. Fig. 5.7 shows the circulation of egress on the first floor for the sample building (black dashed lines) and the location of the elevated egress (red line).

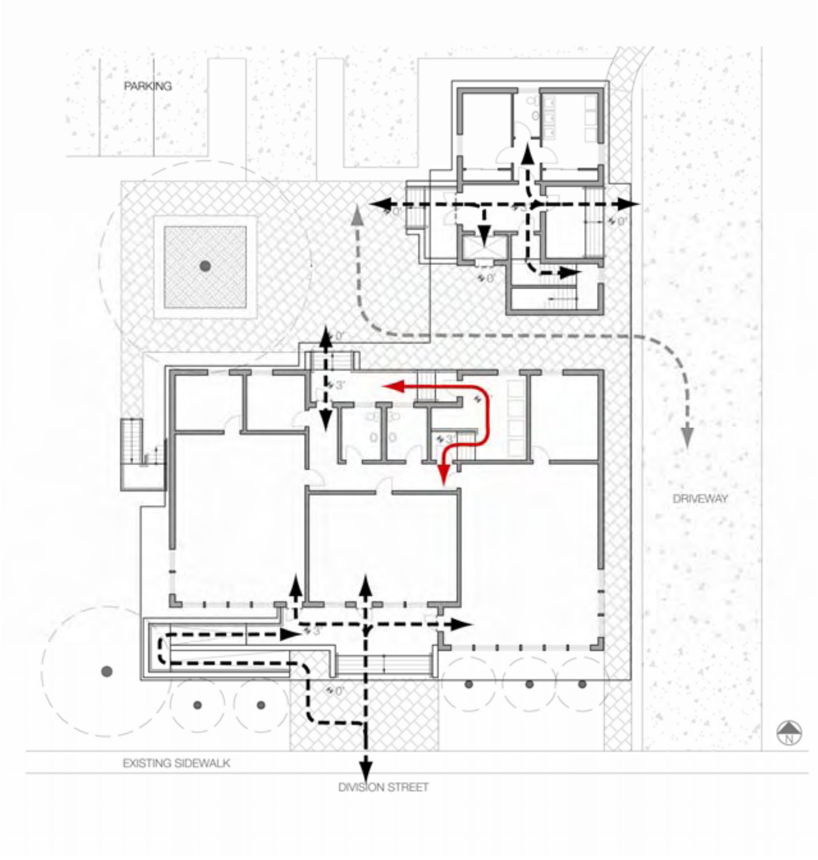


Fig. 5.7. DIAGRAM: Means of egress with egress above dry floodproof construction (red).

5.6 Insurance Considerations

Flood insurance is a requirement for any building located within a floodplain in a community participating in the NFIP. A certified dry floodproofed building is able to be insured with the same rates as a building built with a finished floor just above the BFE. There are no unique rates or penalties for dry floodproof buildings in comparison to elevated buildings.

5.6.1 Insurance Limits

The maximum coverage for a dry floodproofed commercial building insured through the NFIP is $500,000. If a building is worth more than this maximum, many lenders will require the owner to get a secondary insurance policy to cover the difference. Unfortunately, as has been the case during the investigation of potential flood insurance scenarios, learning from local providers along the Mississippi Gulf Coast has been difficult. Local providers are not involved at the level of floodproof construction policy, which is mandated by the NFIP. NFIP "rates are set and do not differ from company to company or agent to agent… [they] depend on several factors including the date and type of construction of your home, along with your area's level of risk" (NFIP, 2011). While a mixed-use development may be profitable, issues of coverage could be an obstacle, as most developments likely are worth more than the $500,000 maximum coverage offered by the NFIP.

5.6.2 Beyond Code

A research goal explored through the design of the sample mixed-use building was to find ways to reduce insurance premiums through construction methods which are more robust than those required by code.

One program given consideration was the Insurance Institute for Business & Home Safety's (IBHS) FORTIFIED building program. The program incentivizes building beyond the local code requirements to strengthen the shell of the building "to increase a new home's resistance to natural perils" (IBHS, 2011). Certification in the program is accompanied by a reduction in insurance premiums through wind-pool insurance. Currently the IBHS is expanding beyond their FORTIFIED for Safer Living program which focuses solely on new single-family residential construction to develop a similar program: FORTIFIED for Safer Business.

The aim of the new program is to "greatly increase a new light commercial building's durability and resilience to natural hazards prevalent in the area where it's being built" (IBHS, 2011). Unfortunately, as is the case with other FORTIFIED programs, there is a requirement for the building to be located outside of a flood zone in order to be considered for certification. Due to this restriction, the sample mixed-use building was designed to similar standards, as outlined in the FORTIFIED for Safer Living program, but would not qualify for certification or receive any wind-pool insurance reductions.

6. CONCLUSIONS

This project combines research of technical and regulatory requirements with added research of construction practices and material specification to better understand dry floodproof construction as a viable method of flood mitigation on the Gulf Coast. The research presents conclusions regarding the preferred locations of dry floodproofing and different methods of dry floodproofing. Several questions are also apparent, which if answered, would help to better inform local professionals and property owners of the implications of dry floodproof construction and design.

6.1 Where to Use Dry Floodproofing

- GIS analysis of BFEs and ground plane elevations shows that dry floodproof construction is allowable in many of the commercial corridors and districts of East Biloxi, and also in a number of other communities along the Mississippi Gulf Coast.
- With proper implementation and consideration of urban design and accessibility issues, dry floodproof construction has the potential to revitalize some of the Gulf Coast's commercial districts that were severely damaged by Hurricane Katrina, while protecting them from future flood events.
- Dry floodproofing is most likely to be used for mitigation of up to 3′ of elevation below the BFE. Greater distances can be mitigated with the combination of dry floodproof construction and additional elevation techniques.

6.2 Ways to Use Dry Floodproofing

- Dry floodproof construction is viable within a variety of construction types.
- The membrane is the key component in flood resistant CMU construction. This membrane could be an industrial product not conventionally used for commercial construction, like a multi-layered polymer sealant, or a more common building material, such as a liquid-applied asphaltic membrane with a consistent application.
- Modular and panelized construction systems, such as SIPs and ICF can be used successfully as part of a dry floodproof assembly, with proper detailing.
- Oversight and inspection during construction is extremely important when building to dry floodproof standards.
- The added cost to dry floodproof the sample building is approximately 15% of the total construction budget.

6.3 Ongoing Questions

- In what ways can ATSM standards to be used to indicate the quality of materials to be used in dry floodproof assemblies?
- How can building designs be used to increase the maximum coverage currently provided by the NFIP of $500,000, which is a factor that limits the viability of project by affecting the size and scope.

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APPENDIX A. OBSERVATIONS AND DATA FROM FLOOD SIMULATIONS

APPENDIX A. OBSERVATIONS AND DATA FROM FLOOD SIMULATIONS

A.1 Observations From Flood Simulation 1

Table A.1 is a log of the visual observations taken during flood simulation 1, which took place between April 6th, 2011 and April 8th, 2011. At specific time intervals, which are noted in the second column of this table, interior water depths were recorded for each test pod. Also, key observations regarding assembly changes are noted where applicable.

Table A.1. Observations from flood simulation 1.

Date	Time	Flooding Simulated Depth (in)	Test Pod A Interior Water Depth (in)	Test Pod B Interior Water Depth (in)	Test Pod C Interior Water Depth (in)	Test Pod D Interior Water Depth (in)	Test Pod E Interior Water Depth (in)	Test Pod F Interior Water Depth (in)
6-Apr	7:00 AM	0	0	0	0	0	0	0
	7:30 AM	**5.5**	0	0	0	0 *seepage at base of wall*	1.25	0 *leakage at channel connection N. wall*
	8:00 AM	*10.5*	0	0	*seepage at base of east wall*	0	**4**	0.75 visible currents
	8:45 AM	*17*	0	0	0.3	0	*14*	2 *three points of leakage*
	9:00 AM	*20.5*	0 *most CMU cells dry, minor seepage*	0 *most CMU cells filling w/ water (audible)*	1.5	0.5	*21*	2.5
	10:00 AM	*30*	0	0.75	2.75	1	*24*	**4**
	11:00 AM	*36*	0	**4**	**9.5**	1.75	*36*	*7*
	12:00 PM	*36*	0	*8.25*	*17*	2.25	*36*	*21.5*
	1:00 PM	*33*	0	*11.5*	*21.5*	2.75	*33*	*33.5*
	3:00 PM	*36*	0	*18.5*	*26.5*	3.75	*36*	*36*
	4:00 PM	*36*	0	*22*	*28.5*	**4.25**	*36*	*36*
	5:00 PM	*36*	0	*24*	*29.75*	*4.75*	*36*	*36*
	6:00 PM	*36*	*slab is half covered with water*	*27*	*31*	*5.25*	*36*	*Floated away from base*
	7:00 PM	*36*	0	*29.25*	*31.5*	*5.75*	*36*	*0*
	8:00 PM	*36*	0	*31*	*32*	*6*	*36*	*0*
	9:00 PM	*36*	0	*32.5*	*32.5*	*6.25*	*36*	*0*
	10:00 PM	*36*	0	*33.75*	*33*	*6.5*	*36*	*0*
	11:00 PM	*36*	0	*34.5*	*33.5*	*7*	*36*	*0*
7-Apr	1:00 AM	*36*	0	*35.5*	*34.5*	*7.75*	*36*	*0*
	3:00 AM	*36*	0	*36.5*	*35.5*	*8.25*	*36*	*0*
	5:05 AM	*38*	0	*36.5*	*35.5*	*8.25*	*36*	*0*
	7:05 AM	*38*	0	*36.5*	*35.5*	*8.25*	*36*	*0*
	9:05 AM	*Missing data*						
	11:00 AM	*29.5*	0.25	*34.5*	*35*	*10*	*29.5*	*0*
	12:00 PM	*24.5*	0.25	*32.5*	*33*	*10*	*25*	*0*
	1:00 PM	*19.5*	0.25	*30.25*	*30.75*	*10.5*	*20*	*0*
	2:00 PM	*16*	0.25	*29*	*28.75*	*10.5*	*16.5*	*0*
	3:00 PM	*13*	0.25	*28.5*	*27*	*10.5*	*13.5*	*0*
	4:00 PM	*9*	0.25	*27.25*	*25.5*	*10.5*	*10*	*0*
	5:00 PM	*5*	0.25	*26.5*	*24.75*	*10.5*	*6.5*	*0*
	7:05 PM	*2*	0.25	*24.5*	*21.5*	*10*	*2.75*	*0*
8-Apr	8:00 AM	*0*	0.25	*18.75*	*14.5*	*8*	*0*	*0*
	12:00 PM	*0*	0.25	*17.75*	*13.25*	*7.25*	*0*	*0*

A.2 Observations From Flood Simulation 2

Table A.2 is a log of the visual observations taken during flood simulation 1, which took place between June 28th, 2011 and June 29th, 2011. At specific time intervals, which are noted in the second column of this table, interior water depths were recorded for each test pod. Also, key observations regarding assembly changes are noted where applicable.

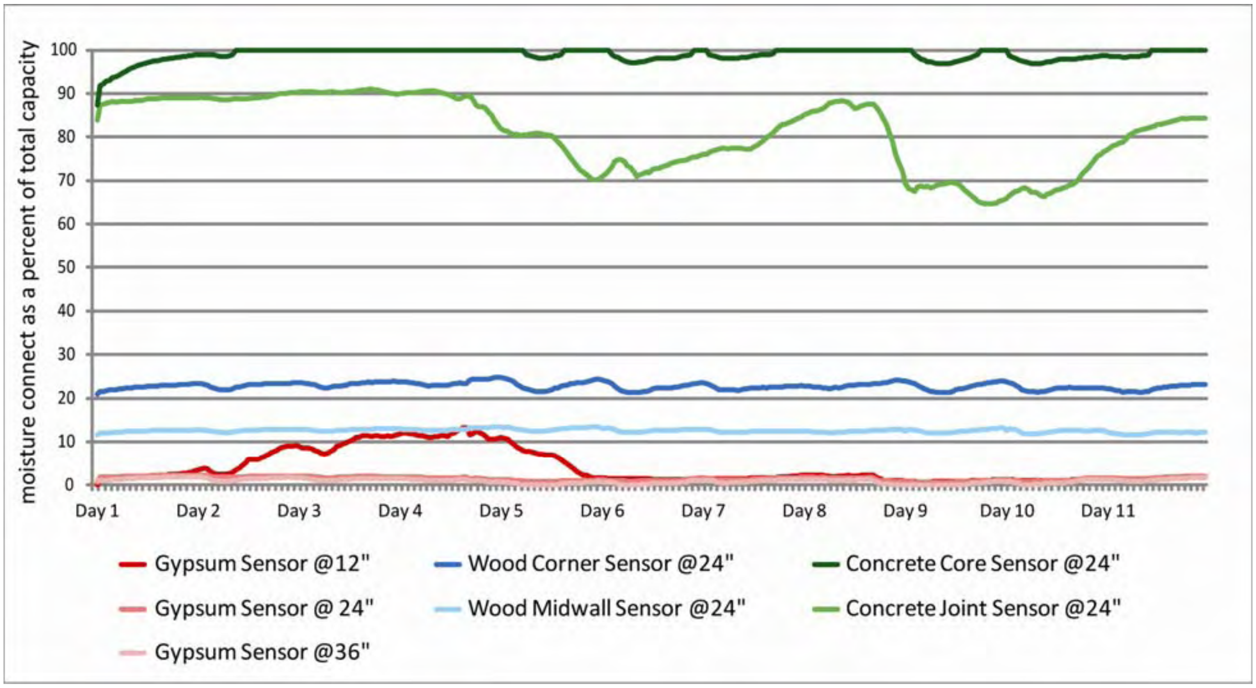
Table A.2. Observations from flood simulation 2.

Date	Time	Flooding Simulated Depth (in)	Test Pod G Interior Water Depth (in)	Test Pod H Interior Water Depth (in)	Test Pod A Interior Water Depth (in)	Test Pod B2 Interior Water Depth (in)	Test Pod D2 Interior Water Depth (in)	Test Pod F2 Interior Water Depth (in)
28-Jun	7:45 AM	0	0	0	0	0	0	0
	8:36 AM	10	*seepage south wall*	0	0	0	*seepage two corners*	*seepage two corners*
	8:50 AM	14	*more seepage, capillary action*	*seepage started*	0	0	*more seepeage*	*more seepage*
	9:45 AM	24	0	seepage	0	*seepage, early cells are seepaging more*	seepage	0.13
	10:45 AM	36	0.25	1.5	0	0.5	0.5	0.25
	11:45 AM	36	0.5	3.75	*corner seepage*	1.5	0.5	0.25
	12:45 PM	36	0.75	***6***	0	2.25	0.5	0.25
	1:45 PM	36	1	*6.5*	0	3	1	0.25
	2:45 PM	36	1	*8*	0	***4***	1.25	0.25
	3:45 PM	36	1.25	*9*	0	*5*	1.25	0.25
	5:45 PM	36	1.5	*10*	0	*7*	3	0.5
	7:45 PM	36	1.5	*12*	0.25	*8*	3	0.5
	9:45 PM	36	2.5	*12.5*	0.25	*9*	2.5	0.5
	11:45 PM	36	2.5	*14*	0.25	*10*	2.5	0.5
29-Jun	1:45 AM	36	3	*13.5*	0.25	*10*	3	0.5
	3:45 AM	36	3	*15*	0.25	*13.5*	3	0.5
	5:45 AM	36	3	*15.5*	0.25	*13.5*	3	0.5
	7:45 AM	36	3.5	*15.5*	0.25	*13.5*	3	0.5
	9:45 AM	36	3.5	*16*	0.25	*14*	3.5	0.5
	10:45 AM	36	3.75	*16.5*	0.25	*14.5*	3.75	0.5
	11:45 AM	31	3.75	*16.75*	0.25	*14.5*	3.75	0.5
	1:45 PM	12	3.75	*17*	0.25	*15.5*	3.75	0.5
	5:00 PM	0	**3.75**	*17*	**0.25**	*15.5*	**3.75**	**0.5**

A.3 Moisture Sensor Data for Drying Period

Prior to flood simulation 1, moisture sensors were placed within test pods A, B, C, D, and E, in order to calibrate pre-flood moisture content within gypsum, wood, and concrete materials of the test pod assemblies. During the 24-hour flood simulation, these moisture sensors were removed, to avoid damage to the sensors from complete inundation. After the flood tank was emptied, the moisture sensors were replaced, in the same locations, and moisture content was monitored over a two-week drying period. The following information (A.3.1-A.3.5) demonstrates the location of each sensor within each test pod assembly, and the resulting moisture content levels that were obtained over the drying period.

A.3.1 Drying Period Test Pod A: Sealed Block



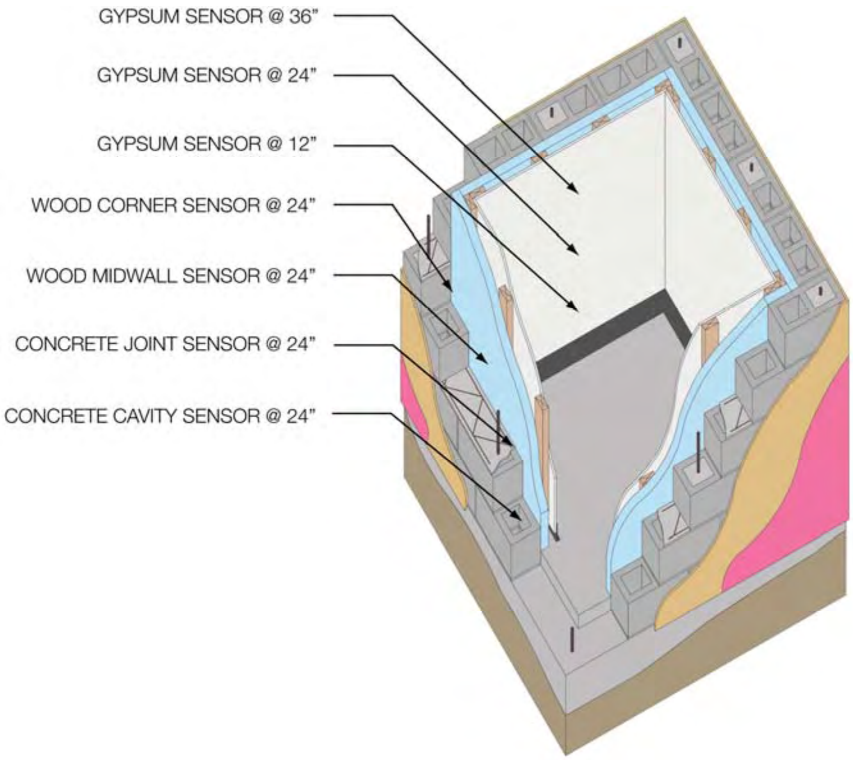


Fig. A.1.DIAGRAM: Drying period test pod A: sealed block and sensor locations.

A.3.2 Drying Period Test Pod B: Cavity Wall

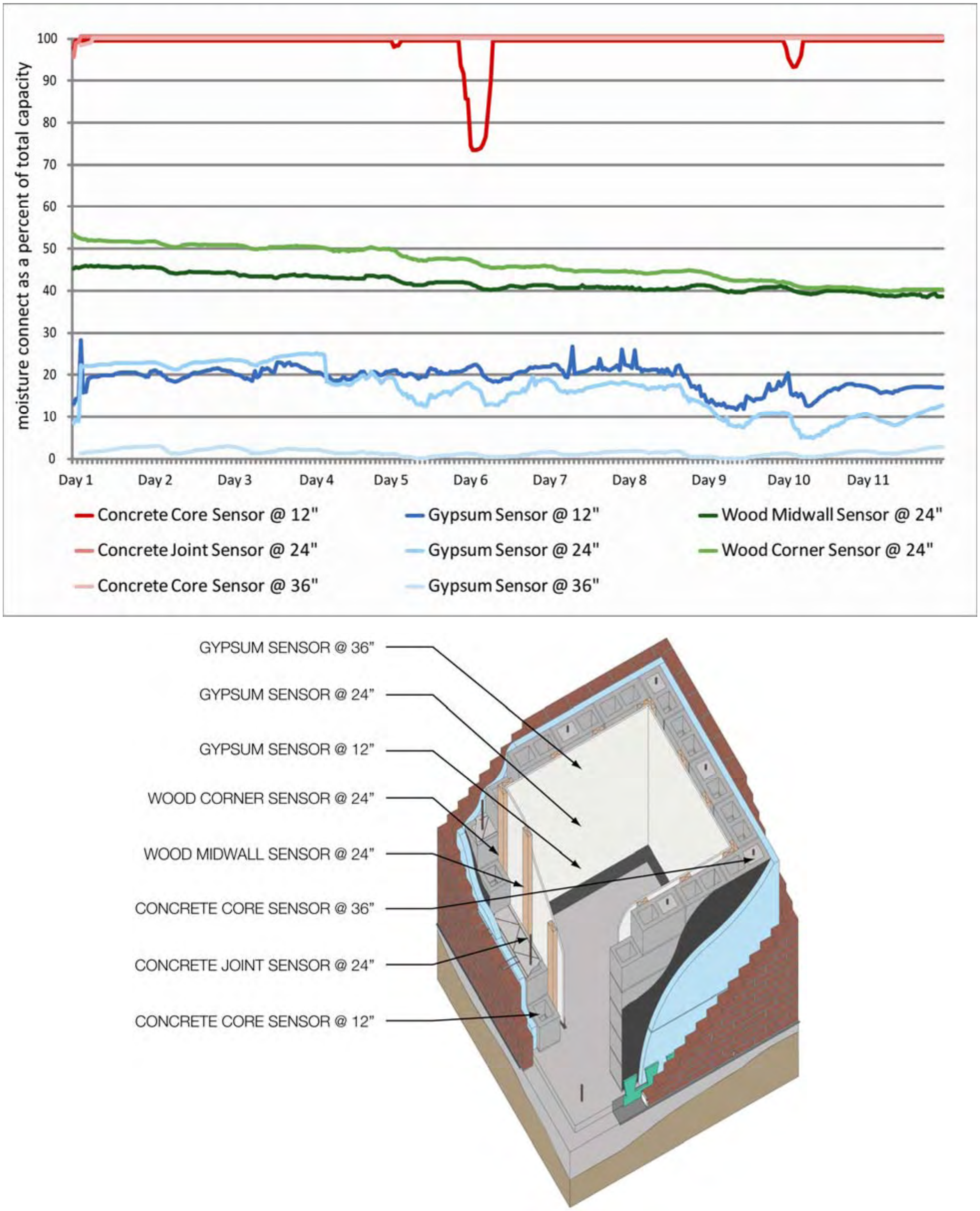


Fig. A.2. DIAGRAM: Drying period for test pod B: cavity wall and sensor locations.

A.3.3 Drying Period Test Pod C: Unsealed Block

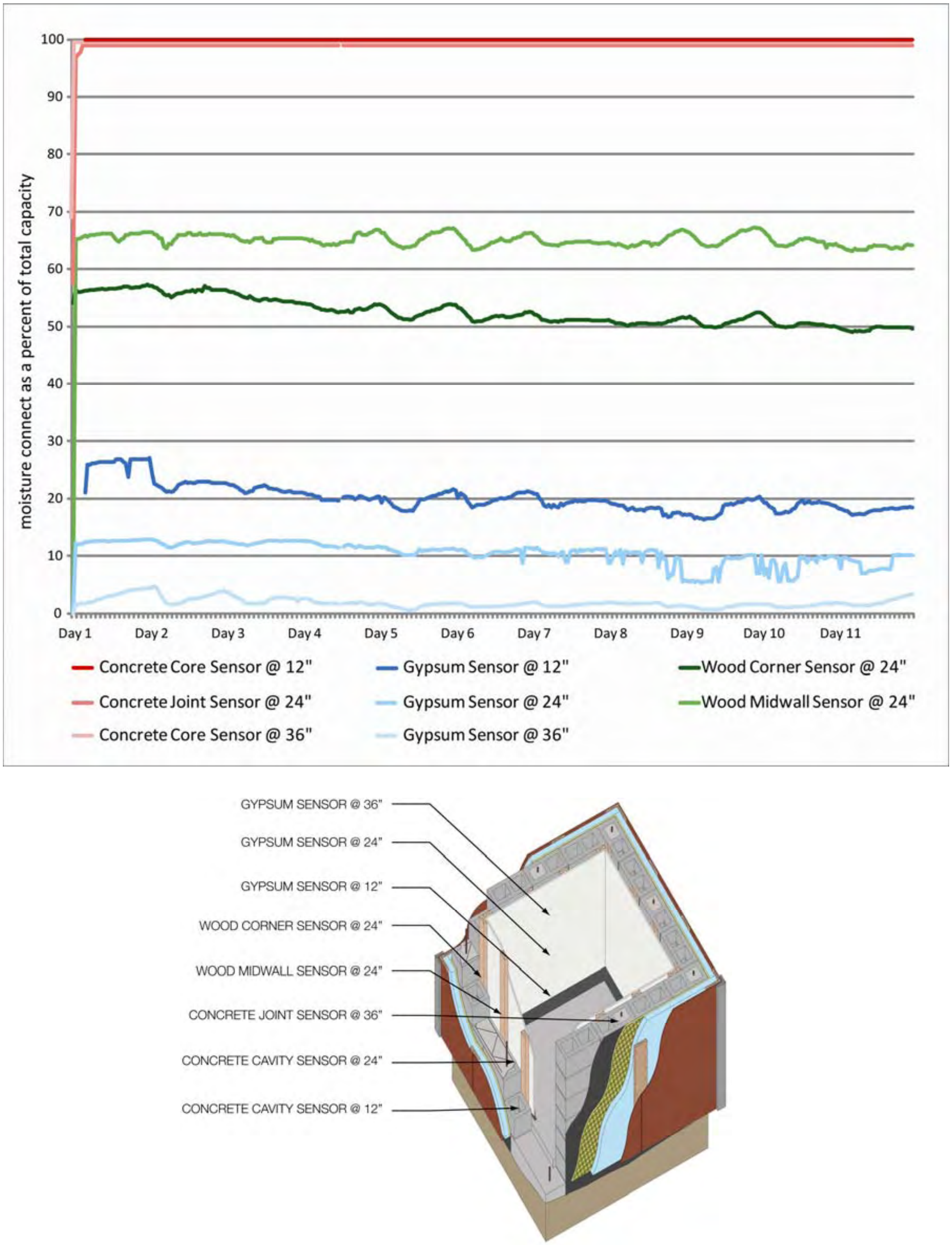


Fig. A.3. DIAGRAM: Drying period for test pod C: unsealed block and sensor locations.

A.3.4 Drying Period Test Pod D: ICF

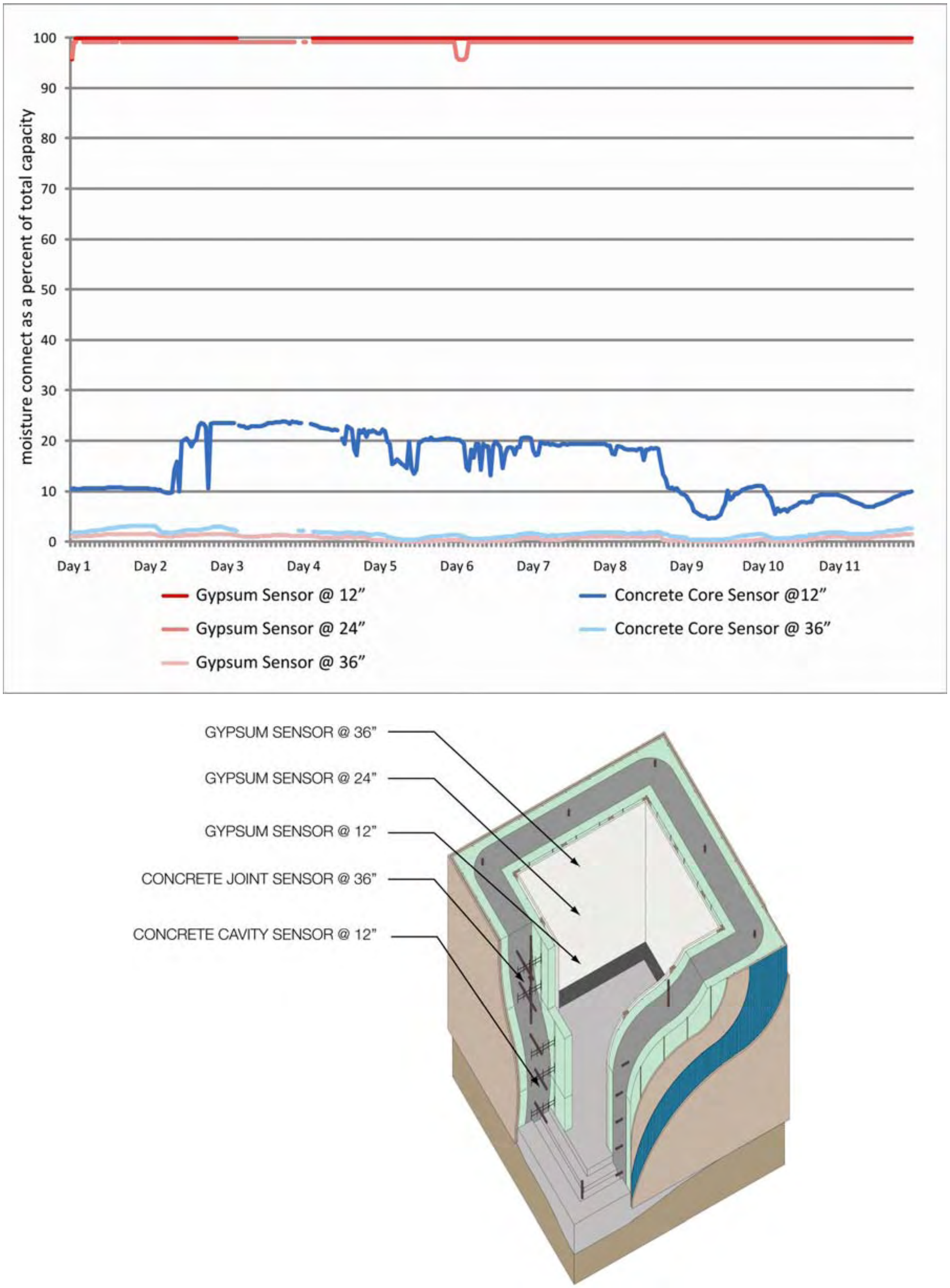


Fig. A.4. DIAGRAM: Drying period for test pod D: ICF and sensor locations.

A.3.5 Drying Period Test Pod E: Metal Stud

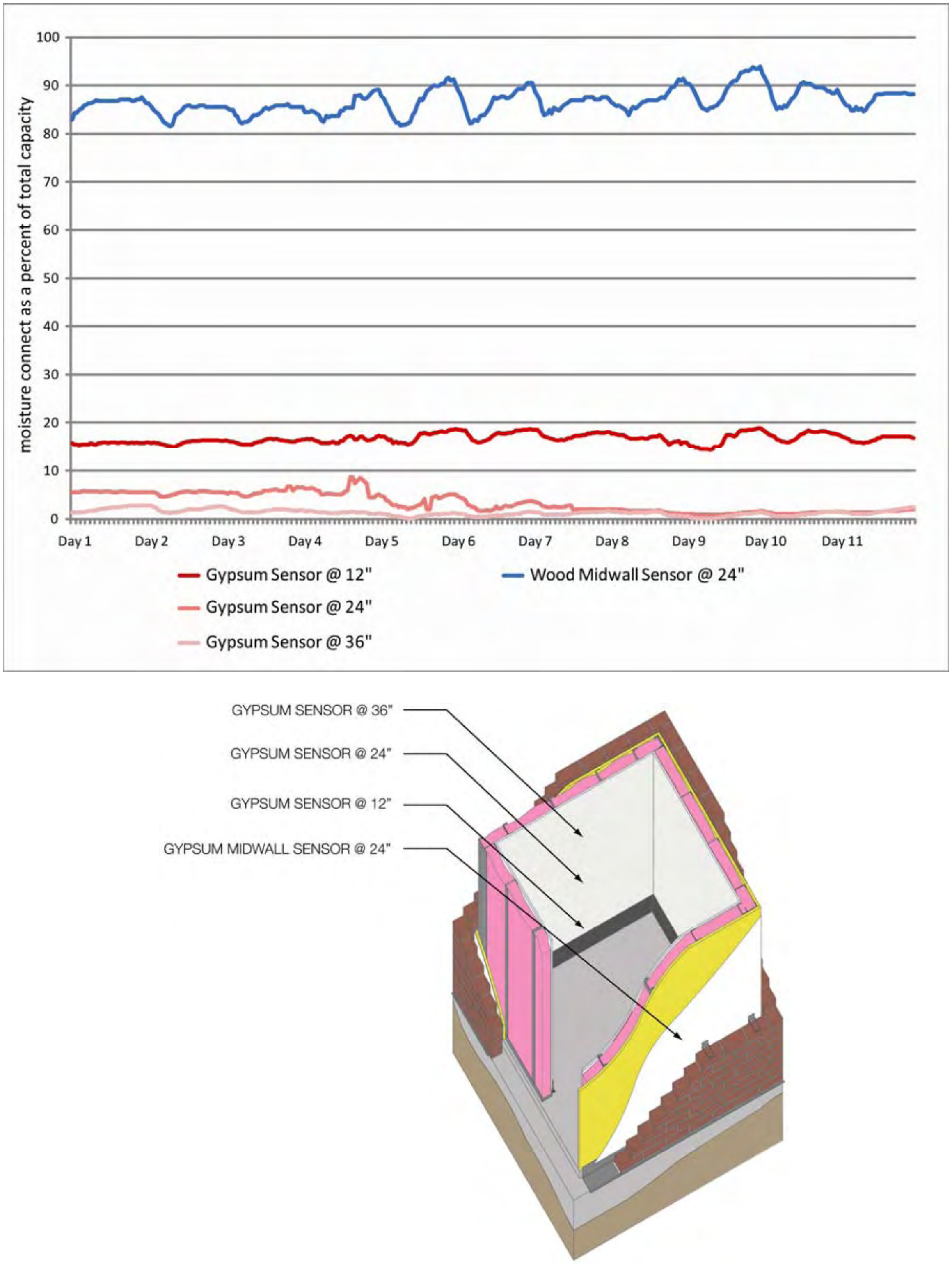


Fig. A.5. DIAGRAM: Drying period for test pod E: metal stud and sensor locations.

A.4 Moisture Content Before and After Flood Simulation

Figures A.6, A.7, and A.8 compare moisture content between different materials (wood, concrete, and gypsum) that were used within a number of the test pod assemblies, 24 hours prior to and after flood simulation 1.

A.4.1 Wood Sensor Readings

Fig. A.6 compares the changes observed in the moisture content of wood within the test pod assemblies, at moisture sensors located at the corners and at a midway point between corners. The data points graphed on the left show inert moisture content found within materials, prior to the flood simulation.

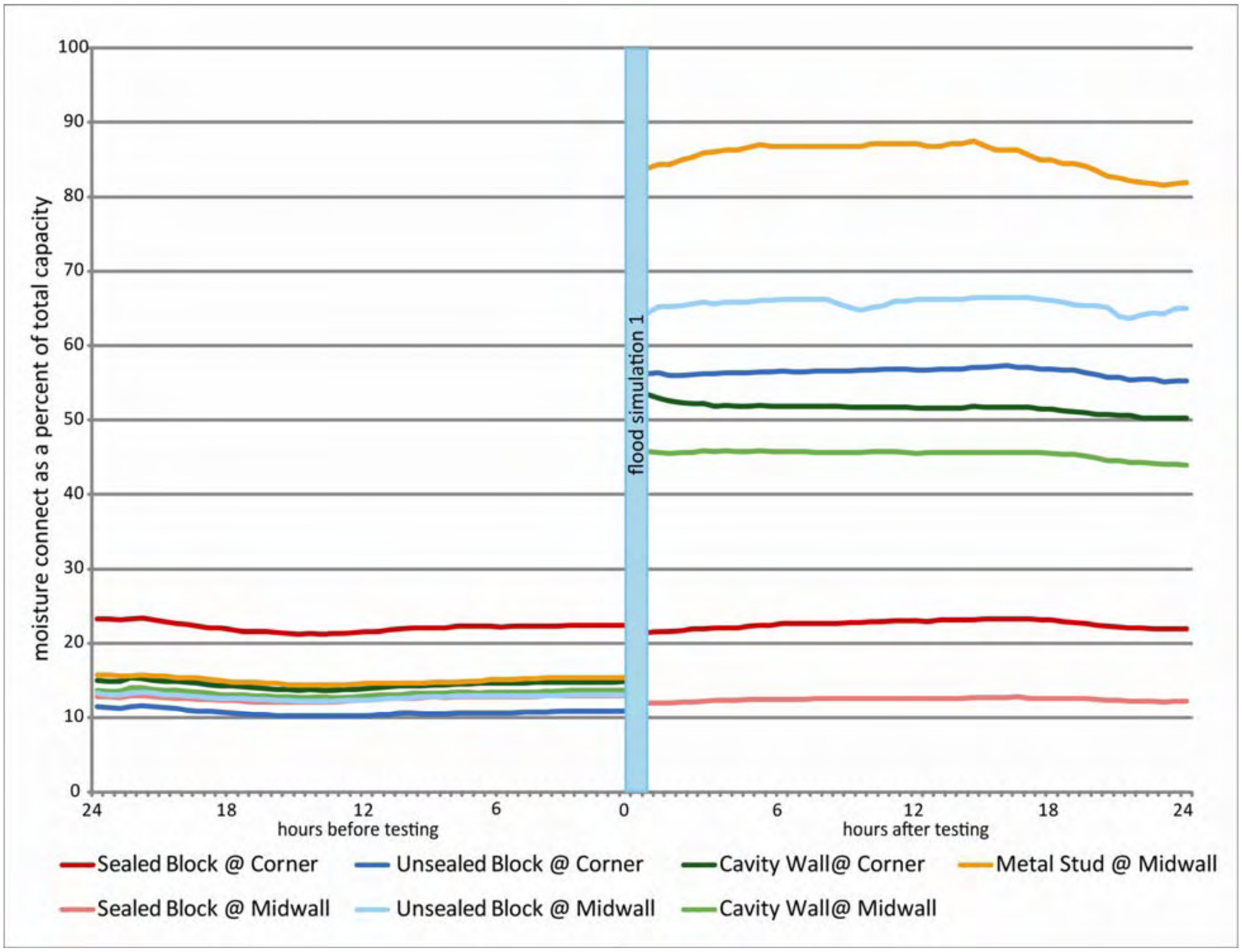


Fig. A.6. GRAPH: Wood sensor readings 24 hours before and after flood simulation 1.

A.4.2 Concrete Core Sensor Readings

Fig. A.7 compares the changes observed in the moisture content of concrete cores within the test pod assemblies, at moisture sensors located at varying heights within test pods. The data points graphed on the left show inert moisture content found within materials, prior to the flood simulation.

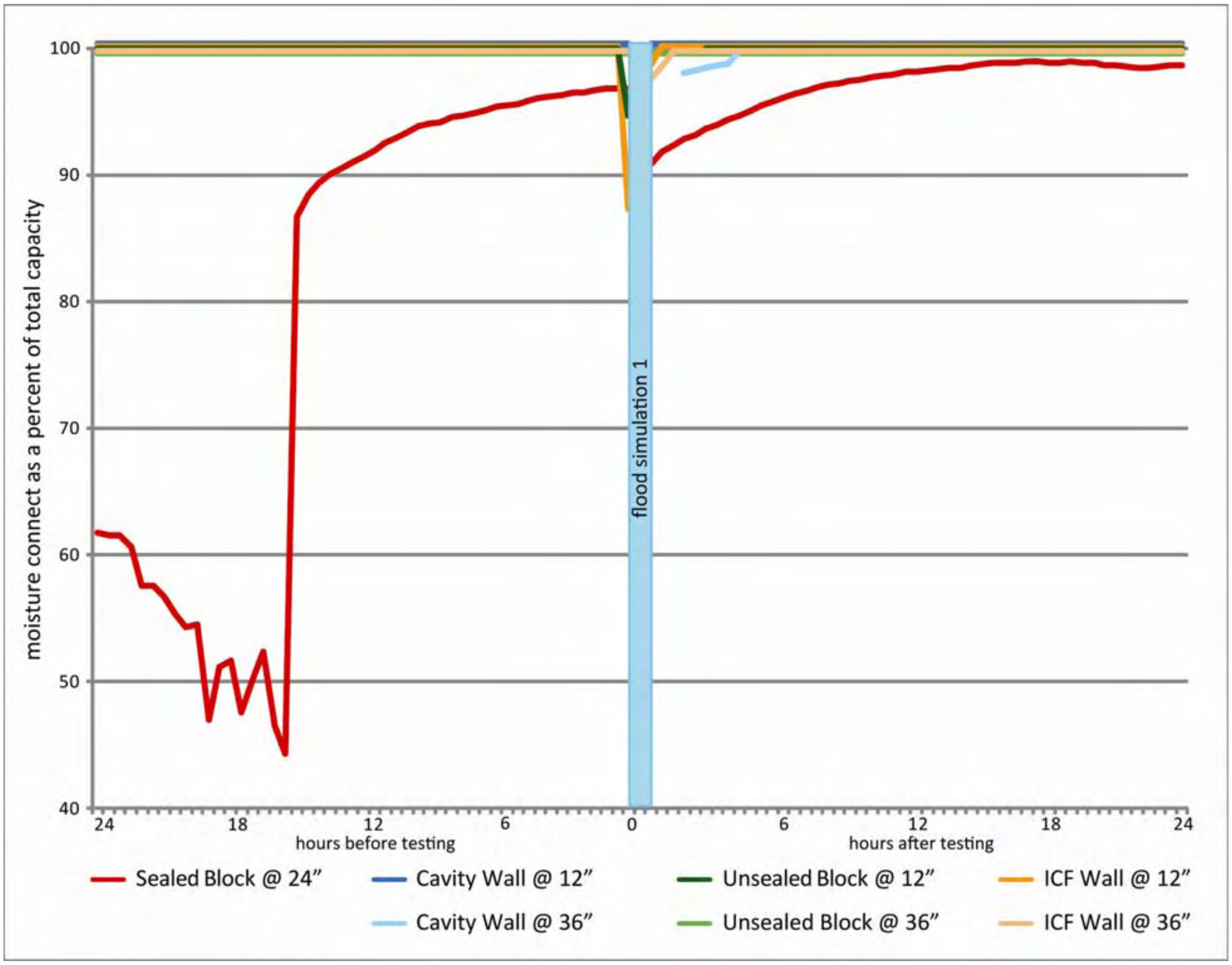


Fig. A.7. GRAPH: Concrete core sensor readings 24 hours before and after flood sim. 1.

A.4.3 Gypsum Sensor Readings

Fig. A.8 compares the changes observed in the moisture content of gypsum materials used within the test pod assemblies, at moisture sensors located at varying heights within test pods. The data points graphed on the left show inert moisture content found within materials, prior to the flood simulation.

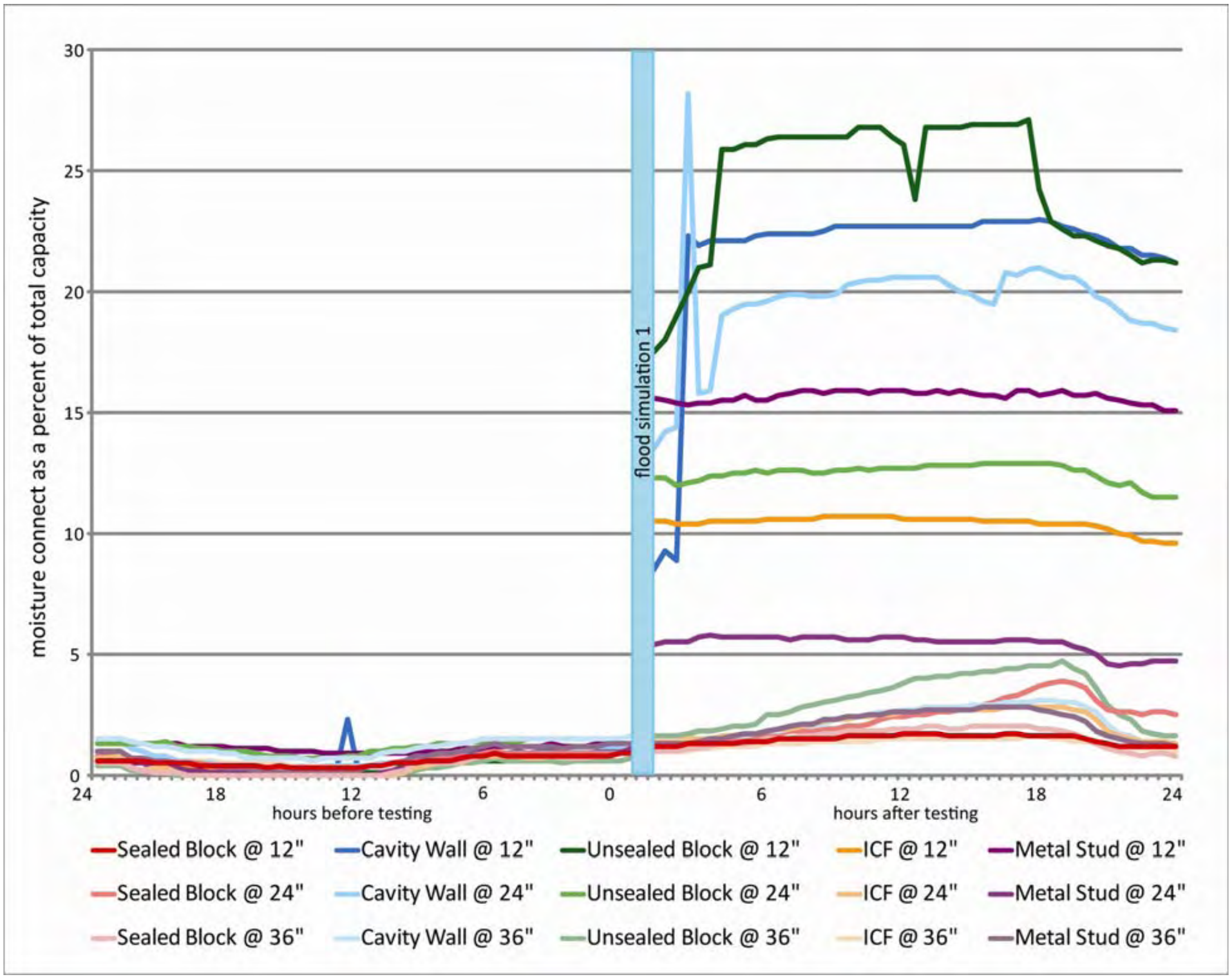


Fig. A.8. GRAPH: Gypsum sensor readings 24 hours before and after flood sim. 1.

APPENDIX B. DETAILED DRAWINGS OF TEST PODS

APPENDIX B. DETAILED DRAWINGS OF TEST PODS

The following diagrams (Fig. B.1-B.11) depict the horizontal and vertical cross-sections used for the construction of each individual test pod used during the flood simulation 1 and 2. The intention of this appendix is to provide material and assembly details for the test pods. Each test pod was four feet tall, and was constructed on a 6′x6′ concrete slab (except for test pods F and F2: metal SIPs, which were constructed on a 4′x8′ slab).

B.1 Test Pod A: Sealed Block

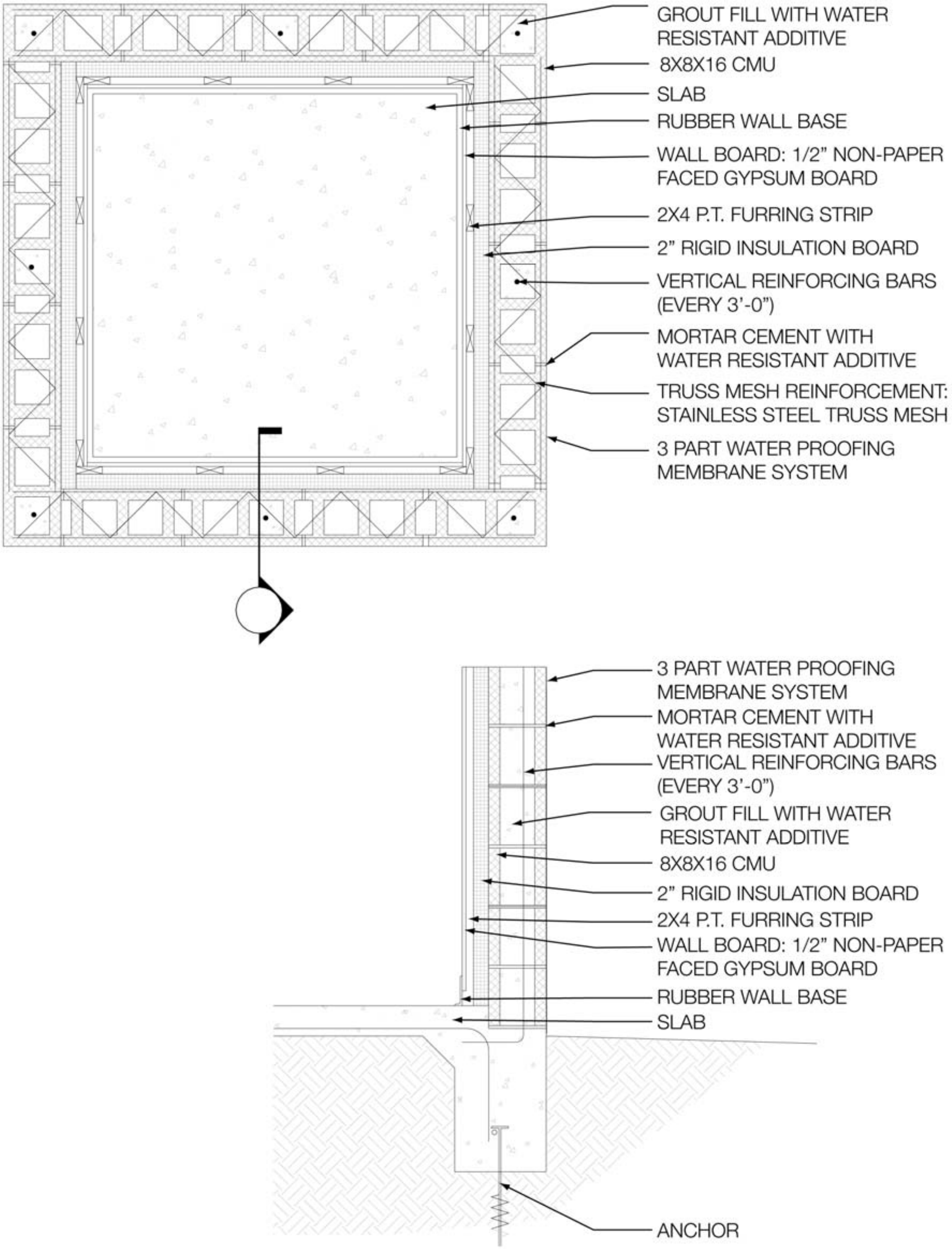


Fig. B.1. DIAGRAM: Detailed drawings, test pod A: sealed block.

B.2 Test Pod B: Cavity Wall

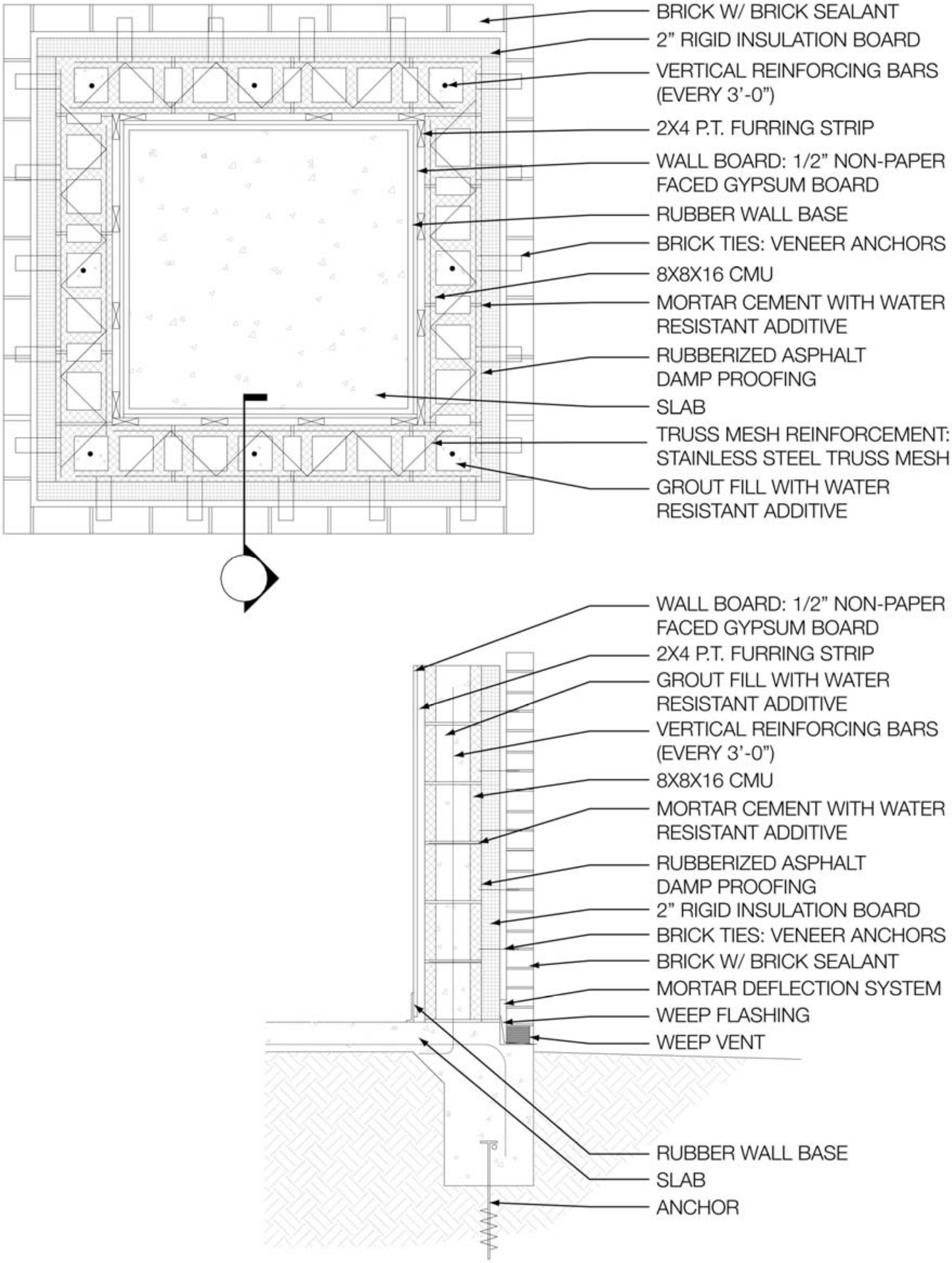


Fig. B.2. DIAGRAM: Detailed drawings, test pod B: cavity wall.

B.3 Test Pod C: Unsealed Block

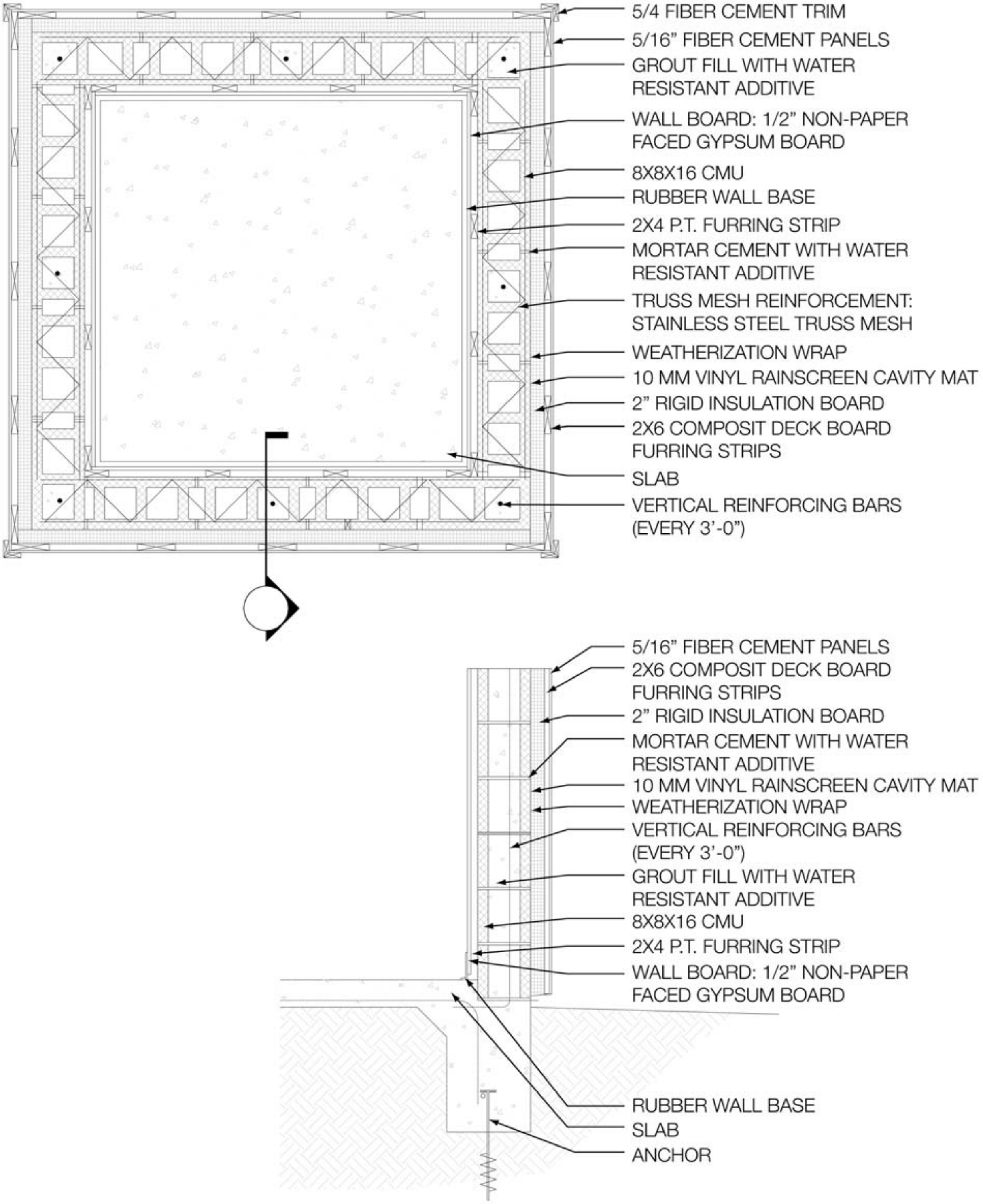


Fig. B.3. DIAGRAM: Detailed drawings, test pod C: unsealed block.

B.4 Test Pod D: ICF

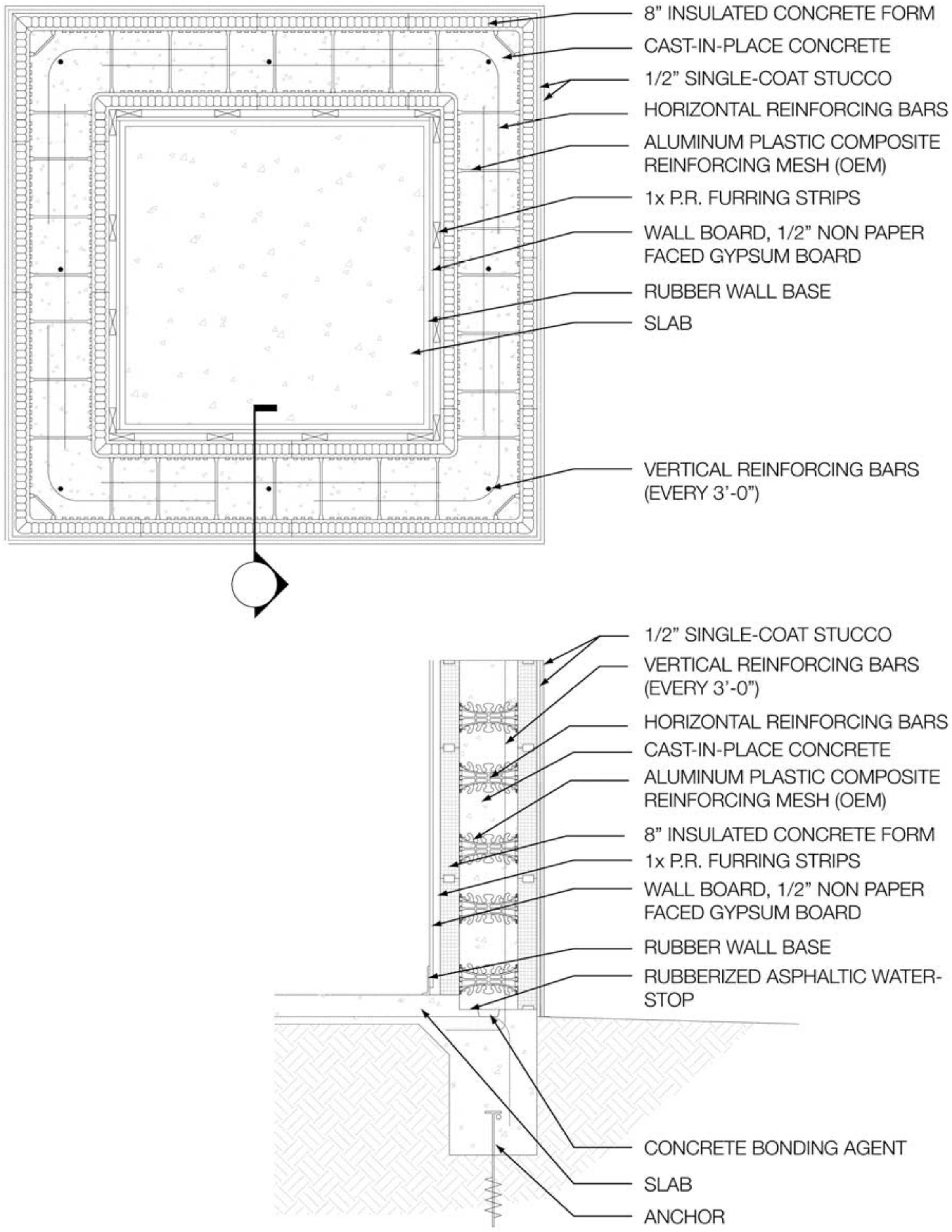


Fig. B.4. DIAGRAM: Detailed drawings, test pod D: ICF.

B.5 Test Pod E: Metal Stud

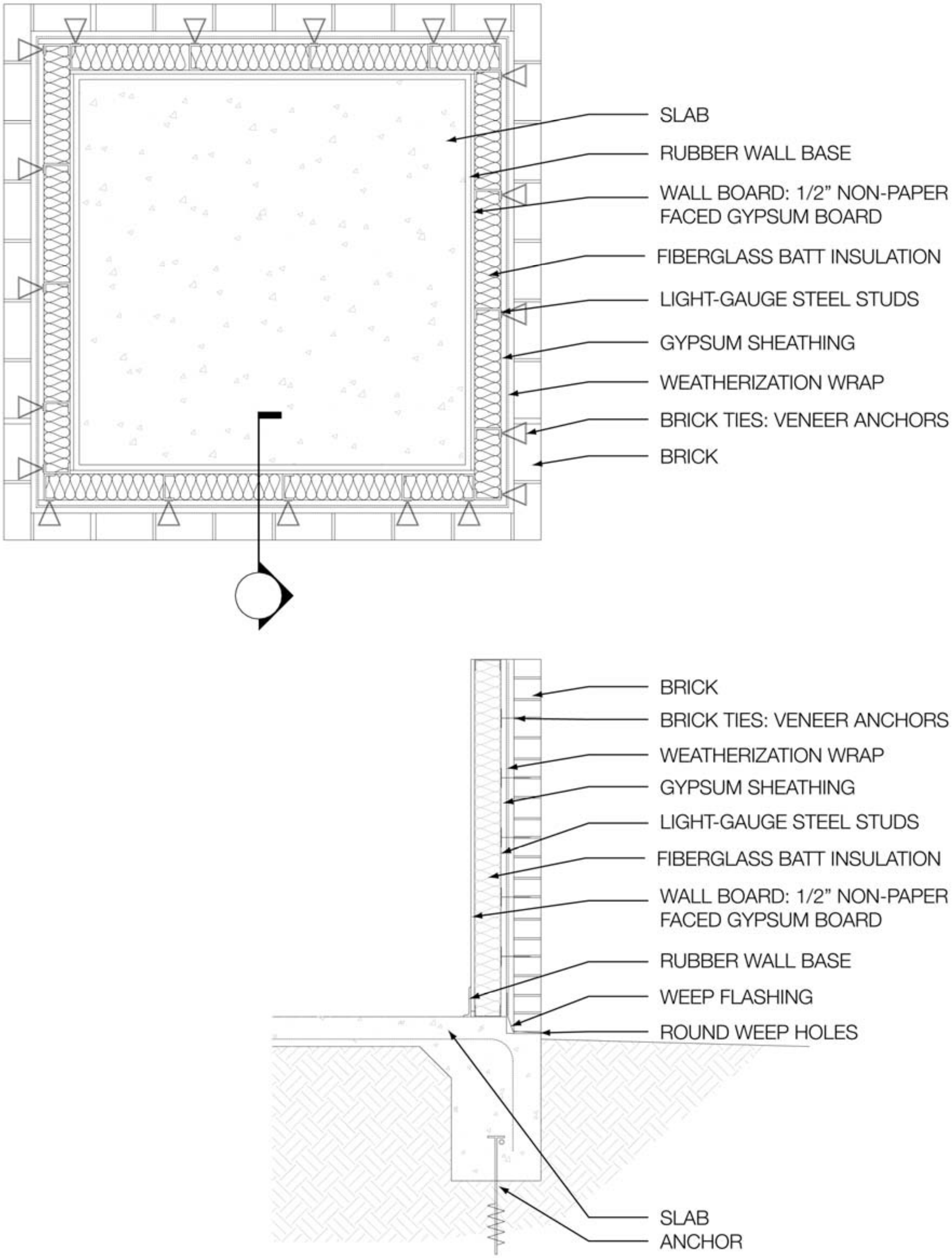


Fig. B.5. DIAGRAM: Detailed drawings, test pod E: metal stud.

B.6 Test Pod F: Metal SIPs

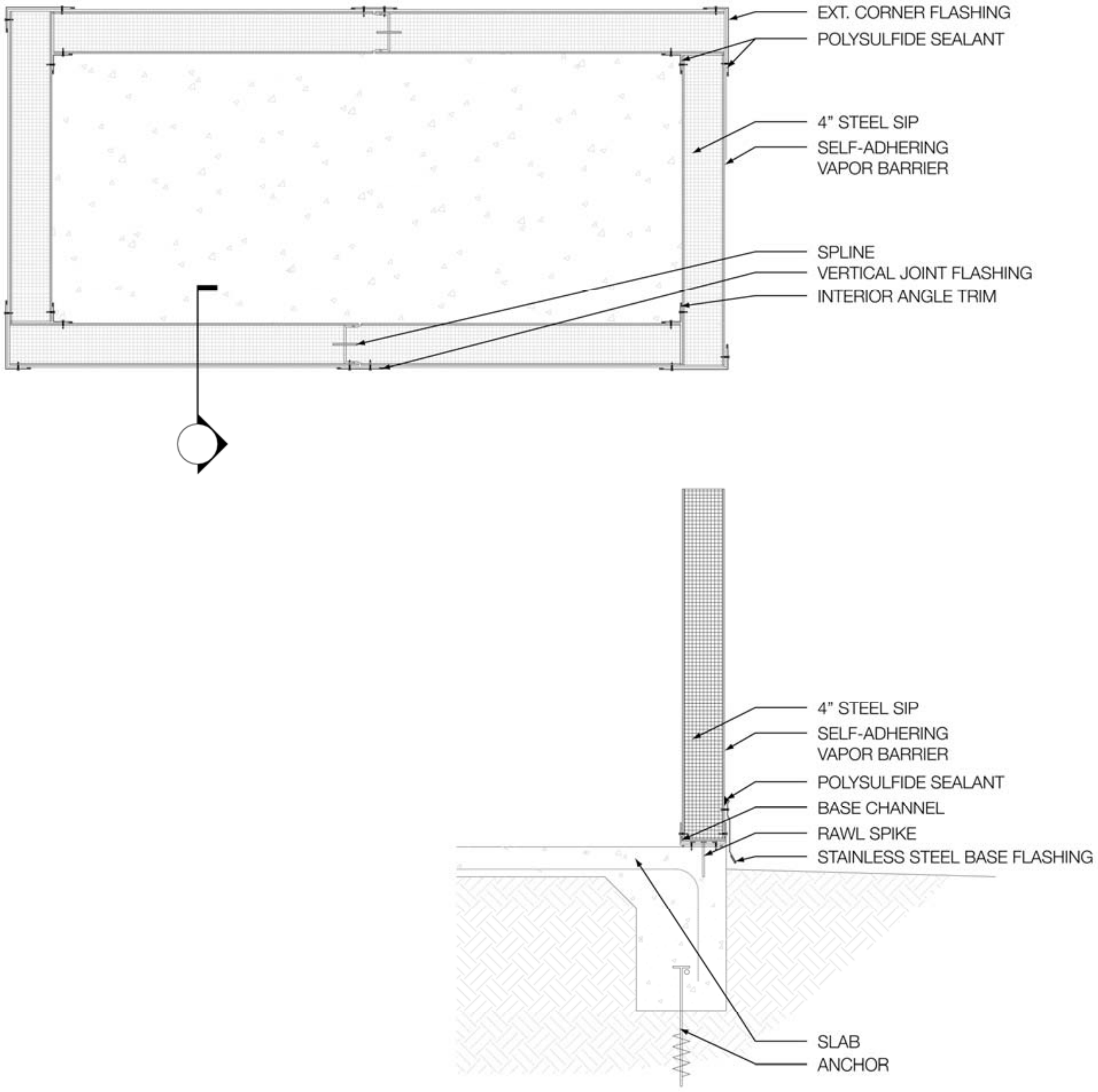


Fig. B.6. DIAGRAM: Detailed drawings, test pod F: metal SIPs.

B.7 Test Pod G: Sheet Membrane Block

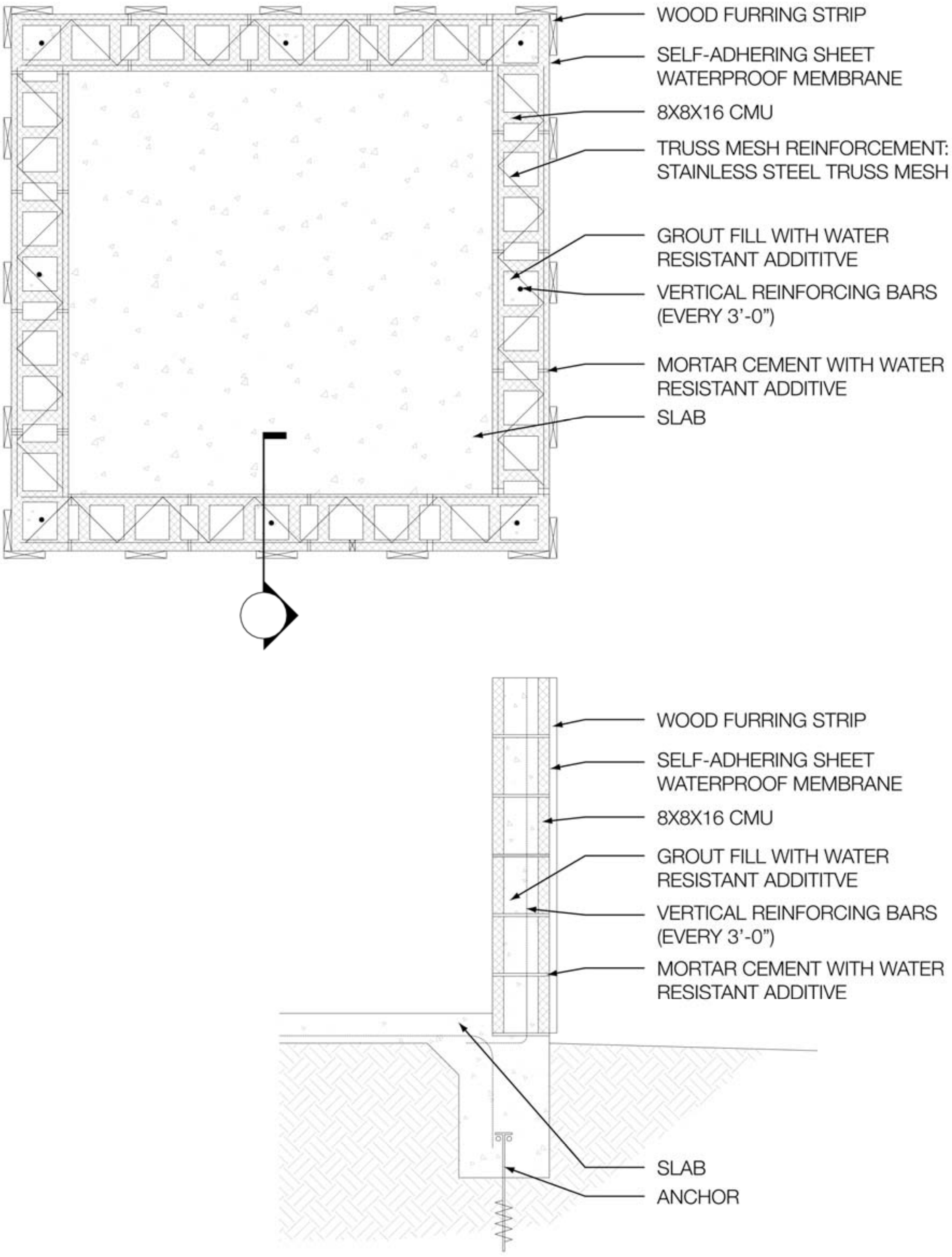


Fig. B.7. DIAGRAM: Detailed Drawings, test pod G: sheet membrane block.

B.8 Test Pod H: Weatherproofed Block

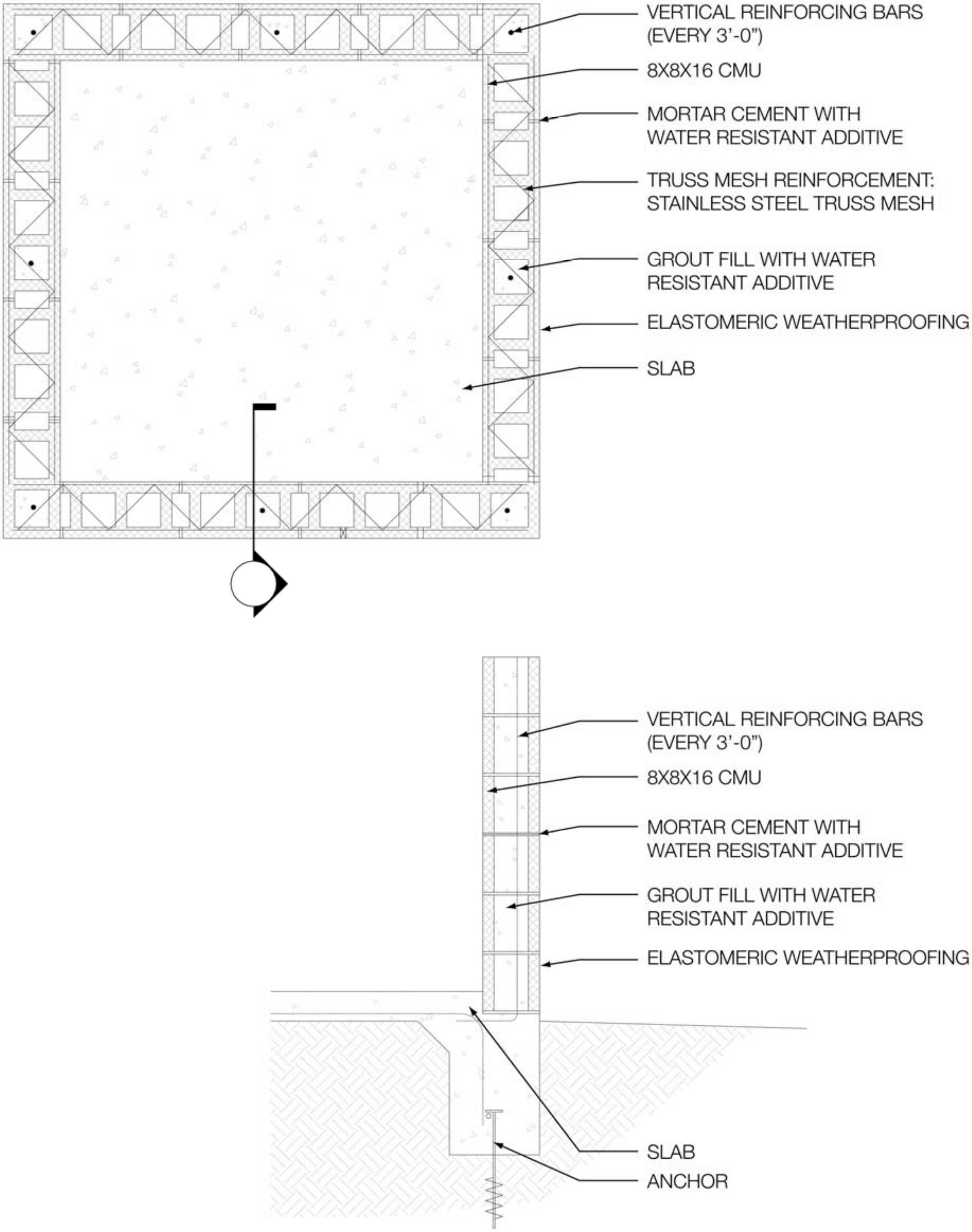


Fig. B.8. DIAGRAM: Detailed drawings, test pod H: weatherproofed block.

B.9 Test Pod B2: Cavity Wall Filled Block

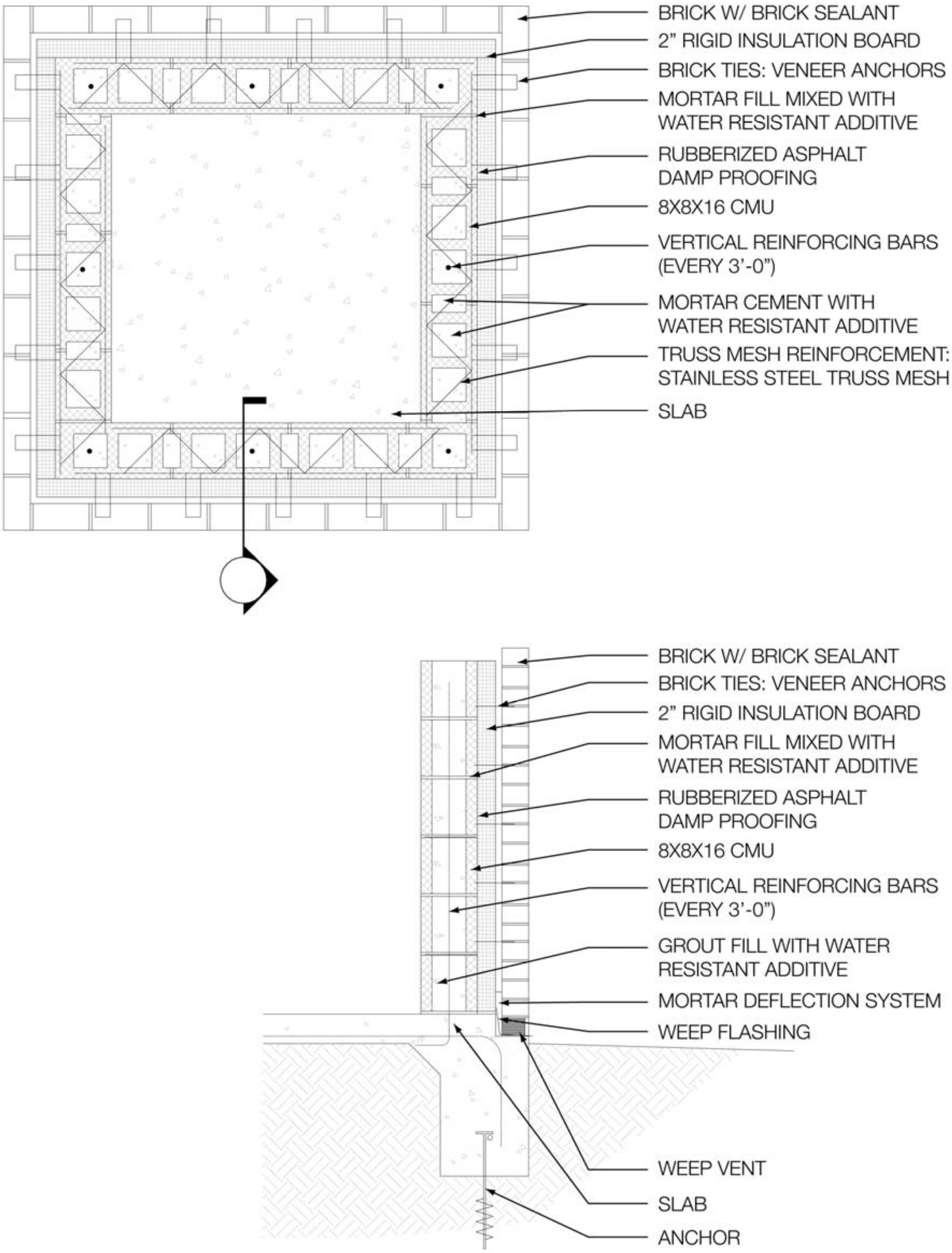


Fig. B.9. DIAGRAM: Detailed drawings, test pod B2: cavity wall filled block.

B.10 Test Pod D2: ICF

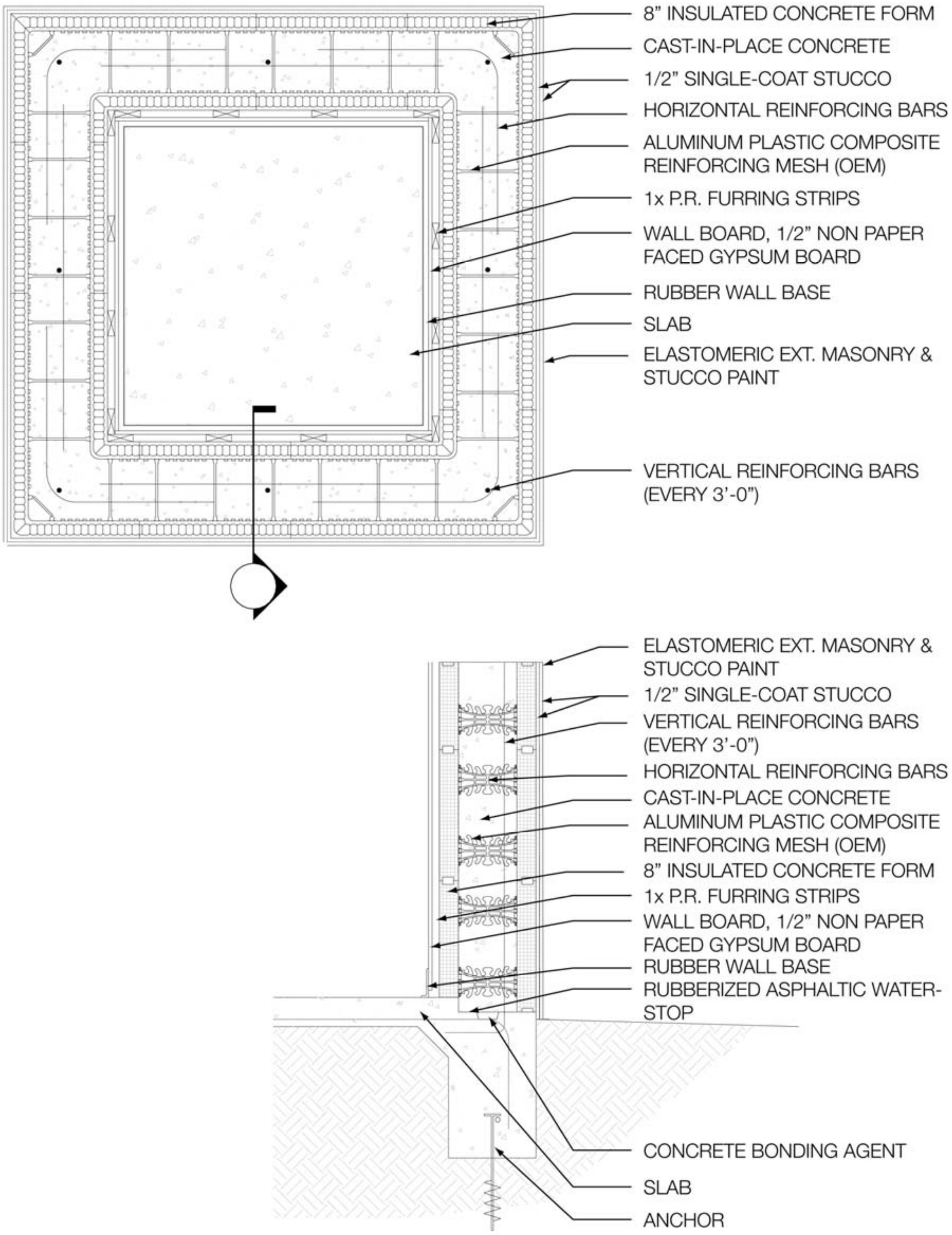


Fig. B.10. DIAGRAM: Detailed drawings, test pod D2: ICF.

B.11 Test Pod F2: Metal SIPs

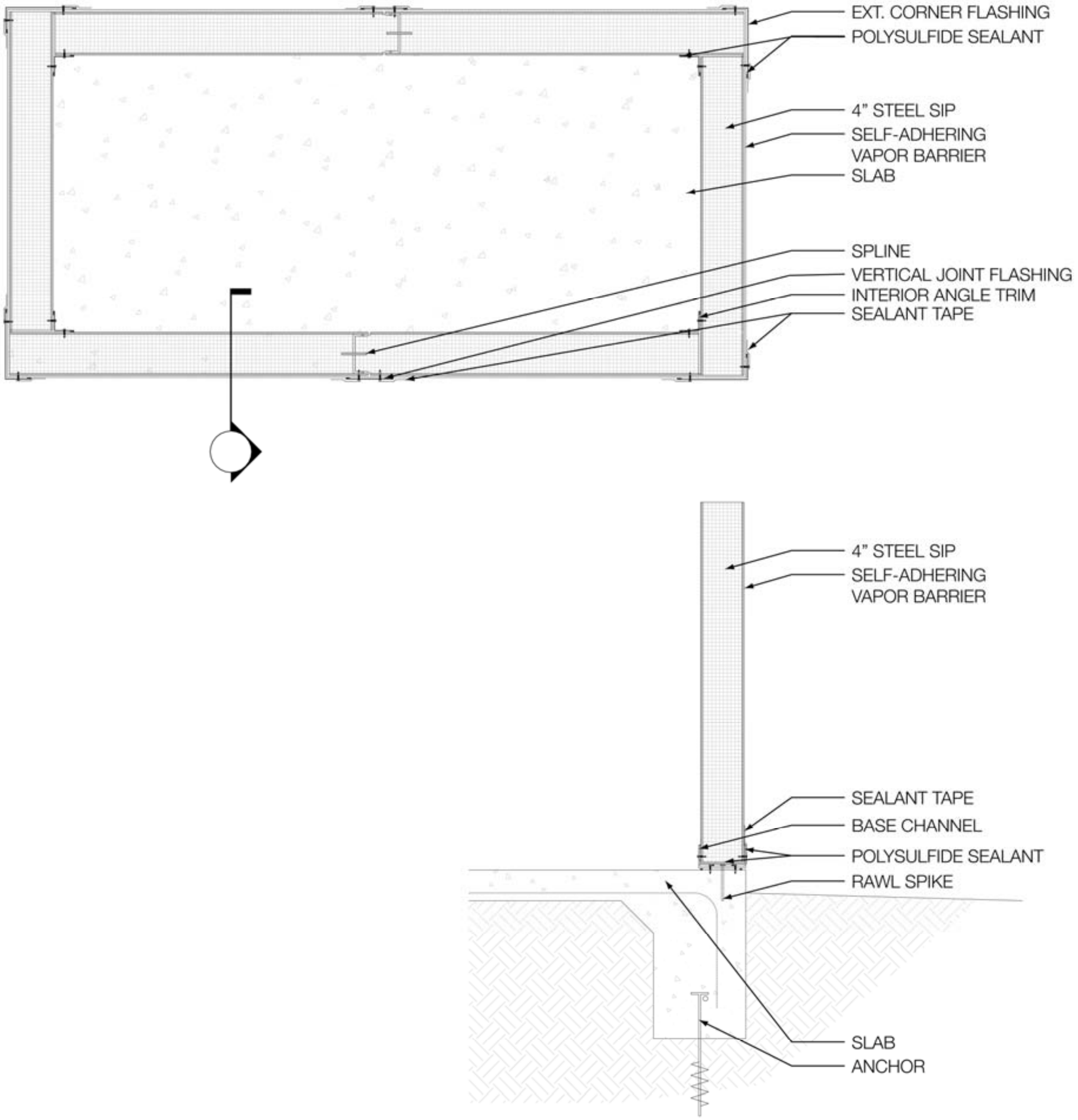


Fig. B.11. DIAGRAM: Detailed drawings, test pod F2: metal SIPs.

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