5 Natural Hazards – Design Considerations

Many regions in the U.S., such as coastal areas, are subjected to severe flooding and wind events at the same time. Other areas are simultaneously subjected to snow and seismic loads. Manufactured homes can be subjected to more than one hazard at the same time and should be designed to appropriate concurrent loading (or load combinations) based on ASCE 7 design standards. However, *Manufactured Home Construction and Safety Standards* (24 CFR 3280) do not require that designs include simultaneous flood and earthquake loads. The MHCSS specifies that snow loads shall not be considered as simultaneously acting with the wind loads. HUD standards also require that foundations for manufactured homes be designed to resist loads for combined wind and flood events.

The first part of this chapter describes what kind of information is provided in FIRMs and FIS reports. The remainder of this chapter describes the characteristics of several natural hazards (flood, wind, and earthquake) that must be considered when making decisions about siting and selecting a foundation system for a manufactured home.

5.1 Flood Data

FIRMs and FIS reports are two sources that can provide vital information about flooding characteristics. Both of these tools are generally available for viewing at community permitting offices such as Zoning and Planning Departments or Building Permit Offices. The local permit official can go over these tools and help to explain floodplain development requirements. These tools are also available from FEMA's Map Service Center and can be accessed online at http://store.msc.fema.gov.

FIRMs provide key information about a property's flood vulnerability by showing the extent of the floodplain, the flood zone, the floodway (when floodway studies are performed), and the BFE (for detailed studies). Figure 5-1 shows an example of a FIRM. For example, Point 1 (white box) is located in the AE zone and has a BFE of 9 feet. For rivers and streams, FIS reports contain stream profiles that provide more accurate BFE data and should be used when determining BFEs for manufactured home installations or other types of development.

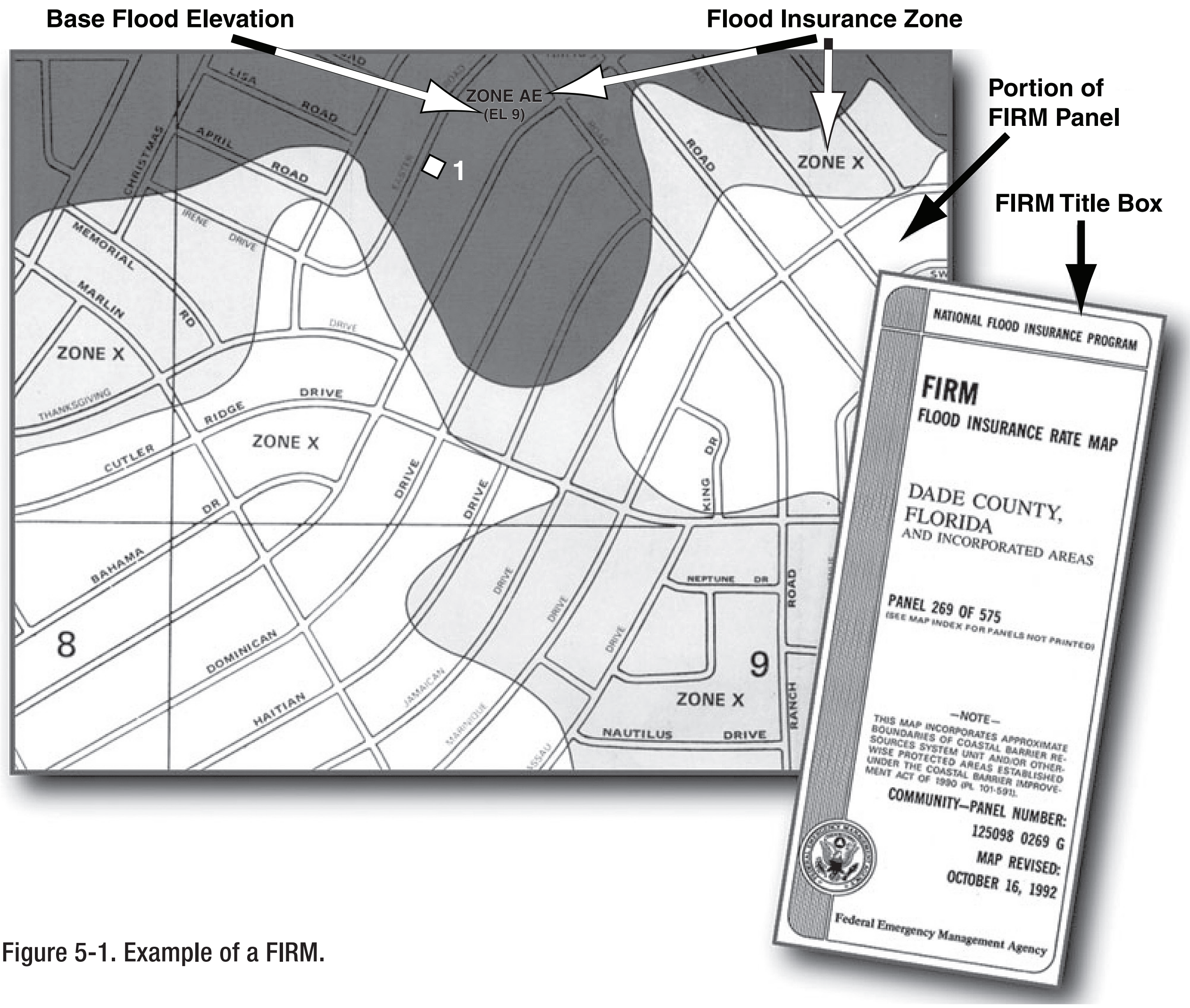


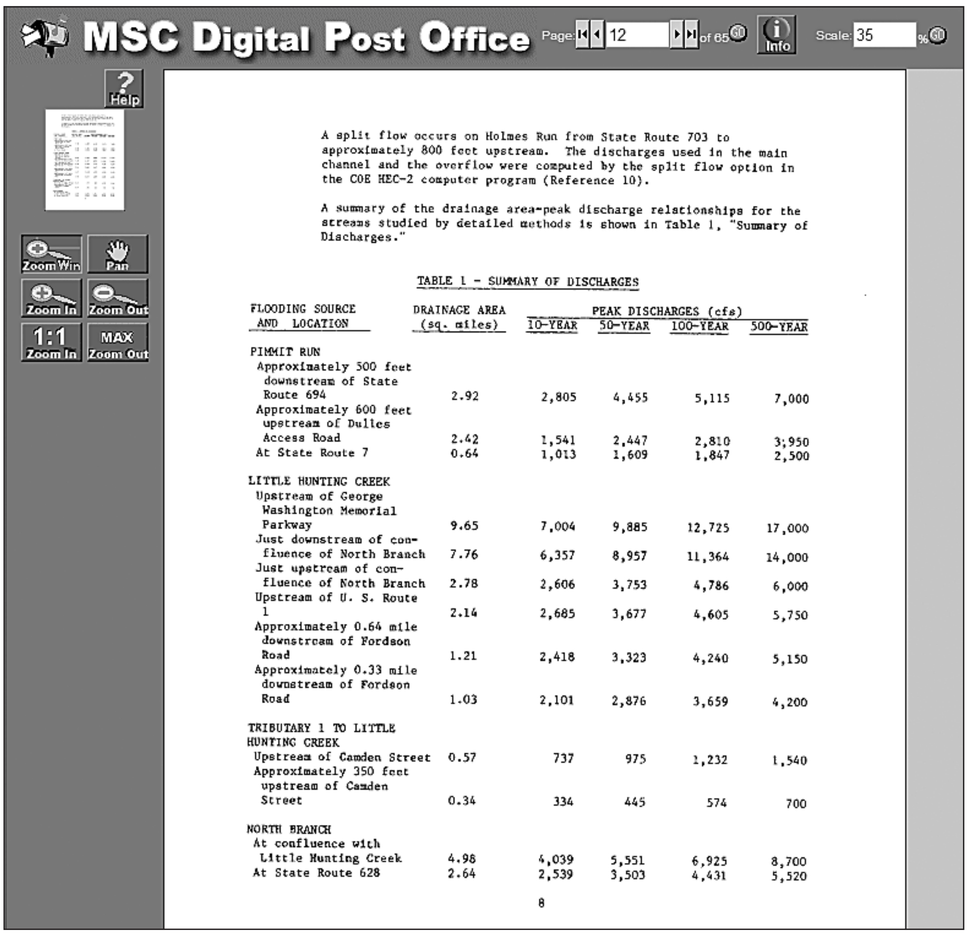
Figure 5-1. Example of a FIRM.

There are two principal digital options for using flood maps. The simplest option is FIRM Scan data. These are simply digital images of a map and are available everywhere FEMA has a published FIRM. FEMA provides tools to view these maps and create a FIRMette, which is a printout of the area of interest, along with FIRM title block, scale bar, and north arrow. There is an online FIRMette tool that allows you to find, view, and print any map when you need it. There is also a Desktop FIRMette tool that can be faster and easier to use if you frequently use the maps for one area or need to use them without an internet connection. You can download or order the FIRMette Desktop and FIRM Scans you need.

The second digital option is flood data in GIS format. GIS technology provides powerful abilities to create custom maps and perform sophisticated analyses. It also requires the user to have specialized skills and software to use. FEMA now produces a GIS product called the DFIRM Database for use with all map updates. Beginning on or after October 1, 2009, FEMA will provide a single paper flood map and FIS to each mapped community. FEMA will convert all other distribution of maps and FIS reports for digital delivery. FEMA will continue to provide free digital map products and data to Federal, State, Tribal, and local NFIP stakeholders.

FIS Reports

Several key components of an FIS report can help users identify specific flooding characteristics. For example, summary of discharge tables report the flow rate of water within streams for a given frequency storm (Figure 5-2). These values can be used with updated topography and cross-section information to conduct hydraulic modeling and to estimate updated flood elevations.[1] FISs generally generate water surface elevations for the 10-year (10-percent annual chance), 50-year (2-percent annual chance), 100-year (1-percent annual chance), and 500-year (0.2-percent annual chance) floods (Figure 5-3). Floodway data tables provide cross-section specific information, including the width of the floodway, mean floodway velocity, and the BFE where there is no encroachment in the flood fringe (or the regulatory BFE) and where there is full encroachment in the flood fringe (Figure 5-4). However, these tables are only available when a floodway study has been performed. See Appendix C for additional information.



A split flow occurs on Holmes Run from State Route 703 to approximately 800 feet upstream. The discharges used in the main channel and the overflow were computed by the split flow option in the COE HEC-2 computer program (Reference 10).

A summary of the drainage area-peak discharge relationships for the streams studied by detailed methods is shown in Table 1, "Summary of Discharges."

TABLE 1 - SUMMARY OF DISCHARGES

FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. miles)	PEAK DISCHARGES (cfs)			
		10-YEAR	50-YEAR	100-YEAR	500-YEAR
PIMMIT RUN					
Approximately 500 feet downstream of State Route 694	2.92	2,805	4,455	5,115	7,000
Approximately 600 feet upstream of Dulles Access Road	2.42	1,541	2,447	2,810	3;950
At State Route 7	0.64	1,013	1,609	1,847	2,500
LITTLE HUNTING CREEK					
Upstream of George Washington Memorial Parkway	9.65	7,004	9,885	12,725	17,000
Just downstream of confluence of North Branch	7.76	6,357	8,957	11,364	14,000
Just upstream of confluence of North Branch	2.78	2,606	3,753	4,786	6,000
Upstream of U. S. Route 1	2.14	2,685	3,677	4,605	5,750
Approximately 0.64 mile downstream of Fordson Road	1.21	2,418	3,323	4,240	5,150
Approximately 0.33 mile downstream of Fordson Road	1.03	2,101	2,876	3,659	4,200
TRIBUTARY 1 TO LITTLE HUNTING CREEK					
Upstream of Camden Street	0.57	737	975	1,232	1,540
Approximately 350 feet upstream of Camden Street	0.34	334	445	574	700
NORTH BRANCH					
At confluence with Little Hunting Creek	4.98	4,039	5,551	6,925	8,700
At State Route 628	2.64	2,539	3,503	4,431	5,520

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Figure 5-2. FIS Summary of Discharges table.

1 Hydraulic modeling can be performed to estimate updated flood elevations where new or more accurate topography data are available. However, if the modeling shows lower flood elevations, they cannot be used for regulatory purposes unless a map revision (e.g., Letter of Map Amendment (LOMA) or Letter of Map Revision [LOMR]) is granted.

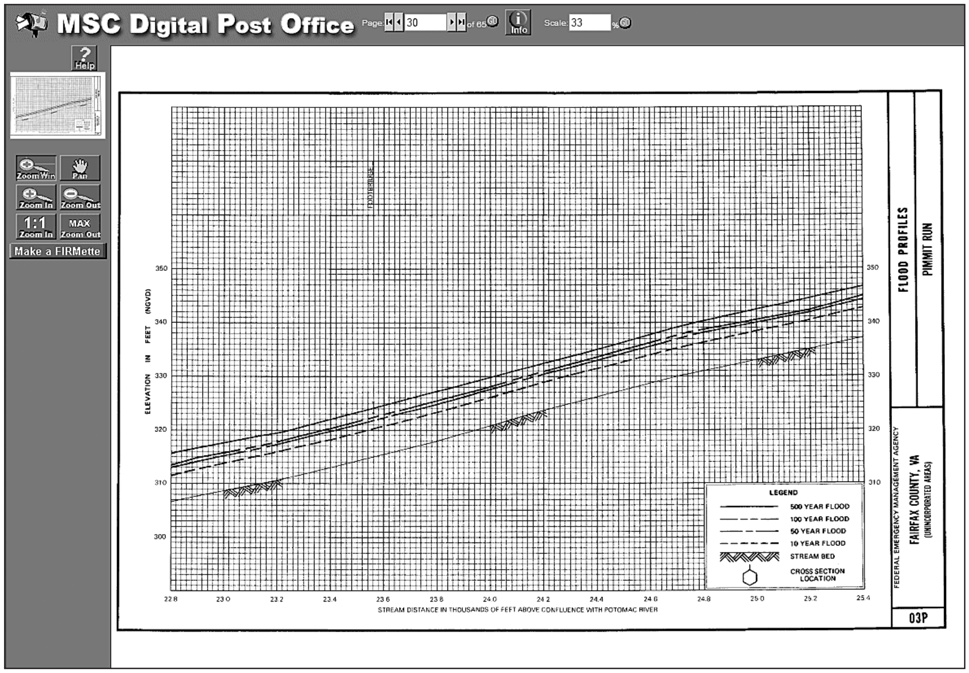
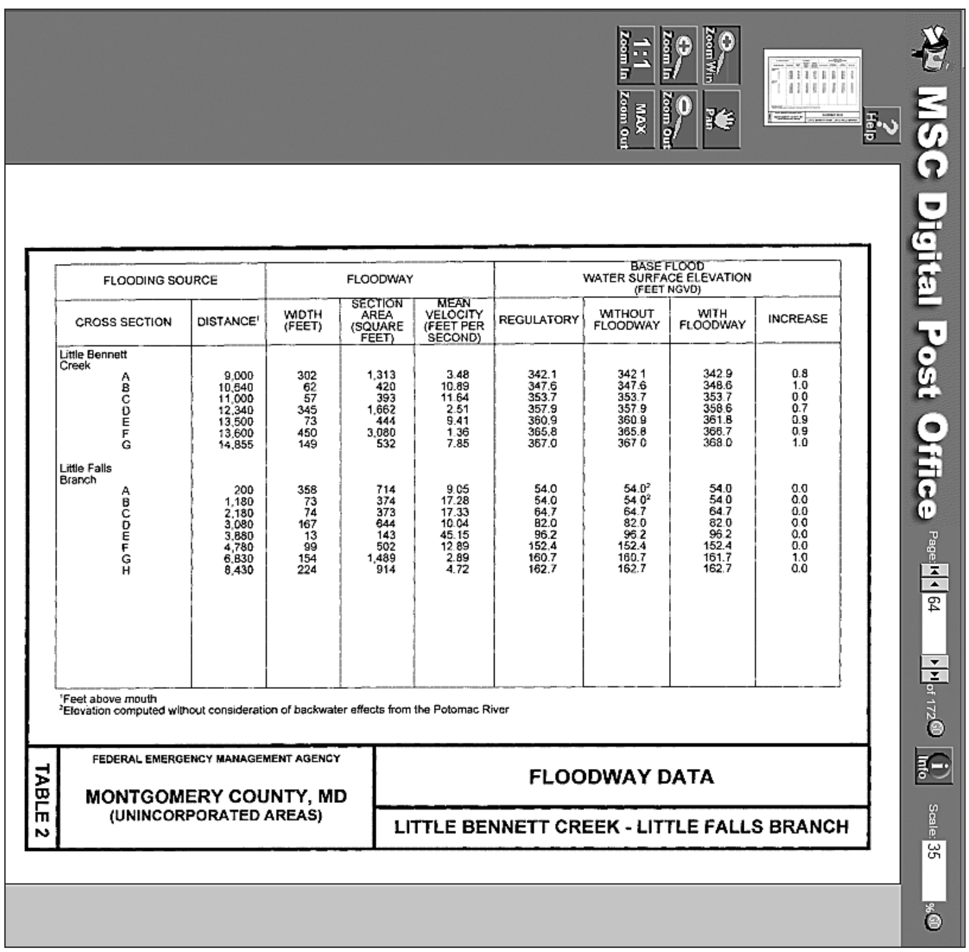


Figure 5-3. FIS Stream Flood Profile.



FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER SURFACE ELEVATION (FEET NGVD)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
Little Bennett Creek								
A	9,000	302	1,313	3.48	342.1	342.1	342.9	0.8
B	10,640	62	420	10.89	347.6	347.6	348.6	1.0
C	11,000	57	393	11.64	353.7	353.7	353.7	0.0
D	12,340	345	1,662	2.51	357.9	357.9	358.6	0.7
E	13,500	73	444	9.41	360.9	360.9	361.8	0.9
F	13,600	450	3,080	1.36	365.8	365.8	366.7	0.9
G	14,855	149	532	7.85	367.0	367.0	368.0	1.0
Little Falls Branch								
A	200	358	714	9.05	54.0	54.0[2]	54.0	0.0
B	1,180	73	374	17.28	54.0	54.0[2]	54.0	0.0
C	2,180	74	373	17.33	64.7	64.7	64.7	0.0
D	3,080	167	644	10.04	82.0	82.0	82.0	0.0
E	3,880	13	143	45.15	96.2	96.2	96.2	0.0
F	4,780	99	502	12.89	152.4	152.4	152.4	0.0
G	6,830	154	1,489	2.89	160.7	160.7	161.7	1.0
H	8,430	224	914	4.72	162.7	162.7	162.7	0.0

[1]Feet above mouth
[2]Elevation computed without consideration of backwater effects from the Potomac River

TABLE 2

FEDERAL EMERGENCY MANAGEMENT AGENCY

MONTGOMERY COUNTY, MD
(UNINCORPORATED AREAS)

FLOODWAY DATA

LITTLE BENNETT CREEK - LITTLE FALLS BRANCH

Figure 5-4. FIS Floodway Data table.

5.2 Flood Characteristics

A variety of factors contribute to the type and strength of flood forces. For instance, structures and their foundations are subject to different forces if they are flooded by standing or slowly moving floodwater versus high velocity or wave action flooding. Similarly, factors such as the duration of flooding and flood depth help to define how structures and foundations will be affected by flood events.

5.2.1 Frequency, Duration, and Rate of Rise

Frequency of flooding is the rate of flood occurrence at a particular location. This frequency is the probability, expressed as a percentage, that a flood of a specific size will be equaled or exceeded in any year. For example, the flood that has a 1-percent probability (1 in 100) of being equaled or exceeded in any given year is referred to as the "base flood" and sometimes called the "100-year flood;" the latter term is simply a convenient way to express probability. The base flood is particularly important for homeowners because it is used by the NFIP to determine flood insurance rates and define regulatory floodplain management requirements.

A 1-percent annual chance flood is a probability term and does not mean that a flood will happen approximately once every 100 years. Nor does it imply that once a 1-percent annual chance flood occurs there is little chance of another 1-percent annual chance flood occurring in the near future. To the contrary, changes in climatic conditions, such as those caused by El Niño or La Niña, often result in a cluster of floods that occur over relatively short periods of time at the same location.

Manufactured homes located within the 100-year floodplain on a FIRM might also be in the 10- or 5-year floodplain and subject to even more frequent flooding. Although more frequent floods such as the 10- or 20-percent annual chance flood (10- or 5-year flood) cause less damage to the manufactured home than the 1-percent annual chance flood, the repetitive damages can result in significant financial loss to the homeowner. Data describing the extent of more frequent but less intense flooding is also important in determining the foundation system most appropriate for resisting forces imposed by the smaller floods.

Information about the base flood can be found in the FIS and the FIRM, including the flood elevation and the extent of flooding. In areas where detailed studies have been performed, flood elevation information may also be available for the more frequent 10- or 2-percent annual chance flood as well as the less frequent 0.2-percent annual chance flood (500-year flood).

For historical flood events, flood frequency estimations are sometimes found in the FIS under the Principal Flood Problems section. Documentation of past flood events is sometimes available from other Federal sources as well as State and local agencies. Table 5-1 lists such sources and agencies.

Table 5-1. Sources for Information About Past Flood Events

Other Federal Sources	State Agencies	Local or Regional Agencies
USACE Floodplain Information Reports	Departments of Environmental Conservation/Protection	Flood Control Districts
USGS Water Resources Investigations	State Floodplain Management Office	Levee Improvement Districts
Natural Resources Conservation Service (NRCS) Watershed Studies	Departments of Natural Resources	Local Planning Commissions
Federal Highway Administration (FHWA) Floodplain Studies	Departments of Transportation	Local Public Works Departments
Tennessee Valley Authority (TVA) Floodplain Studies	Departments of Water Resources	Municipal Utility Districts
	Geologic Surveys	River Basin Commissions
		Water Control Boards

Flood duration is the time from the inundation to the recession of floodwaters. Flood duration provides an estimate of how long a manufactured home's foundation (not the home itself, assuming the home is properly elevated) will be subjected to pressures and forces exerted by floodwaters, the degree of floodwater seepage, and the length of time that a structure may be inaccessible and/or inhabitable for the occupants. For identical flood characteristics, long duration flooding is usually much more destructive than short duration flooding.

The rate of rise is a measure of how rapidly water depths increase during flooding. A slow rise of floodwaters will allow seepage of water into a manufactured home (only if it is not elevated above the flood level) and may prevent buoyancy forces from acting on a home. When water rises rapidly, however, there may be insufficient time for seepage, exposing the home to buoyancy forces. The buoyancy forces could result in failure of the foundation, the floor, or the framing of the home.

The rate of rise (and fall) also affects the amount of warning for an impending flood. For example, homeowners in the floodplains of large rivers like the Mississippi may know days in advance of upstream flooding that will eventually reach their homes. But in the floodplains of streams with high rates of rise, homeowners may have only a few hours' notice (or none at all) of an approaching flood.

The rate of rise and fall is important in planning emergency evacuations and determining the feasibility of emergency loss mitigation procedures. Although surrounding and upstream terrain is a good indicator of the rate, flooding duration for particular areas is best determined from historical data and accounts of past flood events. This information might be available locally from accounts given by homeowners and local emergency management staff, or it may be documented in the FIS or local, State, or Federal studies. See Table 5-1 for a list of potential sources of information.

5.2.2 Flood Elevation and Depth

The BFE is the elevation of the flooding, including wave height, if applicable (in V zones), having a 1-percent chance of being equaled or exceeded in any given year. The elevation of the flooding is the floodwater's height above or below an established reference datum. Ground elevation is the height of the ground surface also above or below an established reference datum. The standard datum used by most Federal agencies and many State and local agencies are the NGVD 29, and the NAVD 88; however, other datum are used. Ground elevations are established by topographic surveys; flood elevations are calculated for a particular flood event. BFEs can be found on FIRM panels where a detailed study has been performed, and should be estimated using the flood profile in the corresponding FIS.

BFE and DFE

Base flood elevation (BFE) – The water surface elevation resulting from the base, or 100-year (1 percent annual chance) flood.

Design flood elevation (DFE) – The elevation to which development in the regulatory floodplain is built. At a minimum, the DFE is equivalent to the BFE. However, in some areas, the DFE includes an additional freeboard height above the BFE as shown in the formula below.

DFE = BFE + Freeboard

Freeboard – An additional elevation requirement some height (1, 2, or more feet) above the BFE that provides a margin of safety above the estimated BFE.

As indicated above, the minimum DFE requirement for NFIP communities is the BFE. However, in communities where a higher degree of protection is promoted or required, the DFE includes a freeboard height above the BFE. This freeboard provides a margin of safety above the estimated BFE and against extraordinary or unknown risks. As in all natural hazard events, the design event can only be predicted in probabilistic terms and some uncertainties remain in any analysis. Freeboard is intended to allow for those uncertainties. The NFIP encourages participating communities to adopt and enforce freeboard requirements as part of their local floodplain management ordinance. This is shown in 44 CFR 60.1(d); which states, "Any floodplain management regulations adopted by a State or a community which are more restrictive than the criteria set forth in this part are encouraged and shall take precedence."

Some flood zones are delineated by approximate methods without BFEs determined. When a manufactured home is proposed on an approximate A zone site, the community must make every effort to obtain, review, and reasonably utilize BFE data and floodway data from a Federal, State, or other source in order to provide a reasonable measure of flood protection in accordance with 44 CFR 60.3(b)(4). If BFE or floodway data cannot be obtained from available sources, the community should consider conducting or requiring the applicant to conduct a site-specific engineering analysis to determine a BFE or floodway. FEMA has developed *Quick-2: Computation of Water Surface Elevations in Open Channels*, which is useful in developing a BFE. *Quick 2* is available from the FEMA web site http://www.fema.gov/plan/prevent/fhm/dl_qck22.shtm. If no BFE data are available through Federal, State, or other sources, communities must ensure that building sites will be reasonably safe from flooding for proposed developments. A simplified method for estimating BFEs as well as other methods for ensuring a building site is reasonably safe from flooding can be found in FEMA 265, *Managing Floodplain Development in Approximate Zone A Areas, A Guide for Obtaining and Developing Base (100-year) Flood Elevations*. Additional guidance on approximate A zones and requirements for developing BFEs in subdivision proposals and other proposed developments can be found in Section 3.6.1.

Flood depth is the difference between the water surface elevation and the grade elevation of the flooded area (Figure 5-5). Any differences in datum between the flood elevation and the grade elevation must be taken into account when calculating flood depths.

Many communities have adopted more stringent requirements for an additional elevation (e.g., 1 foot, 1.5 feet, etc.) above the BFE. The additional height (or freeboard) is used to establish the DFE. Freeboard provides a margin of protection above the estimated base flood.

5.2.3 Hydrostatic (Buoyancy) Forces

For manufactured homes that are not elevated to above the BFE or DFE, hydrostatic forces can cause significant damages. Hydrostatic pressures are also a concern for enclosed areas underneath elevated manufactured homes.

When a body or a structure is immersed in water, the body is subjected to forces exerted by the surrounding water. These forces are called hydrostatic forces and act perpendicular to the surface on which they are applied. For example, hydrostatic forces exert lateral forces on vertical walls and vertical forces on horizontal floors.

The total vertical force (also called buoyancy force) on a submerged structure is equal to the weight of the displaced volume of water. For each foot of fresh water submersion, a buoyancy force of 62.4 psf is created. Salt water, with a greater density than fresh water, creates 64 psf for each foot of submersion. That is

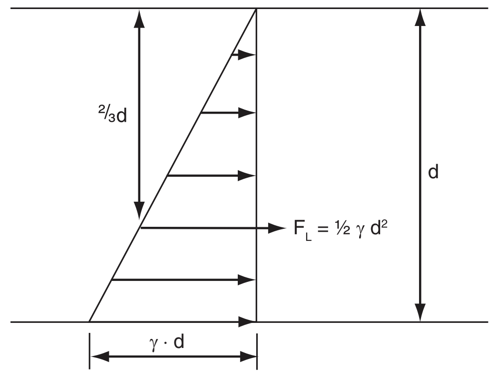
$$F_{buoy} = \gamma \text{ x } V_{OL}$$

Where: γ = specific weight of water (62.4 pcf for fresh water; 64 pcf for salt water)

V_{OL} = volume of water displaced by the submergence object (ft^3)

The lateral force of water acting against a surface is related to the water's depth (d) and specific weight (γ). Hydrostatic forces create a triangular loading on vertical surfaces with zero psf on the water surface to a force equal to γ (pcf) multiplied by d (feet).

$$F_L = \tfrac{1}{2} \gamma d^2$$



Hydrostatic Force Distribution

Where: F_L = lateral force

γ = specific weight of water (pcf)

d = depth (ft)

F_L is applied at a distance 2/3 d from the water's surface.

Hydrostatic forces act perpendicular to submerged surfaces. If the water depth is the same on both sides of a wall, the lateral component of hydrostatic forces are equal such that the resultant force is zero.

If floodwater rises above the lowest floor, hydrostatic forces can lift an inadequately anchored manufactured home off its foundation. If buoyancy forces exceed the weight of a manufactured home, the home will float off its foundation if it is not securely fastened to the foundation. Floods do not need to be deep to displace a home. Flood depths of only 4 to 5 inches above the lowest floor can be capable of floating unsecured manufactured homes off their foundations.

The walls and floors of manufactured homes are not typically designed to resist hydrostatic forces, which can cause extensive structural damage. Floodwaters in contact with a home generally seep into it through openings around doors, windows, vents, and utility entrances. Floodwaters inside the structure add weight to the structure, thus reducing the net buoyancy force of the structure. Figure 5-5 shows hydrostatic forces acting on the walls and lowest floors below the flood level. As illustrated in Figure 5-5, an effective method of avoiding damage from hydrostatic forces is to elevate the home above the flood levels.

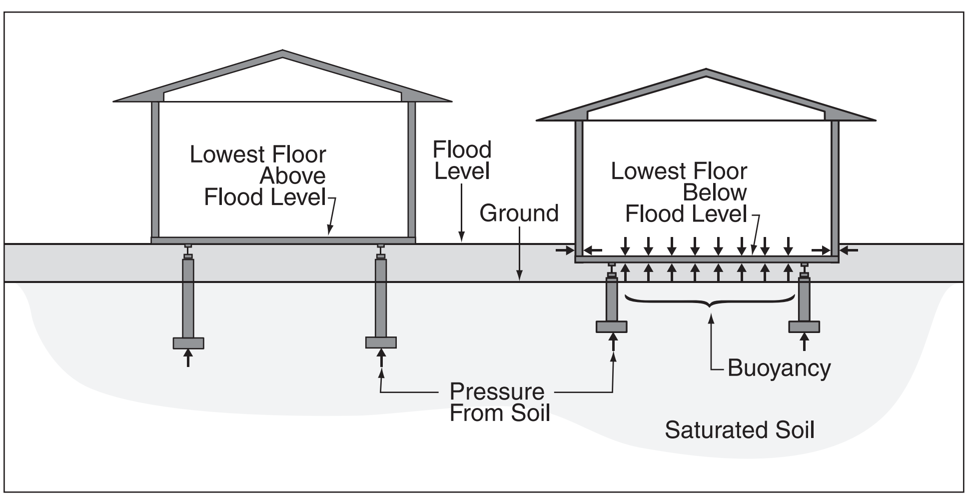


Figure 5-5. Buoyancy forces acting on a structure.

5.2.4 Hydrodynamic Forces

Forces due to moving floodwaters are called hydrodynamic forces. The magnitude of these forces depends on the floodwater depth, floodwater velocity, and the drag coefficient. Higher depths and velocities produce greater hydrodynamic forces. The drag coefficient is a function of the shape of the body subjected to the hydrodynamic forces.

Moving floodwaters can cause foundation failure by pushing (sliding failure) (Figure 5-6) or by overturning. Either can topple foundation elements and destroy a home. In addition, moving floodwaters can cause erosion and scour that can undermine foundation elements (Figure 5-7).

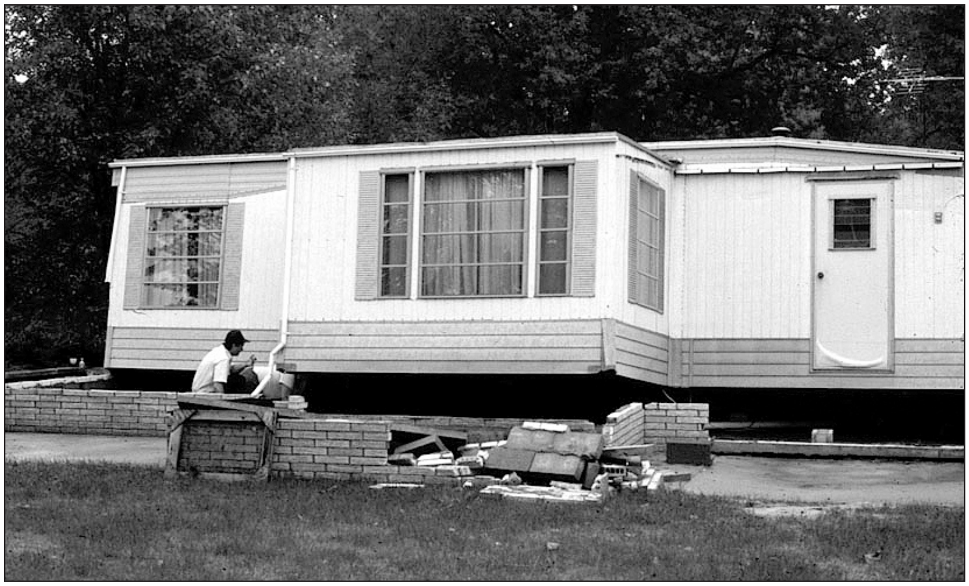


Figure 5-6. Failure due to sliding.

Figure 5-7. A manufactured home destroyed by the hydrodynamic forces of flooding.

Flood velocity depends on the slope and roughness of the terrain. For example, water moves faster along streams in steep mountains than streams in flatter areas, and water moves faster over a parking lot with a paved surface as opposed to an area with dense vegetation or other obstacles. Flood velocities are not shown on the FIRMs, but can be found in the FIS for floodways where floodways have been studied. Mean floodway velocities can be obtained from the FIS by matching the cross-section on the FIRM with the cross-section in the floodway data table. The floodway's mean velocity usually overestimates the flood velocity within the flood fringe; floodwaters generally move slower as they extend outward from the floodway. However, the floodway velocities can be used as a general measure to determine cross-section locations within the floodplain where floodwaters will move relatively faster or slower, and provide an upper limit for velocities in the flood fringe. One of the best sources for flood velocities is records of past flood events. In addition to the FIS, a list of potential sources for documentation of past flooding is included in Table 5-1.

Coastal areas are particularly hazardous because of flooding accompanied by wave impacts that are associated with storm surges from coastal storms. Flow velocity can be further increased by manmade or natural obstructions that restrict floodwaters and channel the flow.

The hydrodynamic force exerted by a fluid in the direction of the flow stream is defined as the drag force F_d. Hydrodynamic forces are calculated as follows:

$$F_d = \frac{C_d \times A \times \gamma \times V^2}{2g}$$

Where: F_d = hydrostatic force (pounds)

C_d = dynamic coefficient (1.25 for round piers; 2.0 for square or rectangular piers; 1.4 for continuous foundations)

γ = specific weight of water

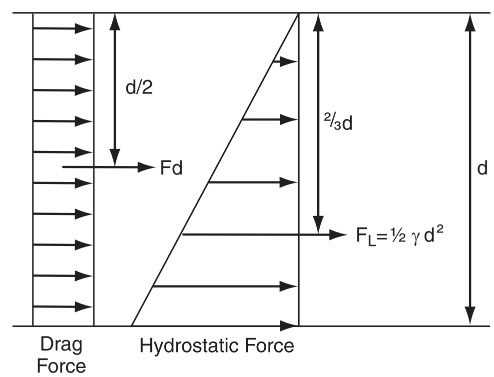
g = acceleration due to gravity (32.2 ft/s^2)

V = floodwater velocity (fps)

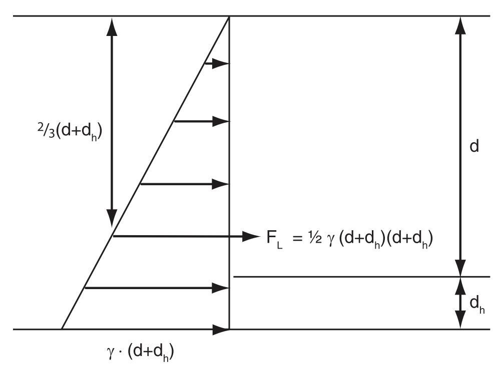
A = projected vertical area submerged (sq. ft.)

A = d x w

w = width of the submerged object



Hydrostatic and Hydrodynamic Force Distribution



Equivalent Hydrostatic Load Approach to Consider Hydrodynamic Force

An alternative approach to consider the dynamic effects of moving water is to use an equivalent hydrostatic load approach. When water velocities are less than 10 fps, ASCE 7 permits adding an equivalent surcharge water depth to the design flood elevation to simulate the hydrodynamic load.

The equivalent surcharge water depth (d_h) is determined by:

$$d_h = \frac{C_d \times V^2}{2g}$$

Where: C_d = dynamic coefficient (1.25 for round piers; 2.0 for square or rectangular piers; 1.4 for continuous foundations)

V = average velocity of water (fps)

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

Hydrodynamic forces apply to any portion of the home or its foundation exposed to moving floodwaters. Elevating the home so that its lowest floor is at the BFE reduces the effects of hydrodynamic forces on the building envelope. However the floor framing, chassis frame, and the foundation elements remain exposed to the hydrodynamic forces. For open foundations, elevating the home so the lowest chassis frame member is at the BFE reduces the effects of hydrodynamic forces by reducing the number of components exposed to those forces during a base flood event.

5.2.5 Erosion and Scour

Erosion is the result of moving waters removing soil from the ground surface. Scour is the result of those moving waters removing soil beneath and around objects located in the path of flow. Scour under and around building foundations and erosion of fill embankments can result in foundation failure. For example, when Hurricane Ike struck Galveston, Texas, in 2008, several homes were destroyed due to a loss of lateral support of pile foundations caused by scouring. Moving floodwaters will erode soil around any obstruction placed in the flow until a maximum scour depth is reached. The maximum scour is a function of flow velocity, soil particle size, and obstruction geometry. Determining maximum potential scour is critical in designing a foundation system that prevents failure during and after flooding. In coastal areas, scour depth can be significant due to both storm-induced erosion and localized scour resulting from storm surge. Because storm-induced erosion is difficult to predict, local regulatory officials should be contacted for further information and historical perspectives.

Scour susceptibility is a function of foundation geometry, flow depth, flow velocity, and the soil particle size. Fine grain soils (i.e., silts and clays) scour at a lower flow velocity than coarse grain soils. Coarse grain, non-cohesive soils can erode and/or scour quickly, possibly reaching the ultimate scour depth in a single flood event. Fine grain, cohesive soils can scour just as deep but take longer to reach the ultimate depth. It is important to note that foundations frequently are well above the ultimate scour depth and that foundation undermining can occur in a relatively short time period. Undermining of foundations can result in the collapse of the home.

Because flood velocities are not shown on FIRMs, the FIS must be consulted to determine flood velocities, which are only provided for floodways. In some SFHAs, floodways and mean floodway velocities have not been determined as part of the FIS.

The preferred scour mitigation technique is to place the manufactured home's foundation below the predicted ultimate scour depth. In areas where placing foundations below maximum scour depth is not economically feasible, alternative scour protection methods include reinforcing foundation soils with large diameter materials such as coarse aggregate or riprap.

5.2.6 Debris Impact Forces

Floodwaters can transport objects of all types (e.g., trees, portions of flood-damaged buildings, automobiles, boats, storage tanks, manufactured homes, etc.). In cold climates, winter floods can also carry large pieces of ice. Substances such as dirt, oil, gasoline, sewage, and various types of debris add to the dangers of flooding. Even when flow velocity is relatively low, large objects carried by floodwaters can easily damage windows, doors, walls, and, more importantly, critical structural components. As the flood velocity increases, the danger of damage from floodborne debris also increases.

Waterborne debris impacts caused significant damage to buildings and enclosures, slabs, decks, utilities, and other ancillary features when Hurricane Ivan struck the Florida panhandle and coastal Baldwin County, Alabama in 2004. Manufactured homes typically are not designed to withstand loads to walls or floor systems that may be exerted by attached carports, decks, porches, or awnings, although some manufacturers have designed homes that are "awning ready" to provide a load path through the structure to handle the increased stresses. The alternative is to build the attachments with adequately anchored foundations to resist these debris impact forces.

Damages caused by floodborne debris impacting a manufactured home depend not only on the weight and velocity of the debris, but also on the size and material. Historically, the forces developed when floating debris hits a home have been estimated using the principles of conservation of momentum with impact duration of 1 second. Recent research, however, indicates that the impact from floodborne debris occurs over intervals of only 0.01 to 0.05 second. Since impact force is inversely proportional to duration (i.e., the shorter the duration, the larger the impact force), historical methods may underestimate impact forces. Typical impact duration ranges from 0.1 second for stiff foundations (such as concrete) to 1 second for flexible foundations (such as wood).

$$F_i = (W/g) \times (V_b/t)$$

Where: F_i = impact force (pounds)

W = weight of floodborne object (pounds)

V_b = velocity of object (fps)

t = time for object to decelerate from V_b to zero (seconds)

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

ASCE 7-05 updates the methods of calculating impact debris forces. Recent research indicates that the impact durations are much shorter and impact loads are significantly higher than previously recommended. Foundations for manufactured homes located in SFHAs should be designed to resist floodborne debris impact forces calculated based on the most recent edition of ASCE 7 protocols.

The relatively light and frequently unreinforced foundation systems used to support and anchor manufactured homes are susceptible to impact damage from floating debris. The cost to strengthen foundations, ground anchors, and anchor straps to resist debris impact may be economically impractical. An alternative method is to install additional foundation elements to provide redundancy in the system. For example, reducing the frame span length by reducing pier spacing allows the frame to span across a damaged pier without excessive deflections or failure. This method requires post-flood inspection and maintenance to repair or replace damaged foundation elements to allow the home's foundation to survive any subsequent events. Also, if more foundation elements than what have been assumed are damaged, a finite risk of system failure remains.

5.3 Wind

Design and installation of foundations of manufactured homes is a controlling factor on the homes' ability to withstand forces from wind events. Connections used to secure the manufactured homes to the foundations have historically lacked the attention given to the manufacturing of the homes themselves. Lack of proper connections has caused numerous homes to fail during high-wind events. Figures 5-8 and 5-9 are examples of wind damage to modular and manufactured homes.

Several factors influence the direction and magnitude of wind forces on a structure, which should be considered in manufactured home foundation design.

When a structure is exposed to these wind forces in combination with flood forces, the damage potential is greatly increased.

Figure 5-8. Failure of a modular home due to high winds. The home lifted off of its foundation (concrete slab) when the connections failed.

Figure 5-9. A manufactured home that failed during a high-wind event.

5.3.1 Wind Forces on Structures

The texture and roughness of the terrain, as well as its surface contours and topography, have a profound effect on the wind loads. A structure in an open flat area with few trees and obstructions is likely to see a substantially higher wind load than one situated in a developed area with numerous buildings or other obstructions. Similarly, a structure situated on a hilltop may be subjected to significantly greater loads than one on flat terrain. All structures should be built to withstand the forces caused by the strongest wind speeds likely to happen at the site.

The basic design wind speeds for the United States can be obtained from the map given in Figure 6-1 of ASCE 7. The wind speeds correspond to 3-second gust speeds in mph at 33 feet (10 meters) above the ground for open terrain with scattered obstructions having heights generally less than 30 feet (9.1 meters), Exposure C category. This includes flat open country and grasslands.

When a building is exposed to wind, the wind flows over and around the building. This imposes positive pressure on the windward side of the building and negative pressure (suction) on the leeward side and roof of the building.

5.3.2 Wind Forces in Combination with Flood Forces

Damage potential is increased when wind forces are exerted on a structure in combination with flood forces, as is often the case in coastal and mountainous areas. For example, tensile forces can develop at the windward piers and the home can be lifted. If the windward piers are exposed to moving floodwaters, they can topple when no longer in contact with the home's steel frame.

Elevating a manufactured home to minimize the effects of flood forces does not significantly increase the wind loads on the home.

The HUD *Model Manufactured Home Installation Standards* require foundations to consider flood and wind load combinations. Sections 2.3.3 and 2.4.2 in Chapter 2 of ASCE 7, *Minimum Design Loads for Buildings and Other Structures* contain load combinations that should be used.

5.4 Earthquakes

Designing resistance of structures and foundations for earthquakes requires a different approach than that used for flooding and wind. Because earthquakes can affect internal building elements without requiring penetration of the building like flooding or wind, there are design considerations specific to earthquakes.

Often designing for wind load standards will allow a manufactured home installation to be adequate for protecting the home from earthquake forces. However, there are instances when forces resulting from earthquakes can result in greater loads than those for wind.

5.4.1 Design Philosophy

Earthquake-caused ground accelerations cause forces on building elements attached to or into the ground. Foundation movements are transmitted to structural and non-structural components. Consequently, exterior and interior building components should be designed for seismic loads to be transferred to the remaining elements.

In the event of an earthquake, a structure will be simultaneously subjected to vertical and horizontal accelerations. The weight of a manufactured home on its foundation is not sufficient to resist a moderate or severe earthquake. Therefore, the manufactured home and its foundation should be properly connected to avoid damage during an earthquake event. Soil liquefaction resulting from an earthquake is also an important consideration for earthquake design because soil liquefaction is a major cause of damage in a seismic event. Refer to Chapter 6 for a discussion on liquefaction.

5.4.2 Design Standard

Regulations governing the construction and design of manufactured homes currently do not specifically address seismic loads but rather specify loading requirements primarily to provide basic wind resistance. However, seismic requirements exist in most model codes and standards. Seismic requirements have been included in the *Model Manufactured Home Installation Guide* (NFPA 225).

Historically, communities with low seismicity have considered wind load provisions as sufficient for resisting seismic events. Although this may be true in the case of transverse loading (i.e., wind pressures acting on the long walls) where wind loads are high, it is often not the case with longitudinal loading where wind loads are low. Also, the nature of seismic loading is greatly different than wind loading. These differences make comparisons between wind resistance and seismic resistance tenuous at best.

Studies list the following typical damages to manufactured homes during design earthquakes:

- Homes falling off support systems
- Damage to floors from piers puncturing them
- Disruption of gas, water, and electrical lines from seismic motions of the home
- Fire resulting from damaged water heaters, and gas and electric lines. (A simple and cost-effective seismic mitigation measure for manufactured homes is to strap the water heater to a wall to prevent it from falling over.)

For a manufactured home installed on a foundation system, providing adequate resistance to lateral movement, uplift, and rotation is very important. It is also necessary to provide tensile connections between the main frame and the piers supporting the home to resist all seismic forces. Earthquake-resistant bracing systems (ERBSs) can be installed to minimize damage to the home, but they do not provide the protection of a seismic-resistant foundation system. ERBSs are secondary supports that do not resist seismic forces, but rather allow the home to fall from its primary supports and "catch" it before it hits the ground.

The State of California has had an ERBS certification program since 1987. To be certified, the ERBS must be able to limit seismic movement and limit vertical drop of the manufactured home to 2 inches. A list of certified ERBSs is available from the State of California, Department of Housing and Community Development, Division of Codes and Standards. The price range of ERBSs is from approximately $2,000 up to $5,000; the average cost of an ERBS is about $2,500. The State of California also permits the use of other systems that do not require the home to fall off supports, as is the case with ERBSs.

5.5 Evaluation of Multi-Hazards

Manufactured homes, like all buildings, can be simultaneously subjected to many natural hazards, and the combined effects of the forces generated from these hazards must be considered. The different loads that must be considered in the design of a manufactured home foundation are shown in Table 5-2.

Table 5-2. Load Combination Nomenclature (ASCE 7)

Nomenclature	Load Description
D	Dead load
L	Live load
F	Load due to fluid with well-defined pressures and maximum heights
F_a	Flood loads
H	Load due to lateral earth pressure, groundwater pressure, or pressure of bulk materials
T	Self-straining force

Table 5-2. Load Combination Nomenclature (ASCE 7) (continued)

Nomenclature	Load Description
L_r	Roof live load
S	Snow load
R	Rain load
W	Wind load
E	Earthquake load

Load combinations are used in the design process to take into account the simultaneous occurrence of different hazards. Manufactured homes and their foundations should be designed to the load combinations indicated by the applicable building code for the area. In the absence of a building code, the manufactured home should be designed in accordance with the load combinations given in ASCE 7.

5.5.1 Load Combinations (ASCE 7)

5.5.1.1 Strength Design (Load and Resistance Factor Design)

Strength design is defined as a method of proportioning structural members such that the computed forces produced in the members by the factored loads do not exceed the member design strength.

According to ASCE 7, the basic load combinations for strength design (using the nomenclature in Table 5-2) are as follows:

1. 1.4(D+F)
2. 1.2(D+F+T) + 1.6(L+H) + 0.5(L_r or S or R)
3. 1.2D + 1.6(L_r or S or R) + (L or 0.8W)
4. 1.2D + 1.6W + L + 0.5(L_r or S or R)
5. 1.2D + 1.0E + L + 0.2S
6. 0.9D + 1.6W + 1.6H
7. 0.9D + 1.0E + 1.6H

When a structure is located in a flood zone, the following load combinations must also be considered:

1. In V zones or Coastal A zones, 1.6W in combinations (4) and (6) shall be replaced with 1.6W + 2.0F_a.

2. In non-Coastal A zones, 1.6W in combinations (4) and (6) shall be replaced by 0.8W + $1.0F_a$.

5.5.1.2 Allowable Stress Design (also known as Working Stress Design)

Allowable stress design (ASD) is defined as a method of proportioning structural members such that computed stresses produced in the members by nominal loads do not exceed specified allowable stresses.

According to ASCE 7, the basic load combinations for ASD are as follows:

1. D + F
2. D + H + F + L + T
3. D + H + F + (L_r or S or R)
4. D + H + F + 0.75(L + T) + 0.75(L_r or S or R)
5. D + H + F + (W or 0.75E)
6. D + H + F + 0.75(W or 0.7E) + 0.75L + 0.75(L_r or S or R)
7. 0.6D + W + H
8. 0.6D + 0.7E + H

When a structure is located in a flood zone, the following load combinations must be considered:

1. In V zones or Coastal A zones, 1.5 F_a shall be added to other loads in combinations 5, 6, and 7 and E shall be set equal to zero in 5 and 6.
2. In non-Coastal A zones, $0.75F_a$ shall be added to combinations 5, 6, and 7 and E shall be set equal to zero in 5 and 6.

Either ASD or strength-based design can be used for manufactured housing. In both design methods, wind and seismic loads need to be evaluated. In addition, increases in allowable stress shall be used with these load combinations where allowed by the locally adopted building code.