9 Recommended Design Process and Criteria for Manufactured Home Foundations in SFHAs

9.1 Performance Criteria

Performance criteria for manufactured home foundation systems are provided in the HUD *Manufactured Home Construction and Safety Standards* (24 CFR 3280) and *Model Manufactured Home Installation Standards* (24 CFR 3285). The HUD regulations require that manufactured homes installed in flood hazard areas use foundations, anchoring, and support systems capable of resisting loads associated with the design flood and wind events. Foundation, anchoring, and support systems must be capable of resisting flotation, collapse, or lateral movement.

The *International Residential Code for One and Two Family Residential Dwellings* also requires that residential structures, including manufactured home foundations, be designed and connected to resist flotation, collapse, or lateral movement due to structural loads and stresses from flooding equal to the design flood event (R324.1.1). *IRC Appendix E: Manufactured Housing Used as Dwellings* requires that foundations be designed and constructed to minimize differential movements (IRC AE502.4).

The NFIP regulations also establish performance requirements for structures, including manufactured homes, installed in flood-prone SFHAs. The NFIP requires homes be:

> "adequately anchored to prevent flotation, collapse, or lateral movement of the structure resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy." [44 CFR 60.3(a)(i)]

9.2 Design Criteria

To meet the performance requirements outlined in Section 9.1, design criteria must be established that identify the anticipated design loads the structure is expected to experience. Design loads can be categorized as dead loads, live loads, or environmental loads.

Dead loads depend on the weight of the manufactured home, its foundation, and any accessory supported by the structure such as walls, piping, electrical service panels and conduits, and HVAC equipment.

Live loads depend on the weight of occupants, furnishings, and non-fixed equipment and the function of the building or specific space.

HUD 24 CFR 3280.305(g) requires floors be designed to support a minimum uniform live load of 40 psf.

Environmental loads are loads for given recurrence intervals specified by the engineering community and vary with locality. Wind loads (which are proportional to the square of the design wind speed) can exceed 80 psf near coastal areas, while those inland can be as low as 15 psf. Snow loads are non-existent in much of the southern U.S., but can exceed 50 psf in northern and mountainous regions.

Environmental loads that act on manufactured homes and foundations include the following:

> **Flood loads** depend on flood depth, flood velocity, surrounding debris sources, wave effects, elevation of the building relative to the flood condition, and surrounding topography and exposure. Flood loads include hydrodynamic and hydrostatic (including buoyancy) and floating debris impact loads.
>
> **Wind loads** depend on the geometry (particularly roof shape and pitch) and building height, exposure, and, of course, on the design wind speed for the site. Coastal areas in the U.S. are generally exposed to greater wind speeds than interior areas, but special wind regions exist in mountainous areas.
>
> **Seismic loads** depend on the mass of the building, additional loads that the building may occasionally support (e.g., snow loads), the building geometry and distribution, its lateral force resisting system, and local soil conditions.
>
> **Snow loads** depend on roof geometry, building orientation, and the geographical location of the site.

Most model building codes contain requirements on estimating the normal and environmental loads on a structure. After the design loads are identified, how these loads interact with the structures can be assessed and the foundation system can be designed.

9.3 Design Process

After the performance criteria are established, the design process can begin. The design process involves the following steps:

Step1	Determine design criteria
Step 2	Select a design methodology and assess load combinations and failure modes
Step 3	Select foundation type and material
Step 4	Determine forces at connections and on foundation components
Step 5	Specify connections and framing methods along with component dimensions to satisfy load conditions
Step 6	Note all design assumptions and details on drawings

Each step of this process is described below. The entire design process is based on the fundamental premise that anticipated normal and environmental loads can and must be transferred through the manufactured home to the foundation in a continuous path to the supporting soils. Any weakness in the continuous path is a potential point of failure of the building, and any failure creates the possibility for large property losses and the loss of life.

This guide does not cover every combination of loads, materials, building shapes and functions, hazard risks, and elevations. Engineering judgment will need to be applied to a range of problems during the design of a manufactured home foundation located in an SFHA. Therefore, the intent of this guide is to provide sufficient background for designers to effectively design manufactured home foundations for forces and issues encountered when sited in an SFHA.

9.3.1 Step 1: Determine Design Criteria

As discussed in Section 10.1, HUD's *Model Manufactured Home Installation Standards* require manufactured home foundations be capable of resisting loads associated with the design flood and wind events. However, the designs do not consider flood or seismic loads (24 CFR 3285.303 footnotes to Tables 1, 2, and 3). The HUD standards do not provide guidance on determining the design criteria for flood and seismic events.

The IRC establishes required minimum design loads for residential structures, including manufactured homes. The IRC requires minimum design wind loads where basic wind speeds exceed 100 miles per hour (mph) in hurricane-prone areas or 110 mph elsewhere shall be in accordance with ASCE 7, *Minimum Design Loads for Buildings and Other Structures.* ASCE 7 is a state-of-the-art consensus standard that establishes minimum required design loads to be resisted by structures and their foundations.

9.3.2 Step 2: Select a Design Methodology and Assess Load Combinations and Failure Modes

9.3.2.1 Design Methodology

The two predominant design methods being used in engineering practices today are allowable, or working, stress design (ASD) and strength design. ASD (sometimes referred to as elastic design) is based on the calculated stress in members due to service loads. Strength design (also known as limit state design) is based on ultimate loads (i.e., the load that will cause a member to fail) and the mode associated with the failure. For designing manufactured home installation, either ASD or strength design methodology is acceptable.

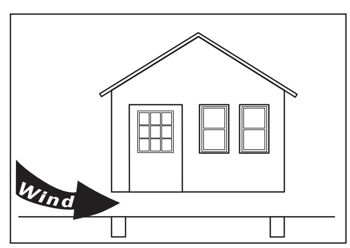
9.3.2.2 Load Combinations

After the design criteria are determined, the possibility of more than one hazard occurring at the same time must be considered for all modes of failure as well as the possibility of imposed loads counteracting gravity loads. For example, it is common to expect simultaneous flooding with high winds during hurricane events. In similar situations, uplift forces due to the high winds from hurricanes can counteract gravity loads. Load combinations are used to assess the probability of more than one hazard occurring simultaneously and the probability of imposed loads exceeding gravity loads. Refer to Section 5.5.1 for a discussion of ASCE 7 load combinations.

Load combinations must be resolved directionally so that all loads in a given combination are acting in the same direction, either vertically or horizontally. The Commentary in ASCE 7 states "Wind and earthquake loads need not be assumed to act simultaneously. However, the most unfavorable effect of each should be considered in design, where appropriate. In some instances, forces due to wind might exclude those due to earthquake, while ductility requirements might be determined by earthquake loads."

All design loads create forces in and on the building. All forces acting on the manufactured home must be transferred through the foundation and into the soil that supports the structure. The foundation designer must ensure integrity of this load path. The primary failure modes in load path integrity include uplift failure, overturning, and sliding (or shearing).

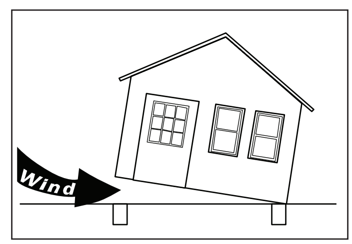
9.3.2.3 Primary Failure Modes



Uplift failure occurs when vertical forces caused by wind or buoyancy exceed the weight of both the structure and the strength of the soil anchorage. The structure fails by being lifted off its foundation or because the foundation pulls out of the soil.

Uplift failure mode is particularly likely when the 3-foot pier rule is used in areas where the BFE is greater than 3 feet above the ground elevation. In that situation, the home will become submerged and exposed to buoyancy forces. For relatively low levels of flooding (9 to 12 inches or less), buoyancy forces can exceed the weight of the home and lift the home off its foundation. To resist buoyancy, foundations must provide sufficient resistance to overcome buoyancy (and wind) and all connections between the home's foundation must be designed to prevent flotation, collapse, or lateral movement, of the submerged home (Figure 9-1).

Figure 9-1. A home that was partially submerged and displaced from its foundation by hydrostatic forces. Although it appears the openings are too high, the bottoms of the openings are less than 1 foot above the top of the interior slab.



Overturning failure occurs when the combined forces of wind, waves, and buoyancy or earthquake exceed the resisting forces of the building's weight and anchorage. The building fails by rotating off its foundation or rotating out of the soil (see Figure 7-8).

Sliding or shearing failure occurs when horizontal forces exceed the friction force or strength of the foundation. The building fails by sliding off its foundation, shear failure of components transferring loads to its foundation, or the foundation sliding.

All three of these failure modes can result in a wide range of damage, from minor, such as loosening of the anchor straps, to catastrophic, such as structural collapse. It is important to emphasize that other load combinations and failure modes may exist, and professional judgment should be exercised in any situations not covered by this guide.

9.3.3 Step 3: Select Foundation Type and Material

After loads are determined and failure modes are assessed, the foundation type and materials must be selected. Both are described in Chapter 8 as well as advantages and special considerations for the selection process.

9.3.4 Step 4: Determine Forces at Connections and on Foundation Components

The loads on components and at connections through the load path must be determined to design an adequate foundation. Some examples of critical points of the load path include the following:

- Connections between the site-built foundation and the home's steel frames (and the home's wall ties if in higher wind zones)
- Load path connections through the site-built foundation
- Load path connections from the foundation to footings
- Adequacy of the footing and surrounding soil

9.3.5 Step 5: Specify Connections and Framing Methods Along with Component Dimensions to Satisfy Load Conditions

The loads determined in Step 4 are used in the design and detailing of connections, foundation components, and anchoring. The loads at connections will be used to design the connections (i.e., number of bolts or nails, size of clip angles). The reactions at the support points will be used to design the foundations (i.e., size of piers and footings, amount of reinforcement, and spacing between piers and ground anchors).

Components and connections design should meet the requirements of an appropriate material standard, some of which are listed in Table 9-1.

Table 9-1. Design Standards and Publishers for Building Materials

Building Material	Standard and Publisher
Wood	*National Design Specification* (NDS) *for Wood Construction* and *Commentary* published by American Forest and Paper Association (AF&PA)/American Wood Council (AWC)
Steel	*Manual of Steel Construction* (AISC 325-05) published by American Institute of Steel Construction (AISC)
Concrete	*Building Code Requirements for Structural Concrete* (ACI 318) published by American Concrete Institute (ACI)
Masonry	*Building Code Requirements for Masonry Structures* (ACI 530) published by ACI

9.3.6 Step 6: Note All Design Assumptions and Details on Drawings

To ensure a quality design and installation, all assumptions, calculations, and details should be clearly documented or noted on the construction documents so that installers and floodplain managers clearly understand the design and design assumptions.

Appendix F provides a detailed example of vertical and lateral load, overturning moment, and, foundation and ground anchor calculations.