

DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS

Guide to Hurricane Strengthening for Hawaii Single-Family Residences

Prepared with the assistance of Martin & Chock, Inc. December 2015

Cover image source: NOAA, Hurricane Iselle and Hurricane Julio approaching the Hawaiian Islands, August 7, 2014.

State of Hawai'i Guide to Hurricane Strengthening of Homes,

2015



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DISCLAIMER

The information contained in this publication is intended for property loss reduction, not for loss elimination or protection of life or protection from bodily injury. By using this publication, the user agrees to hold the State of Hawaii and any of its employees, agents or independent contractors harmless from any liability arising directly or indirectly from such use. The State of Hawaii and any of its employees, agents or independent contractors makes no warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, product, or process included in this publication. The usefulness of the advice contained in this publication depends on the windspeed and the condition and site of the structure. The user is forewarned that actual hurricane conditions may vary and that at higher windspeeds the loss mitigation techniques described in this publications is solely the responsibility of the user and the user assumes all risk and liabilities, if any, with respect to the use of the wind resistive devices or the information in these Specifications. This publication is not a recommendation to shelter in place in the event of high winds.

This publication with generic information does not ensure conformance with building codes applicable to new construction and alterations and additions to existing structures. For that type of work, the county building code should be used. The Department of Business Economic Development and Tourism, Office of Planning, has sponsored a *Guide to the Wind Design Provisions of the Hawai'i State Building Code* to assist building officials and design professionals with explanatory information on the significant wind design provisions that the State adopted to amend the International Building Code for use in Hawai'i.

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1 ABOUT THE GUIDE

The guide is based in part on previous technical specifications utilized for a Loss Mitigation Grant Program for Wind Resistive Devices that was administered by the Department of Commerce and Consumer Affairs (DCCA) Insurance Division from 2006-2008 per an authorization from the State Legislature. This information has been updated in part to enable greater public access to the wind retrofits that were specifically developed for Hawaii construction; this also supports the state resilience strategy for wind hazard mitigation. In accordance with Hawaii Revised Statues Chapter 431P, Section 12, the Hawaii Hurricane Relief Fund administered by the DCCA Insurance Division is tasked with developing a plan for loss reduction of existing structures. The Department of Commerce and Consumer Affairs Hawaii Insurance Division commissioned Martin & Chock, Inc., Structural Engineers in 2015 to create an updated engineering based guide for retrofitting residential structures for loss reduction. This guide does not cover protection against water damage following roof system failures and window breakage.

1.1 WHY WAS THIS GUIDE DEVELOPED?

The engineering and design of our buildings improve over time as our knowledge increases. Hawaii's past hurricanes that made landfall, Iniki (1992) and Iwa (1982), have shown that Hawaii's older houses are more vulnerable to major structural failure from wind forces. Modern building code requirements based on the International Building Code and the ASCE 7 Standard are stricter to reflect lessons learned from the damage of past hurricanes and updated analysis of hurricane climatology. There is a significant gap in structural vulnerability between older and newer homes.

This guide is intended to enable the voluntary retrofit of older homes built under earlier building codes that did not include high wind uplift provisions. Current provisions require that a continuous load path be implemented in the construction of a house. A continuous load path is mentioned frequently in this guide and is defined as the members and components that are responsible in resisting and transferring the high lateral and uplift wind forces through each member until the forces are resolved into the ground. Without a continuous load path, a structural failure is likely to occur at the weakest link during a high wind event. This guide will assist in providing various methods to repair or improve an existing structure so that there will be an effective continuous load path.

The costs of a retrofit will vary depending on what is repaired or replaced. For example, installing hurricane clips can be very inexpensive if you can safely perform the labor yourself. However, hiring a licensed contractor to install your retrofits is a good idea if you do not have the physical ability or technical expertise to follow construction plans and specifications and manufacturer's installation procedures. You may also wish to consider using a licensed engineer or architect to prepare the plans for the retrofit and to inspect the work.

Please be aware that hurricane retrofitting is intended to reduce losses from structural damage, not for life safety purposes. Although you may decide to shelter in place in your home in the event of a hurricane, there is no promise that a hurricane retrofit will protect you from harm.



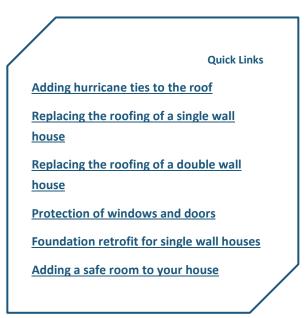
1.2 How to Use the Guide

This guide was written to provide homeowners and their contractors a guide to retrofit existing residential structures in Hawaii.

The following topics are covered in this document:

- *Hurricanes & Hawaii* provides a brief history of hurricanes in Hawaii
- *Retrofit Guide* provides an overview on how your home or building is affected by strong wind forces and outlines the procedures for retrofitting your property
- *Appendix* provides the technical requirements, drawings, and references

If you want to jump right to the retrofit information that are common among many homes, click on the desired link on the right.



1.2.1 Reading Electronically

The guide was organized to be read either as a printed document or as an electronic document, but the use of this guide is optimized for electronic use. There is heavy use of hyperlinks (or links) to assist the reader in efficiently navigating this document. Because Adobe PDF Reader is most widely used, some help regarding their menu items are provided below. Similar functions should be available for other programs.

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Figure 1.2-1: Adobe PDF Reader menu icons (your menu bar may have more or less icons)

You may be quite familiar with using Adobe Reader, but please note the two icons shown below. These icons will be used frequently if you are reading this document electronically.

Table 1.2-1: Adobe Reader Navigation Buttons

\bigcirc	These are the back and forward icons that you may be familiar with using in your web browser. However, they may not show up by default on your PDF reader. To get these icons to appear on the menu bar, follow these steps: Right click the menu bar → Go to 'Page Navigation' → 'Check 'Previous Page' and 'Next Page'
P	The bookmark icon is typically located on the left navigation menu bar. By clicking this icon, you will open a table of contents and have this available while you read the guide.



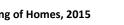


1.3 **OTHER RESOURCES**

In addition to this guide, there are many available resources that provide information on how to prepare for hurricanes and other natural disasters. Simply searching on the web can return many useful "Do-It-Yourself" or DIY guides. Below are two major government agencies that focus on improving public safety in disaster events.

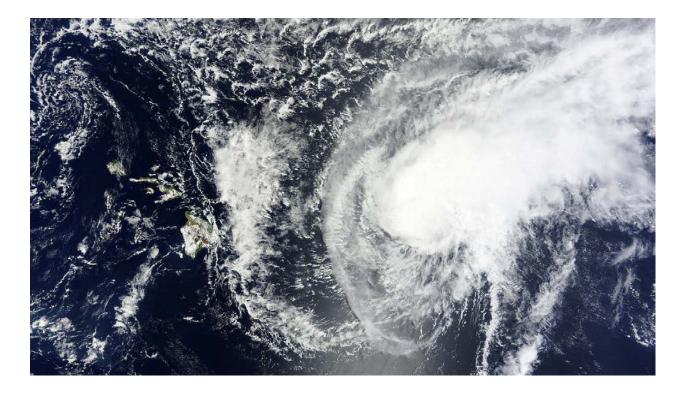
On the national level, FEMA is the Federal Emergency Management Agency, a national government agency of the Department of Homeland Security, which focuses on mitigating and recovering from the damage caused by natural disasters, among other emergency situations. FEMA produces a wide variety of publications that are publicly available to use. (For example, there is a Wind Retrofit Guide for Residential Buildings, FEMA P-804, 2010). Some of the content in this report is based on information from the many FEMA resources, reorganized and adjusted to address the specific needs of structures in Hawaii.

On the local level, HI-EMA is the Hawaii Emergency Management Agency formerly the Hawaii State Civil Defense Division. HI-EMA also hosts resources on disaster preparedness. To visit HI-EMA's website, go to http://www.scd.hawaii.gov/.



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2 HURRICANES & HAWAII

A hurricane is a tropical cyclone with maximum sustained winds above 74 miles per hour (NOAA). A tropical storm is a weaker tropical cyclone with sustained winds between 39 to 73 miles per hour. Hurricanes form over warm oceans through a repeated process of evaporation and condensation of the moisture in the air and ocean. As warm, moist air evaporates and rises, a low air pressure zone is formed near the surface of the ocean, pulling air from the surrounding area inward. The new air flowing in subsequently becomes warm and rises, causing the cyclone system to grow at an increasing rate. A high air pressure zone is formed at the top of the clouds, pushing air away from the center at an increasing speed. Hurricanes will typically dissipate when making landfall, where there is less available moisture that can enter the hurricane system.

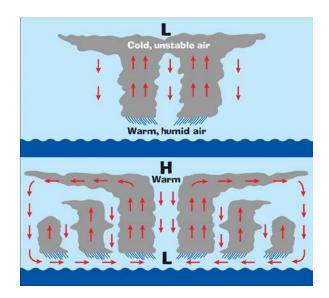


Figure 2.2-1: Formation of tropical cyclone courtesy of NOAA

The residents of Hawaii and their homes are particularly vulnerable to tropical storms and hurricanes because many of the homes were not built to withstand hurricane force winds. Building code requirements for high wind resistance of single-family homes were only imposed recently. Except for the island of Kauai, the other islands have not experienced a direct hurricane landfall in the past 50 years. Unfortunately, the actual hurricane hazard to Hawaii was not considered in building standards for single-family residences until beginning in the late 1980's. Single-family residential construction was typically permitted to be built using "conventional construction" provisions based on historical trade practices that





did not consider hurricanes. There were <u>no</u> requirements for high wind connectors in single-family residences built up through the late 1980's. The weaknesses of these practices were demonstrated by the unacceptable levels of wind damage to homes during Hurricanes Iwa (1982) and Iniki (1992). As a result, many older houses are susceptible to severe damage, particularly due to wind uplift on roofs. The damage to homes that do not have the wind uplift connectors that create a "complete load path" of wind resistance will greatly exceed the levels of damage typically described in the Saffir-Simpson Hurricane Wind Scale.

2.1 HURRICANE CATEGORIES

The Saffir-Simpson Scale is widely used to measure the intensities of hurricanes. Table 2.1-2 has descriptions of each category of this scale. The scale is useful for anyone because it also provides descriptions of the expected levels of damage. For perspective, Hurricane Iniki impacting Kauai was the only Category 4 hurricane that ever made landfall in Hawaii. Other hurricanes that made landfall in the past 60 years include Iwa (1982) and Dot (1959), but these hurricanes were only Category 1. Fortunately for Hawaii, many strong hurricanes have reduced to a tropical storm before impacting with the islands, generally due to wind shear effects or by moving over areas of colder sea surface temperatures.

Structural engineers design buildings that meet requirements outlined by the Hawaii State Building Code, which, in turn, references the ASCE 7 Standard for *Minimum Design Loads for Buildings and Other Structures*. In the 2010 edition of this standard, ASCE 7-10, requires that new buildings in Hawaii be designed for wind speed gusts of 130 mph. So, how does the wind speed that is used by engineers compare to wind speeds used to measure hurricanes? Hurricanes are measured and categorized by the highest 1-minute sustained wind speed, which is the average wind speed measured in a period of a minute. Engineers design for a 3-second gust which is the maximum wind speed of any three second duration. Table 2-1 below, from the ASCE 7-10 commentary, shows the corresponding 3-second gusts for each hurricane category. Engineers in Hawaii design structures to have the strength to resist wind effects expected for a Category 3 hurricane (about a 120 mph sustained wind speed or a 130 mph gust). That is to say, engineers design for the 3-second gusts that occur as peak speeds within the 1-minute sustained wind; they also account to the amplifying effects of topography.

<u>Table 2.1-1: Relationship between wind speed measurements taken with different averaging periods</u>

Soffin/Simpson	Sustained W Over W	1		ind Speed Water ^b		ind Speed Land ^c
Saffir/Simpson Hurricane Category	MPH	(m/s)	mph	(m/s)	mph	(m/s)
1	74–95	33–43	90-116	40.2-51.9	81-105	36.2-46.9
2	96-110	44-49	117-134	52.3-59.9	106-121	47.4-54.1
3	111-130	50-58	135-158	60.3-70.6	122-143	54.5-63.9
4	131-155	59-69	159-189	71.1-84.5	144-171	64.4-76.4
5	>155	>69	>190	>84.5	>171	>76.4

 Table C26.5-2 Approximate Relationship between Wind Speeds in Asce 7 and Saffir/Simpson Hurricane Scale

^a1-minute average wind speed at 33 ft (10 m) above open water

^b3-second gust wind speed at 33 ft (10 m) above open water

^c3-second gust wind speed at 33 ft (10 m) above open ground in Exposure Category C. This column has the same basis (averaging time, height, and exposure) as the basic wind speed from Figure 26.5-1.

Source: ASCE 7-10, p. 536

Note: The Saffir/Simpson Scale was slightly modified in 2012 to adjust the threshold speeds for Category 4 to 130 mph and 5 hurricanes to greater than 157 mph, as shown in Table 2-2.



Table 2.1-2: Saffir-Simpson Scale

Category	Description
1	• Sustained winds 74-95 mph (119-153 km/hr).
	• 3-sec peak gust of 81-105 mph.
	• Some damage to well-built building structures could occur, including those with wood roofs
	 Corrugated metal roofs and light roofing material stripped and become airborne
	 Damage to unanchored structures and poorly constructed signs.
	• Loose outdoor items will become projectiles, causing additional damage.
	 Persons struck by windborne debris risk injury and possible death.
	• Numerous large branches of healthy trees will snap and some trees will be uprooted, especially
	where the ground is saturated.
	 Many areas will experience power outages with downed power poles.
2	• Sustained winds 96-110 mph (154-177 km/hr).
	• 3-sec peak gust of 106-121 mph.
	• Some roofing material, door, and window damage of well-built buildings will occur.
	• Considerable damage to unanchored structures and poorly constructed signs is likely. Loose
	outdoor items will become projectiles, causing additional damage.
	 Persons struck by windborne debris risk injury and possible death.
	• Numerous large branches will break.
	• Many trees will be uprooted or snapped.
	• Extensive damage to power lines and poles will likely result in widespread power outages that
	could last a few to several days.
3	• Sustained winds 111-129 mph (178-209 km/hr).
	• 3-sec peak gust of 122-142 mph.
	 Some structural damage to well-built houses and buildings will occur.
	 Unanchored structures and poorly constructed signs are destroyed.
	 Persons struck by windborne debris risk injury and possible death.
	• Many trees will be snapped or uprooted and block numerous roads. 30% to 50% defoliation of
	many trees
	• Near total power loss is expected with outages that could last from several days to weeks.
4	• Sustained winds 130-156 mph (209-251 km/hr).
	• 3-sec peak gust of 143-173 mph.
	• Even well-built wooden or metal structures severely damaged or destroyed
	• Extensive damage to doors and windows is likely. Numerous windows in commercial and
	residential buildings would be broken.
	• Nearly all signs blown down.
	• Air is filled with windborne debris that will cause extensive damage and persons struck by the wind blown debris will be injured on killed
	wind-blown debris will be injured or killed.Most large trees will be snapped or uprooted. Fallen trees could cut off residential areas for days
	to weeks. 50% to 90% defoliation of trees.
	 Most wood power poles downed/snapped.
	 Electricity will be unavailable for weeks after the hurricane passes.
5	 Sustained winds greater than 157 mph (252 km/hr).
5	 3-sec peak gust greater than 173 mph 252 kilvin).
	 Complete roof failure on many non-concrete residences and industrial buildings will occur.
	 Some complete building failures with small buildings blown over or away are likely
	 Complete destruction of unanchored structures. Severe and extensive window and door damage will occur.
	 Severe and extensive window and door damage will occur. Severe injury or death is likely for persons struck by wind-blown debris.
	 Severe injury of death is fixery for persons struck by white-blown debris. Nearly all trees will be snapped or uprooted and power poles downed. Fallen trees and power
	 Nearly an trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas.
	 Power outages will last for weeks to possibly months.
	- I ower outges will fust for weeks to possibly indiffus.

Source: Adapted from NOAA; http://www.prh.noaa.gov/cphc/pages/saffir_simpson.php





2.2 PAST HURRICANES

To understand the extent of what is necessary to protect your property, the homeowner must be aware of the damage caused by past hurricanes and storms. During El Nino years, a greater number of tropical cyclones traverse through the Hawaii region of the Central Pacific. Hawaii has frequent encounters with hurricanes, but only three hurricanes have made landfall in the past 60 years: Hurricane Iniki (1992), Hurricane Iwa (1982), and Hurricane Dot (1959). Recently, Tropical Storm Iselle (2014) did make landfall on the Big Island, but had been downgraded to a tropical storm before impacting. Hurricane Iniki has remained the largest hurricane and natural disaster that has struck the Hawaiian Islands.

2.2.1 Hurricane Iniki (1992)

The hurricane warning for Iniki came only the evening before Iniki made landfall on Kauai due to its quickly recurving path from the south. The hurricane made landfall on September 11, 1992 at 3:30 pm Hawaii Standard Time at Category 3 to 4 intensity and quickly passed over the island by 4:10 pm. Iniki was a relatively small and compact storm with a radius to maximum winds of about 15 km, with sustained winds in open terrain of at least 130 mph and peak gusts of 160 mph or more due to topographic speed-up caused by mountainous terrain. Many homes lost their roofs and some were even completely blown over. Power was out for four

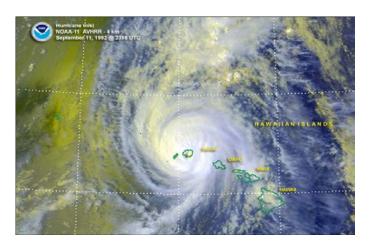


Figure 2.2-2: Hurricane Iniki as it traveled over Kaua'i

weeks after the storm. Hurricane Iniki claimed six lives.

The total cost of damage is estimated at \$1.8 billion dollars (or \$3.1 billion in 2015 dollars). The damage to single family residences and contents in the homes totaled \$865 million (based on insurance claims made), which is about half of the above figure. It should be noted that if Iniki had struck Honolulu, which has approximately five times the population of Kauai, then the cost of damage could have been closer to \$9 billion (\$15.3 billion in 2015 dollars).

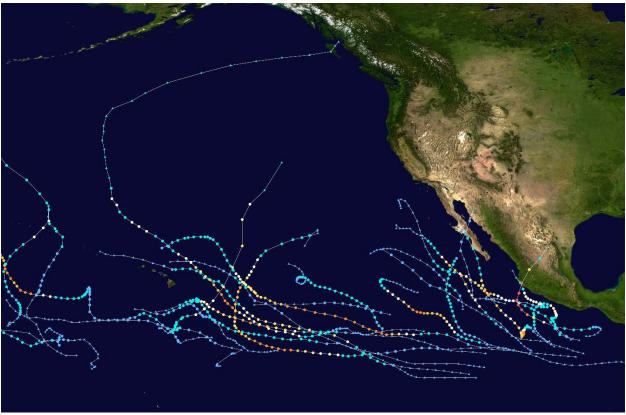




2.2.2 Other Tropical Cyclones

Hurricanes, tropical storms, and tropical depressions are all types of tropical cyclones. **Tropical depressions** are cyclones with sustained wind speeds less than 39 mph. **Tropical storms** are stronger than depressions, with sustained winds ranging from 39 to 73 mph. Once a tropical depression becomes a tropical storm, it takes on a name from an alphabetically-ordered list established by the World Meteorological Organization.

In 2015, there were over 25 tropical cyclone events in the Pacific Ocean. Figure 2.2-2 shows that many of these tropical cyclones tracked very closely to Hawaii. The islands have not been directly impacted by a category hurricane since Hurricane Iniki, but the 2015 hurricane season has shown that Hawaii's residents should be proactive and prepared.



WikiProject Tropical Cyclones/Tracks; updated on November 6, 2015

Figure 2.2-3: The tracks of all tropical storms of the Pacific Ocean in 2015





2.3 HISTORY OF WIND RESISTANT DESIGN IN HAWAII

Past hurricanes have shown that the most vulnerable structures in a hurricane are light-framed residential houses that have been built prior to when the local building regulations started enforcing stricter hurricane protection. This includes older single wall homes that were a popular construction method in Hawaii in the past. These units typically have not endured a design-level hurricane since their construction, and unless they have been retrofitted, they will be vulnerable to structural collapse under a hurricane's high wind pressures and wind-borne debris impacts.

For Hawaii, the benchmark years for mandatory wind uplift ties of the roof to the wall and for a complete load path down to the foundation are shown in Table 2.3-1 and Table 2.3-2, respectively. If your home or building was constructed *before* the years listed below, then it is critical that you have an inspection done to check for a complete load path on your structure.

Table 2.3-1: Benchmark Years when roof	to wall wind uplift (ties were first required:
--	-----------------------	---------------------------

County	Date of Plans	Built after
Kauai	1989	1990
Oahu	1987	1988
Maui	1989	1990
Hawaii	1993	1994

Source: WRD Specifications 2007

Table 2.3-2: Benchmark Years when a complete load path of connectors was first required:

County	Date of Plans	Built after 1993 1995		
Kauai	1992	1993		
Honolulu	1994	1995		
Maui	1994	1995		
Hawaii	1993	1994		

Source: WRD Specifications 2007

The Wind Resistive Devices (WRD) Technical Specifications were developed to address these major weaknesses in older homes. Table 2.3-3 below shows the probable WRD retrofit needed depending on the location and time the house was built. For more information of the WRD Specifications, see Section 3.1.4.



WRD Type	ĸ	auai Cour	nty		/ & Count 10lulu – O	•	N	/laui Coun	ty	Hawai	County	All Counties
Date	Up to 1989	1989+	1992+	Up to 1987	1987+	1994+	Up to 1989	1989+	1994+	Up to 1993	1993+	New Construction
1. Roof to Wall Ties												
 Fastening of roof sheathing and secondary waterproofing Exterior opening protection 												depends on design
4. Foundation uplift restraint												
5. Residential safe room												

Table 2.3-3: The Most Probable Retrofits Based on Date Constructed

a. This table assumes that houses were originally built in conformance with the building code at the time

b. Green = Retrofit NOT likely needed, Red = Retrofit likely needed

Later, in the codes after the year 2000, other requirements for windborne debris and high-wind rated roofing assemblies were added, in addition to an increase in the windspeed gusts to be used for engineering designs. Furthermore, in the period of 2007 to 2012, the amplification of windspeed due to topography was included in the codes adopted by the state and counties.

However, during the same period, the counties of Kauai, Honolulu, and Maui also adopted an "International Residential Code" with prescriptive trade practices for constructing residences without structural engineering, assuming wind gusts will be less than 100 mph. Due to topographic effects, the effective windspeeds in Hawaii exceed 100 mph in many areas. This residential code is not used in major subdivision developments due to that increased risk, but the counties allow it to be used by architects that decide not to engage engineers to design the structure of the home. This type of construction is not expected to withstand Category 2 hurricanes without significant structural damage, especially due to wind uplift. Therefore, even if your home was built after 2007, it is important to determine whether it was permitted under the International Building Code (that has engineering requirements) or the International Residential Code (that does not include engineering of the structure).

When located on a site with ocean exposure or hillside or ridgeline exposures, the wind resistant capacities between engineered designs and prescriptive designs can be extremely different. The following maps show where the International Residential Code is allowed. If the plans for your home were issued a building permit under the International Residential Code but lies outside of the green-shaded areas, then there may be a potential problem with a design error or a mistake in the permitting process.



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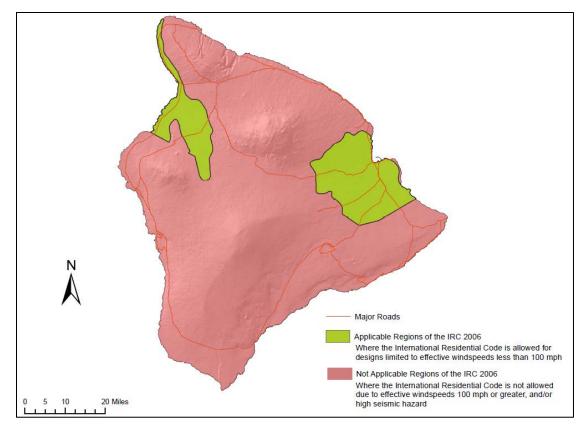


Figure 2.3-1: County of Hawaii Map showing where the International Residential Code is allowed without an engineered structural design using the ASCE 7 wind standard

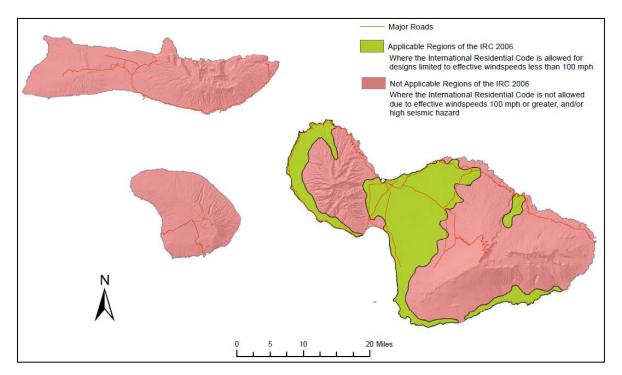


Figure 2.3-2: County of Maui Map showing where the International Residential Code is allowed without an engineered structural design using the ASCE 7 wind standard

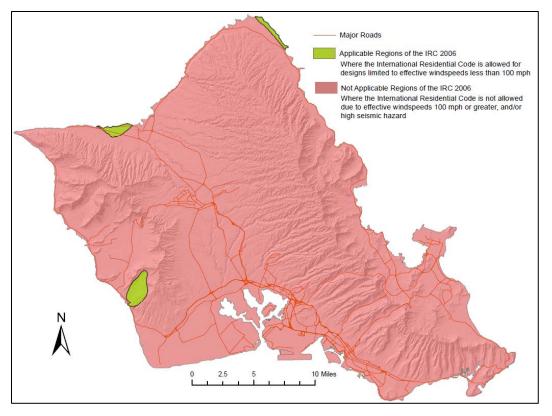


Figure 2.3-3: City and County of Honolulu Map showing where the International Residential Code is allowed without an engineered structural design using the ASCE 7 wind standard

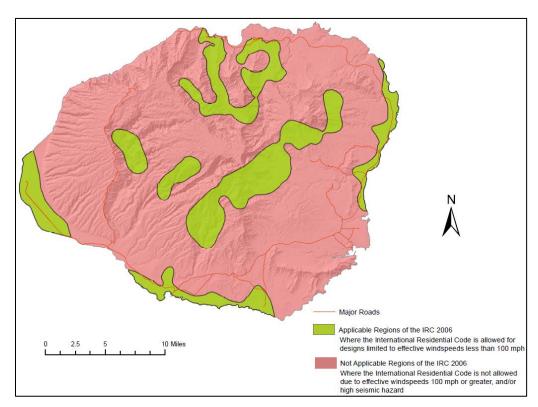
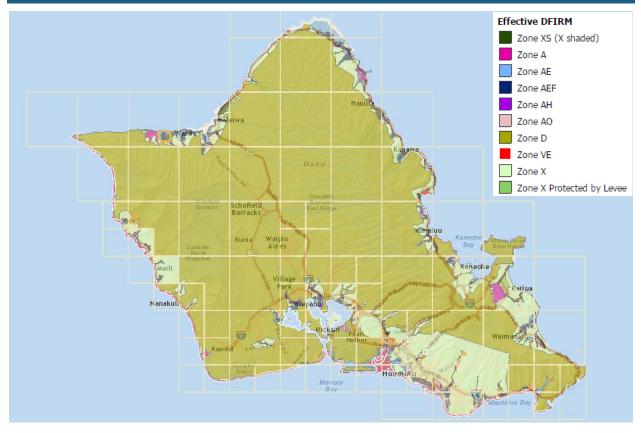


Figure 2.3-4: County of Kauai Map showing where the International Residential Code is allowed without an engineered structural design using the ASCE 7 wind standard

2.4 FLOOD ZONES



In addition to damage from high winds, tropical storms generate storm surge causing varying degrees of damage. A **storm surge** is defined as an abnormal rise in sea level accompanying an intense storm (NOAA). Storm surge with wind-driven waves are associated with tropical storms and hurricanes, including those that pass close to the islands but do not directly landfall. Impacts from these events can be severe and lead to beach erosion, large waves, and marine overwash even despite the fact that a hurricane may have missed the island. The amount of storm surge also depends on the tide during the event. Wind-driven waves accumulating on top of the storm surge pose a number of added problems, referred to as "wave set-up". The wave set-up can flood areas not reached by the surge itself. The scouring power of waves is also considerable.

Buildings located in flood zones are extremely prone to damage from high storm surge during tropical storm and hurricane events, especially when located without building setbacks from the shoreline. Tropical storms and hurricanes can also bring intense rainfall that adds to flooding and flash flooding. Mitigation of coastal flood hazard includes adequate building setbacks, elevation of the structure above the flood level, break-away ground floor walls that permit overwash flooding without compromising the entire structure, deep foundations to resist scour, and the use of flood-resistant construction materials. Floods can cause costly damage to interior spaces and may require water damage/mold remediation.

Flood damage usually results from a hurricane but is not covered by hurricane insurance. The federal government created the National Flood Insurance Program (NFIP) that provides insurance funding for losses from floods. Under the NFIP, each county has mapped the flood hazard areas and established a permit system to regulate development within these flood hazard areas. The Flood Insurance Rate Maps (FIRM) identify a flood hazard area as the area that would be inundated by a 100-year flood, or a flood with a 1% chance (1:100 odds) of occurring every year. This signifies a very high level of hazard, because the chance of floods in excess of the map flood elevation is about 40% over a 50-year period.





FIRM maps include coastal areas prone to surge flooding (A zones) and surge flooding with high waves (V zones). A homeowners insurance policy usually does not include coverage for a flood, but must be purchased separately through a property insurance agent. If the building is located in a flood zone, flood insurance will be required by most mortgage lenders.

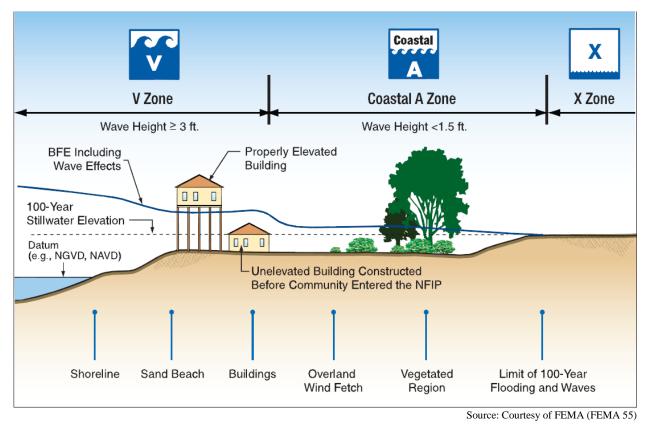


Figure 2.4-1: Different flood zones and relationship between water elevations

Illustrative maps of the flood zones in Hawaii follow, but these maps are always subject to updates. Digital versions of the flood maps are available from the counties and from the State of Hawaii Department of Land and Natural Resources with an online Flood Hazard Assessment Tool at http://gis.hawaiinfip.org/FHAT/. The source of flood zone information contained in the FHAT is FEMA's Digital Flood Insurance Rate Maps (FIRMs). Individual counties may amend these maps as a part of their enforcement of local flood ordinances. In August of 2015, FEMA released revised preliminary Digital Flood Insurance Rate Maps (DFIRM) for Hawaii County that are now shown in the FHAT.





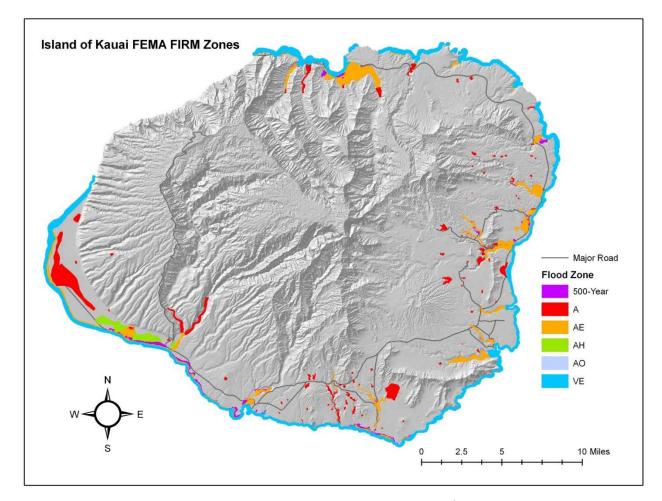


Figure 9.1 Island of Kaua'i (County of Kaua'i) FEMA FIRM Zones¹

¹ This general illustrative map based on digital data published on November 26, 2010. Updated detailed maps are available from the County of Kauai

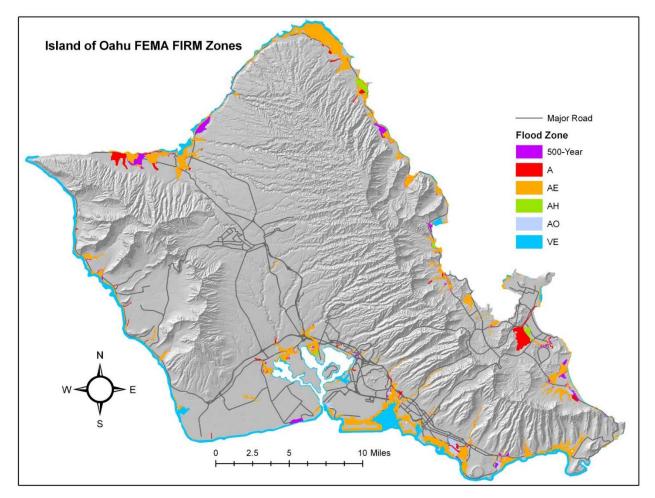


Figure 9.2 Island of O'ahu (City and County of Honolulu) FEMA FIRM Zones²

 $^{^2}$ This general illustrative map based on digital data published on January 19, 2011 .Updated detailed maps are available from the City and County of Honolulu.

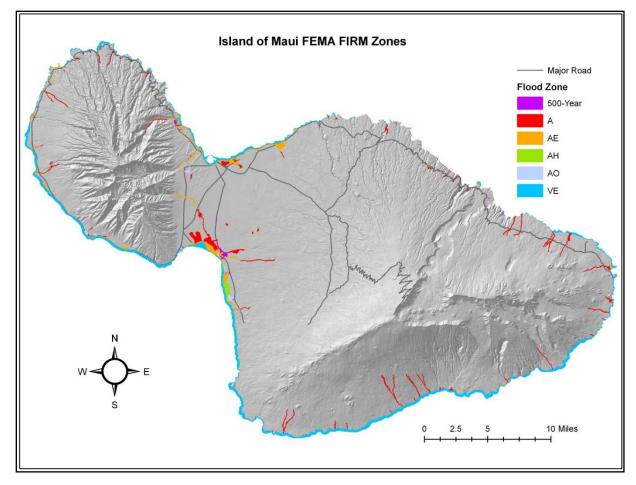


Figure 9.3 Island of Maui (County of Maui) FEMA FIRM Zones³

³ This general illustrative map based on digital data published on September 19, 2012. Updated detailed maps are available from the County of Maui.

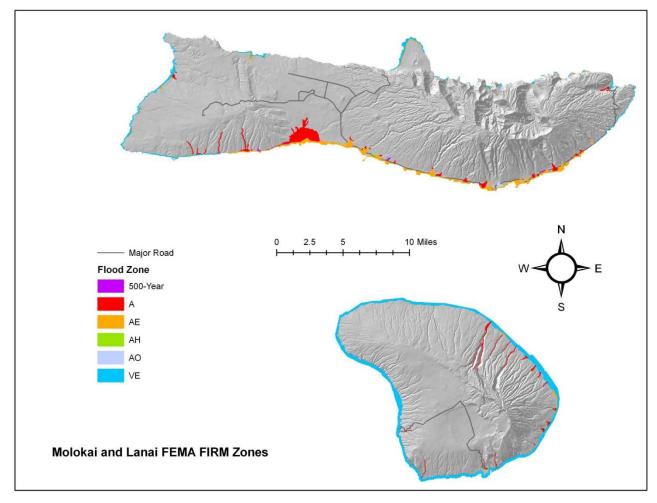


Figure 9.4 Island of Moloka'i (County of Maui) FEMA FIRM Zones⁴

⁴ This general illustrative map based on digital data published on September 19, 2012. Updated detailed maps are available from the County of Maui.

Table 2.4-1: Flood Map Legend from Hawaii DLNR National Flood Insurance Program

VE/V Zones	Zone VE is the flood insurance rate zone that corresponds to the 100-year coastal floodplains that have additional hazards associated with storm waves. Whole-foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone.
AO Zone	Zone AO is the flood insurance rate zone that corresponds to the areas of 100-year shallow flooding (usually sheet flow on sloping terrain) where average depths are between 1 and 3 feet. Average whole-depths derived from the detailed hydraulic analyses are shown within this zone.
AE Zone	Zone AE is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by detailed methods. In most instances, whole-foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone.
AH Zone	Zone AH is the flood insurance rate zone that corresponds to the areas of 100-year shallow flooding (usually areas of ponding) where average depths are between 1 and 3 feet. Whole-foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone.
A Zone	Zone A is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by approximate methods . Because detailed hydraulic analyses are not performed for such areas, no base flood elevations or depths are shown within this zone.
Floodway	The floodway is the channel of a stream plus any adjacent areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.
X Zone	Zone X is an area determined to be outside of the 0.2% annual chance floodplain . No base flood elevations or depths are shown within this zones.
X Protected by Levee Zone	Zone X Protected by Levee – This area is shown as being protected from the 1-percent-annual chance or greater flood hazard by a levee system that has been provisionally accredited . Overtopping or failure of any levee system is possible. Check with your local community to obtain more information, such as the estimated level of protection provided (which may exceed the 1-percent-annual chance level) and emergency action plan, on the levee system(s) shown as providing protection for area on this panel. To maintain accreditation, the levee owner or community is required to submit data and documentation necessary to comply with Section 65.10 of the NFIP regulations by February 1, 2010. If the community or owner does not provide the necessary data and documentation or if the data and documentation provided indicate the levee system does not comply with the Section 65.10 requirements, FEMA will revise the flood hazard and risk information for this area to reflect de-accreditation of the levee system. To mitigate flood risk in residual areas, property owners and residents are encouraged to consider flood insurance and flood proofing or other protective measures.
XS Zone	Zone X S (X shaded) is an area within the 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood. No base flood elevations or depths are shown within this zones.
D Zone	Zone D is the flood insurance rate zone that corresponds to unstudied areas where flood hazards



Climate change can be summarized as including the following potentially adverse future effects to the Hawaii coastal zone:

- i. Increase in the rate of sea level rise and increasing rates of beach erosion
- ii. Groundwater rise in low-lying areas
- iii. Increase in Sea Surface Temperatures and more influential El Nino events with more intense tropical cyclone activity
- iv. Increased likelihood of greater inundation / flooding from storms and tropical cyclones

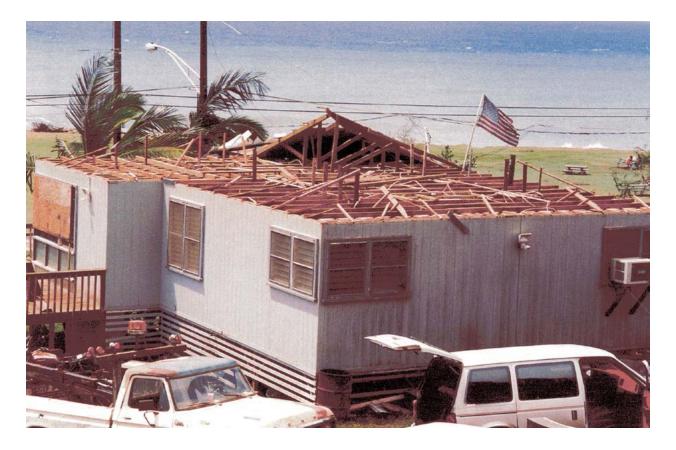
These effects are pertinent to the vulnerability of buildings and their foundations located in the coastal zone. Insurance companies are concerned about the growing risk of stronger hurricanes that may occur more frequently in the future. Insurance companies have typically used historical data to estimate risks, but recently, they have started to change their economic models to consider climate prediction models (Geneva Association, 2013). So, if the insurance industry is considering climate change more seriously for future insurance rates, homeowners also should undertake more precautionary measures to mitigate the increasing severity of hurricane effects, especially if their home is deficient even for the present risks.

2.6 CLIMATE VARIABILITY: THE EL NIÑO-SOUTHERN OSCILLATION

Climate variability refers to relatively short-term variations in the natural climate system. The climate variations often deviate significantly from the "normal" climate, such as the patterns associated with the El Niño-Southern Oscillation (ENSO) cycle (El Niño, conversely La Niña). El Niño is an oscillation of the ocean-atmosphere system in the tropical Pacific having important consequences for weather and tropical cyclone activity in the Pacific. During El Niño periods, the sea surface temperatures in the Central Pacific become several degrees warmer, which also affects the prevailing wind climate. During El Niño, the Hawaii region of the Central Pacific Ocean experiences a much greater number of tropical storms and hurricanes.







3 RETROFIT GUIDE

Image source: WRD Specifications 2007; "Hurricane Iniki roof damage to an unprotected home"

Retrofitting an existing home is a daunting task for any homeowner to take on. It is a project that is complicated in predicting the overall scope and the final cost. As you start addressing one weak point, there is the chance that you may discover additional underlying issues. Therefore, it is important to define the areas in the home that should have priority for repair and to understand the associated time and costs.

This section will cover the primary parts of a house and identify the weak points that exist in each area. If you already know which area you want to focus on use the following links on the right to quickly navigate to the desired section. **Quick Links**

Adding hurricane ties to the roof

Replacing the roofing of a single wall house

Replacing the roofing of a double wall house

Protection of windows and doors

Foundation retrofit for single wall houses

Adding a safe room to your house





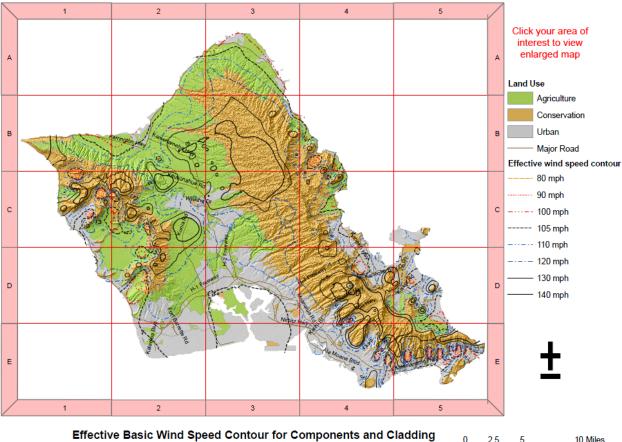


3.1.1 Site Assessment

A major factor that can affect the necessary level of protection is if the site is located in a wind-borne debris region. The entire state is considered a windborne debris region in the Hawaii State Building Code (2010). The City of Honolulu Building Code (2012) defined it as:

- 1) Within 1 mile of the coastal mean high water line where the effective basic wind speed in 110 mph or greater, or
- 2) Where the effective basic wind speed is 120 mph or greater

The effect of mountainous terrain and downslope wind acceleration has been published in building code maps. The basic (flat land) wind speed of 105 mph for Hawaii. The effective basic wind speed can be determined from a wind speed map that includes topographic amplification. An effective wind speed of greater than 105 mph indicates the degree of heightened wind hazard. An example of a wind map is shown in Figure 3.1-1. Larger figures can be found in the Appendix Section 4.3.



for Buildings less than 60 feet tall

Figure 3.1-1: Effective basic wind speed map

The roofs of nearby buildings should be surveyed to determine if gravel aggregate surfaced roofing are used. During a hurricane, the aggregate will loosen and become airborne. Once airborne, the aggregate debris can cause damage to adjacent structures and break windows. This type of roofing is usually found in commercial areas and are not as prevalent in residential neighborhoods that typically have steeper roofs.

The site should also be assessed for tall trees that have the potential to cause damage to a structure if the tree fails to withstand a hurricane. Trees that have branches near and over the roof should be cut back. This risk also exists with power poles that may not be designed to resist strong hurricanes. If you will be sheltering at home, determine the area that would have the least amount of risk from falling trees or power poles. Emergency supplies should be located where it is easily accessible. All outdoor furniture should also be tied down in the event of a hurricane warning. Stray items in the yard, such as toys or tools, should be stored in a safe place to avoid becoming windborne projectiles.

3.1.2 Home Assessment

If you have the construction plans for your home, it will be a great help to you and to the contractor that will perform the retrofit work. This guide will provide the basics for carrying out your own inspection. Hiring an inspector or a structural engineer can also be useful. In cases where you need professional services, this guide will keep you informed so that you may communicate effectively with your inspector or contractor. FEMA outlines the key additional assessments that can be provided by a professional inspector, shown in Table 3.1-1.

Table 3.1-1: FEMA Homeowner Evaluation vs. Professional Home Inspector Evaluation

Homeowner evaluation	Professional building inspector evaluation
1. Year of construction	1. Weaknesses in building envelope
2. Construction plans, drawings, blueprints	2. Weaknesses in structure
3. Receipts from home improvement work	3. Weaknesses in foundation
4. General construction type	4. Whether retrofit can effectively improve
5. Areas of noticeable deterioration	resistance to wind-related damage
6. Exterior openings (size, shutters, impact-rated)	5. How much retrofit would cost
7. Roof-to-wall ties (if visible from outside)	6. The most cost effective retrofit project for the
	home

Adapted from FEMA P-804

3.1.2.1 Weak Points

In the following sections, there will be instructions focusing mainly on how to develop a continuous load path for a house. FEMA (P-804, 2010) identifies three areas that are vulnerable to hurricane forces:

- Roof coverings
- Wall coverings
- Openings
- Load path connections
 - o Roof-to-wall connection
 - o Foundation connection

As the homeowner, you can perform a visual inspection of your house. Locate any missing shingles/shakes/tiles on your roof or any apparent damage to the exterior siding of the walls. This is a strong indication that your roof and wall coverings are not performing to an acceptable level. As these coverings age and wear, their connection to the primary structure gradually weaken. If a strong storm strikes at this inopportune moment, the permanent structure of the house, such as the roof and wall studs and plywood, may become compromised from excess moisture and damage from windborne debris. Replacing these more permanent structural members can be significantly more costly, in money and time, than having the coverings of the house replaced.

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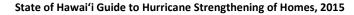
Inspect the window and door openings of your house. Identify areas that appear to be damaged from excess moisture, rot, or termites. Check if the frame is cracked. The goal is to stem any further damage from moisture and pests.

Finally, locate the connection points from your roof to the wall and from the wall to the foundation. The connections may be concealed, so a professional inspector may be useful in locating them. If you happen to have existing drawings of your house, you should be able to locate the type of connectors in the roof sections and details. (The building permit drawing records for residential subdivision homes may be available from the archives of the city or county building department. The developer should also have record drawings.)

3.1.2.2 Cost vs. Benefit

The owner has the responsibility of deciding the degree of retrofit that is appropriate for their home. The idea of retrofitting a home is unappealing to many homeowners because of the cost. However, the cost of not retrofitting should also be seriously considered. Reconstruction costs may be alleviated by insurance payouts, but the cost of being displaced from your home and of rebuilding may be much more significant.

The main benefit of having the retrofit done is that it increased the chance of survival of the home with less damage. The home's improved performance also decreases the risk for the occupants and property within the home. Many insurance companies offer lower insurance premiums for homes that have been retrofitted for hurricanes. Although, you should check with your insurer to determine the specifications they require to qualify for their discounts.



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Table 3.1-2: Construction Types for Houses

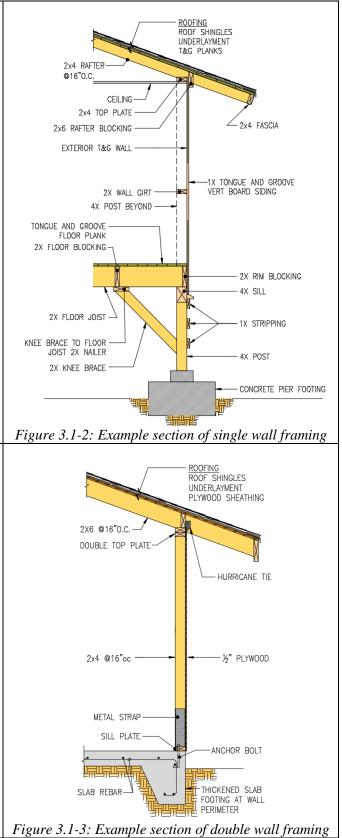
Single Wall Construction

Single-wall construction utilizes flat tongue and groove (T&G) boards placed vertically to form a load-bearing exterior wall without studs. A flat, wood top plate is attached against the vertical siding boards to serve as a "supporting" ledger for the roof rafter. The T&G siding boards are nailed at the bottom to a rim joist and sill beam of the floor, transferring its load through vertical shear (see Figure at right). These connections typically have low uplift capacity. Roof construction in single-wall residences is typically light non-engineered framing with composition shingles on spaced battens, sometimes on tongue and groove (T & G) wood decking, or corrugated metal deck roofing directly attached to rafters. The foundation of many single construction homes are not properly anchored down to the ground. Therefore, single wall construction homes have multiple problem areas that will require inspection and retrofit. Single wall construction developed a significant portion of the housing stock in the past due to its low cost.

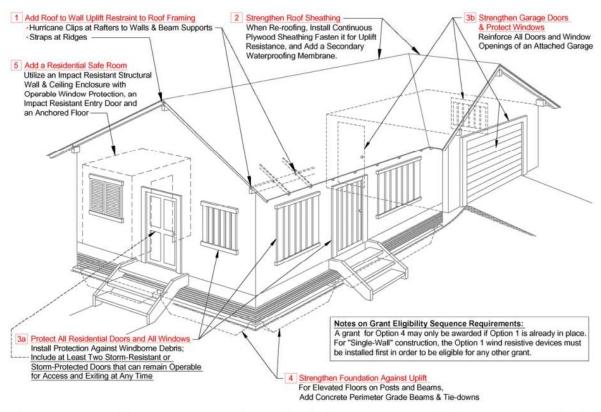
Double Wall Construction

The 'double wall' term comes from the fact that the walls are framed with exterior sheathing on the outside and drywall on the inside. The sheathing may be plywood but is more commonly manufactured siding. This construction method differs from single wall construction in the use of sheathing on the walls instead of the "single" T&G planks without any studs. The wall studs are framed between the exterior sheathing and drywall and provide higher out-of-plane bending capacity compared to single wall homes. Double wall houses also have much stronger shear walls and floor diaphragms, which are essential in providing stability. The foundation typically is a slab-on-grade system that allows for anchor bolts, metal

system that allows for anchor bolts, metal straps, and holdowns to be installed. This provides far greater uplift capacity compared to single wall homes.



3.1.4 Wind Resistive Devices and the Loss Mitigation Grant Program



OVERVIEW OF THE FIVE OPTIONS OF WIND RESISTIVE DEVICES ELIGIBLE FOR THE STATE LOSS MITIGATION GRANT PROGRAM

Source: WRD Technical Specifications, June 2007

Figure 3.1-4: Overview of the general WRDs

From 2006 to 2008, the Insurance Division of Hawaii's Department of Commerce and Consumer Affairs (DCCA) ran the Loss Mitigation Grant Program authorized by the State Legislature, which reimbursed homeowners 35% of the cost for hurricane retrofits, up to \$2,100. To qualify for the grant, homeowners were required to comply with the specifications for installing pre-approved wind resistive devices (WRDs). The Loss Mitigation Grant Program was active for only two fiscal years, from 2006 to 2008. The most common retrofit was the installation of hurricane ties to the roof. Approximately 430 homes were retrofitted and received a grant subsidy. The five general WRDs are:

- 1) Roof to Wall Uplift Restraint Ties at Roof Ridges and Roof Framing Members to Wall or Beam **Supports**
- 2) Fastening of Roof Wood Sheathing or Roof Metal Decking for High Wind Uplift
- 3) Exterior Opening Protection
- 4) Foundation Uplift Restraint Strengthening
- 5) Hawaii Residential Safe Room Performance Specifications





3.1.5 Property Insurance

It is important to note that hurricane insurance only covers damage caused by wind. It is a good idea to retrofit your home against hurricane damage even if you have hurricane insurance because your life and financial situation will be severely disrupted if your home suffers significant damage. Some property insurance companies will give you premium credits for hurricane retrofitting. Each insurance company may have its own specifications and requirements that may differ from the approaches given in this guide. Although retrofitting will not prevent loss in all situations, particularly at higher wind speeds, it will likely reduce losses. Of course, actual outcomes from a hurricane will vary depending on the wind speed and what connections are provided to maintain the integrity of the structure of our home.

3.1.6 Hawaii's Building Code Regulations on Existing Buildings

One possible complication to initiating retrofit work for your property is that if your retrofit work is bundled with other addition or alteration work that is substantial, the building department might require you to also improve the other parts of the structure. To avoid delays, you should try to make the hurricane retrofits a separate project from other improvements that require a building permit. Fortunately, most hurricane retrofit work includes improving connections so that there is a complete load path, and not any alteration of the original structural members.

3.1.7 The Main Wind Force Resisting System (MWFRS)

Structures resist the weight of gravity loads most of the time and face strong horizontal or lateral loads only a small percentage of time. Structural engineers design buildings with a main wind force resisting system to resist forces from wind and earthquakes, and provide connection details for a continuous or **complete load path**. A continuous load path will resist and direct the wind force applied to the house through the roof and floors, then to the walls, and then to the foundation.

Pressure forces from wind will act upon the walls and the roof. Horizontal pressures on the walls will transfer to the roof and floor diaphragms. The diaphragm will resist the horizontal forces and transfer the forces to the shear walls. The shear walls will then resist the force and transfer them to the foundations. The foundation will transfer the force to the ground through friction with the soil surface or resistive pressure from the soil.

Vertical pressures on the roof will have to be resisted by the roof rafters and girders. The roof framing members will transfer the forces to the walls or columns, and the walls or columns will transfer the forces to the foundation. The total self-weight or dead weight of the walls, columns, and foundation is evaluated as part of the resistance to this uplift force.

Per an exception to the local Hawaii building codes, detached one- and two-family dwellings, and multiple single-family dwellings (townhouses) not more than two stories in height are not required to involve a licensed structural engineer in the design. Therefore, many existing homes may not be engineered as described above to effectively resist hurricane forces (see Section 2.3).

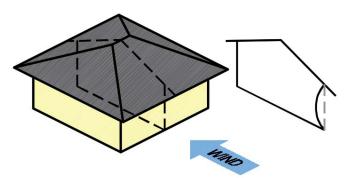
3.1.7.1 Wind Pressures on the Walls

All exterior walls will be subject to inward and outward pressures in a hurricane event. **Out-of-plane** bending describes the behavior of a wall when wind pressure is applied to its surface. The wall bends outwards or inwards and should be designed to transfer the loads to the diaphragm above and below without failing or becoming permanently deformed. Figure 3.1-5 shows a cross-section of the house subjected to out-of-plane bending on the wall. Figure 3.1-6 shows a simple diagram of a wall bending





with its top and bottom restrained, similar to a wall that is connected to the roof diaphragm above and the ground below. Compared to diaphragms and shear walls, out-of-plane walls behave with much more flexibility. The figures below exaggerate the degree of bending for illustrative purposes.



ACTUAL MODEL **CROSS SECTION** Figure 3.1-5: Cross-section of house subject to out-of-plane bending on a wall

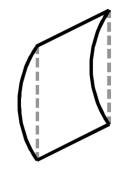
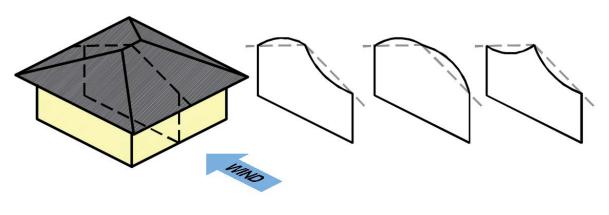


Figure 3.1-6: 3D representation of out-of-plane bending

3.1.7.2 Wind Pressures on the Roof

Similar to walls, the roof will also be subject downward and upward pressures. Figure 3.1-7 below shows multiple ways a roof can bend as it endures high wind pressures. The figures below exaggerate the degree of bending for illustrative purposes. The pressures on the roof are resolved through the roof's connection to the walls. Wind uplift is more critical, especially for older homes. Design provisions for roof-to-wall hurricane ties have only been required as early as 1987 for Oahu and later for the other islands (2007 WRD Specifications). It is important to note that the wind pressure occurs on all the roofing components attached to the surface of the roof structure. The high pressures often lead to roof coverings, such as shingles or concrete or clay tiles, detaching and becoming windborne debris.



ACTUAL MODEL

CROSS-SECTIONS

Figure 3.1-7: Cross section of a house subject to different out-of-plane roof bending conditions

Structural engineers design the roof for varying pressures depending on the zone of the roof. Figure 3.1-8 shows an example of the how zones are defined on a roof. The layout of the zones is dependent on the roof shape, size, and slope or incline of the roof. In general, the edges and the corners of the roof are subject to roof pressures up to two to three times higher than the rest of the roof. The overhang areas of the roof are also subject to these higher pressures. For homes that were built before 1982, the building code at the time did not consider the higher uplift pressures that occur at the edges and corners of the roof (FEMA 577, 2007).



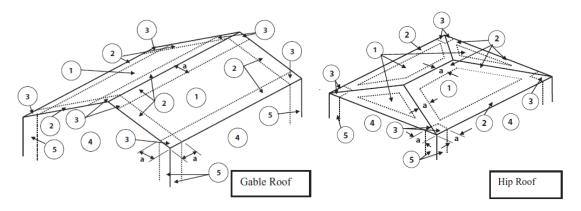


Figure 3.1-8: Layout of zones for wind design of roofs

3.1.7.3 Diaphragm

A diaphragm provides horizontal strength and stability to the top of a structure and ensures that the loads imparted by the hurricane will be transferred appropriately to the shear walls or frames. This strength comes from the sheathing or decking material used on the roof. The diaphragm must have members and connectors strong enough to transfer the forces from the diaphragm to the shear walls or lateral force-resisting frames. (Some homes will not have roof diaphragms, and lacking it, the structure will have less capability to behave as a unified system.)

In the figure below, the bending or deflection is exaggerated for demonstration purposes. The analytical model only shows the effects of the diaphragm. The left and right ends are fixed to shear walls and the maximum movement of the diaphragm is expected in the middle between the shear walls.

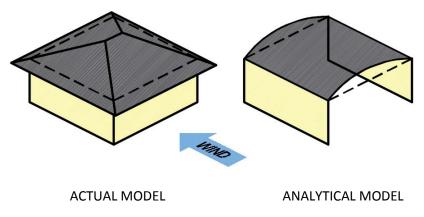


Figure 3.1-9: Simplified representation of the roof diaphragm bending due to hurricane forces





3.1.7.4 Shear Walls and Frames

Shear walls and lateral force-resisting frames provide lateral strength for the building. These elements are critical when a building is subjected to hurricane forces. They are responsible for limiting the sway of a building and for transferring lateral forces down into the foundations. In many cases, gravity loads are also supported by shear walls and frames, so they have to be designed to resist combined forces in both vertical and horizontal directions.

In the figure below, the bending or deflection is exaggerated for illustrative purposes. The analytical model only shows the effects of the shear walls. The bottom of the walls are anchored to the foundation and the maximum movement of the wall occurs at the top.

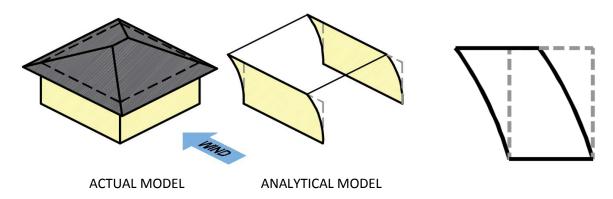


Figure 3.1-10: Example of shear walls bending due to hurricane forces

Figure 3.1-11: 2D representation of a shear wall bending





3.2 ROOF SYSTEM

The roof serves two main purposes:

- horizontal weather barrier to keep out intense sunlight, rain and other precipitation
- structural diaphragm to provide lateral stability to an engineered house or building

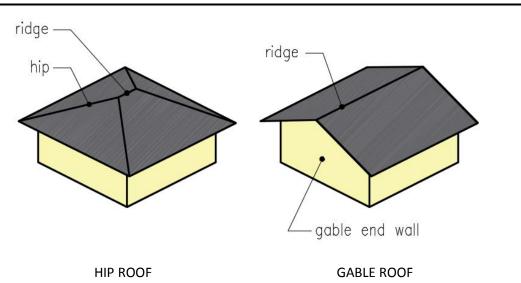
The roof is made up of many different components, each serving distinct purposes. It is important to monitor the performance of the roof and to note any missing damaged tiles or shingles. A small deficiency or defect in the roof may be an indication of a larger underlying problem that can result in significant damages in a hurricane storm.

The following are common methods of retrofits:

Adding hurricane ties to single wall home or double wall home to resist wind uplift

Replace roofing of single-wall home and add a structural diaphragm

Replace roofing of double wall home and add a structural diaphragm



3.2.1 Roof Shape

Figure 3.2-1: Typical roof shapes

A roof can take the form of many shapes depending on the design or use of the building. For residential structures, the roof is likely to be either a hip or gable roof. Roof framing typically utilize a rafter-joist or truss system. The ridge beam is located at the apex of the roof. Rafters or trusses are the primary framing members and are spaced typically up to a maximum of 24 inches on center.

How do hip roofs compare with gable roofs in performance? Historically, gable roofs result in more failures in a hurricane compared to hip roofs. Older gable end walls tend to lack sufficient bracing from the wall to the roof diaphragm. Gable end walls are also significantly taller than walls in hip roof houses, and therefore, they are subject to more wind pressure. Hip roofs are comparatively more aerodynamic and are supported on shorter walls.



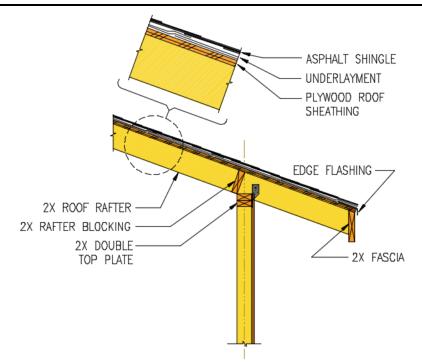


Figure 3.2-2: Typical roof components of conventional wood-framed construction

In Figure 3.2-2 above, the detail shows members that are typical for light-framed home construction today. If your home is single-wall construction, then you may find that some of the members in your own home are not oriented or provided as shown above. However, this section will still be relevant for both single-and double-wall construction as both construction types share the same major components.

The following sub-sections will cover the different components that make up a roof structure. The sections are sorted from the most interior component to the most exterior component.

3.2.2.1 Roof Framing

There are two major types of roof framing for houses: **rafter-joist framing and truss framing**. The primary difference is that rafter-joist framing involves construction workers cutting and assembling the roof framing members on site, while truss framing involves a truss manufacturer that delivers pre-fabricated trusses to the site. (Trusses have a higher upfront cost but are usually more economical because they reduce time required for construction and labor.)

Corrosion-resistant fastening, such as nails, screws, and metal straps or connectors, should be used for the roof framing as well as for all the components described below.

3.2.2.2 Sheathing

The plywood sheathing on an engineered roof provides a diaphragm that is connected to the roof framing members and serves to distribute wind or earthquake forces to the structural walls. The strength of the diaphragm is dependent on the thickness, the wood grade, and the nailing pattern of the plywood to the structural framing. Longer roof spans between shear walls will require thicker plywood sheathing and

more fasteners. If your home does not have a plywood diaphragm, definitely consider installing it when your roofing needs replacement.

3.2.2.3 Underlayment

Underlayment is a necessary component of the roof system for a secondary waterproof barrier under high wind conditions and should be either self-adhering polymer modified bitumen or synthetic polyethylene or polypropylene or rubberized asphalt underlayment. Underlayment is applied directly on the plywood sheathing and provides a secondary waterproofing membrane against water intrusion in case the primary roof covering is compromised. If a secondary membrane is not currently place on your roof, then it is recommended that it be installed when your roofing needs to be replaced. This protection can prevent major water damage from affecting the interior and property inside the home. The underlayment should be installed per the manufacturer's instruction as well as any additional recommendations for high wind regions.

3.2.2.4 Flashing

Flashing is a term used to describe thin, bendable metal sheets used to create a drip edge for rain flowing down the roof, seal the edges and transition joints of the roof, and prevent water from infiltrating the waterproofing barrier. Similar to roof tiles and shingles, the attachment of flashing and gutters should be inspected in order to determine whether repairs are necessary. Because flashing materials tend to be flexible, if they are not fastened down properly, damage to the flashing may cause progressive damage to the roof covering. Flashing should be installed per the manufacturer's instruction as well as any additional recommendations for high wind regions.

3.2.2.5 Roof Coverings

The roof covering, such as the shingles and concrete or clay tiles, is the outermost line of defense. For this reason, the roof covering is most likely to be damaged in a hurricane. Properly installed roof covering will have the best chance of staying intact in a hurricane. If the roof covering is damaged and blown away, the roof becomes vulnerable of water infiltration and may lead to damage to the interior space, unless there is a secondary waterproofing barrier. The ridge and hip of the roof, as well as the edges and corners are vulnerable to failure of the roof covering. For homes that were built before 1982, the building code at the time did not consider the higher uplift pressures that occur at the edges and corners of the roof (FEMA 577, 2007). These areas should be closely inspected to determine if the covering needs to be replaced, resealed, or if additional fasteners are required.

Hawaii is considered a high-wind region, so manufacturer instructions for high-wind or hurricane regions should be followed. For example, asphalt shingles may require additional fasteners in high-wind regions and would need to have a high wind rating of ASTM D7158 Type G or H that should appear on the packaging. Code regulations require only 4 nails, but from new hurricane data and evidence, a 6-nail pattern will perform better in preventing your shingles from tearing off and becoming wind-borne debris. Concrete tiles should be installed with stainless steel holdown clip fasteners, and not just with pads of mortar.

3.2.2.6 Solar Photovoltaic Systems on Rooftops

Photovoltaic (PV) panels have been installed in large numbers on Hawaii homes mostly beginning in the 2000's. Hurricane forces can cause the failure of the panel connections to the roof structure, and the panels may pry up on the roof framing as well. It is prudent to make sure that the roof structure is secured with hurricane ties and is in overall good condition before installing expensive PV equipment on the roof.





PV panels are typically installed and anchored to structural roof members beneath the roof covering. Where they are tilted at a different orientation from the roof slope, they can significantly increase the wind load on the roof structure. In these cases, any vulnerability in the roof to wall connection is increased.

3.2.3 For Single Wall Homes

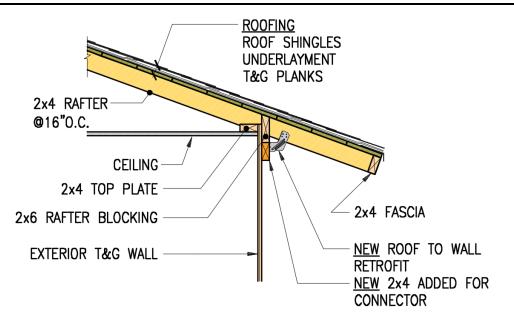


Figure 3.2-3: Typical section of roof eave of single wall home with a roof to wall connection retrofit

Roofs on single wall homes do not have a plywood sheathing system which is utilized for engineered light-framed homes. Without the plywood sheathing, there is no structural diaphragm. The performance of these older systems is dramatically poorer in a high wind event. As Hurricane Iniki has shown on Kauai, the roofs of single wall homes are vulnerable to major structural failure. WRD Option 2 requires that plywood sheathing be installed if there is no existing sheathing. If there is existing sheathing, then the sheathing should be inspected to determine if replacement is needed, or additional nailing installed. For construction details, see Appendix Section 4.2.2.

Because the roofs of many older homes have aged significantly, many may be affected by roof leaks during heavy rains. To correct this issue, the homeowner should consider reroofing. This would alos provide an opportunity to improve the strength and performance of the roof system to withstand hurricane forces with a structural diaphragm and roof to wall hurricane ties. There is also a technique to provide self-adhering membrane underlayment for secondary waterproofing that is given in WRD Option 2.

In single wall construction homes, the roof covering is typically asphalt shingles or metal decking. During a hurricane event, shingles and corrugated metal roofing are typically the most common object to be torn from the roof. Roofing at the hip and ridge are the most susceptible to detaching and becoming windborne debris. The loss of shingles and metal roofing may compromise the waterproofing of the roof and also eventually lead to progressive failure of the roof framing.

3.2.4 For Double Wall Homes

Roof sheathing provides for structural diaphragm action, allowing the wind forces to be distributed throughout the roof area. Roof sheathing failure is mostly caused by a shortage of nails, especially at high



pressure zones at the edges and corners of the roof. If the diaphragm fails in one area, it will greatly reduce the rigidity of the roof and will increase the chance of failures occurring in other areas, and possible instability of roof framing members. It should be noted that not all double wall homes will have a sheathing diaphragm. In non-engineering construction, there may be just rafters, secondary wood battens, roofing felt, and shingles nailed through the felt to the battens. In that case, during a hurricane, loss of shingles will lead to holes in the roofing through which water can pour and wind can enter.

If the roof covering is to be replaced, the homeowner or inspector will have the opportunity to inspect the condition and the attachment of the structural plywood sheathing, or find out if the sheathing is missing. Any plywood that shows sign of moisture damage should be removed and replaced with new plywood. The thickness of the plywood should be minimum 5/8" (2007 WRD Specifications). If not installed already, metal straps (18 gauge; Simpson MSTA18 or equivalent) should be installed on rafters or trusses along the ridge of the roof at 48" on center.

For homes that were built before 1982, the building code at the time did not consider the higher uplift pressures that occur at the edges and corners of the roof (FEMA 577, 2007). Therefore, the existing nail pattern on the roof may not meet current building standards. If the roofing is to be replaced, it is highly recommended that additional nails be used on the existing plywood and that new plywood be fastened with closely spaced nails. Ring-shank or spiral-shank nails should be used in lieu of typical smooth shank nails. These nails have higher withdrawal capacity but can still be installed with typical pneumatic nail guns.

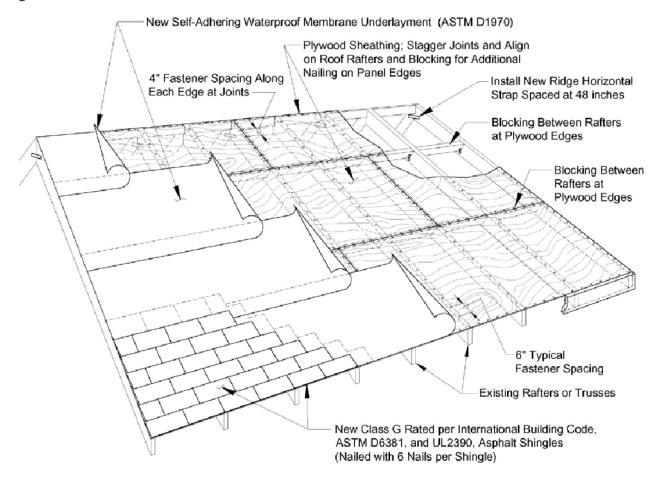


Figure 3.2-4: Roofing renovation per 2007 WRD Specifications

3.2.5 Roof to Wall Connection

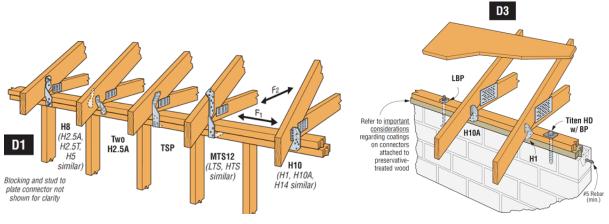
The connection between the roof and walls is an essential first step in implementing a complete load path. Requirements for a complete uplift load path are required in modern construction, but many older woodframed houses and some permitted under the International Residential Code do not have a properly engineered load path in place for high wind uplift. Historical performance of older roofs have shown decisively that, without proper holdowns, the roof is vulnerable to complete separation from the walls of the house. This failure mode becomes even more probable when exterior openings are breached and pressurization occurs. The roof becomes subjected to higher internal pressures, increasing the total uplift force on the roof-to-wall connectors.

The effects of Hurricane Iwa (1982) led the Building Codes to mandate roof to wall uplift ties. If your home was constructed before the benchmark years in Table 3.2-1, then your home should be inspected for the installation of hurricane ties. Hurricane ties are metal connector plates that should be installed at every rafter or truss and fastened to the top of wall studs. Hurricane ties come in various shapes to allow for compatibility with many types and styles of construction.

Table 3.2-1: Wind Vulnerability Benchmark Years for Existing One and Two-Family Residences

Kauai	Honolulu	Maui	Hawaii
1989	1987	1989	1993
Source: Uniform St	atewide Building Code Task Force: R	eport and Recommendations to the H	Hawaii Legislature, December 9, 2005.

Installing hurricane ties can reinforce this connection, as seen in Figure 3.2-5. For perspective on the recommended capacity of this connection, WRD Option 1 requires that there be a minimum of 400 lb of uplift resistance at each rafter or 200 lb of uplift resistance per foot, whichever is greater.



Source: http://www.strongtie.com/products/highwind/TrussRafter-WDTP.html

Figure 3.2-5: Various types of metal connectors for roof-to-wall connections manufactured by Simpson Strong-Tie

Simpson Strong-Tie has developed the HPT Hurricane Tie that is optimal for connecting the roof rafters to the walls in *single wall* construction homes. The HPT clip provides 400 lbs of allowable uplift capacity. To ensure effective performance, the HPT clip will need to be installed and spaced evenly throughout the house.







Source: http://www.strongtie.com/products/connectors/hptz.asp

Figure 3.2-6: Simpson Strong-Tie HPT clip designed for Hawaii's single family houses (before being painted afterwards to the same color as the wood framing)

To inspect if your house already employs roof-to-wall connectors, access to the connection can typically be done from the exterior. In many cases, there is no soffit constructed under the roof overhang for single-wall homes. Depending on the framing configuration, a different metal connector may be more practical than the one shown in Figure 3.2-6. WRD Option 1 outlines many different acceptable configurations for providing an acceptable roof to wall tie.

Double-wall homes should also be inspected for roof-to-wall connectors. Access to the connection may be difficult for double-wall homes. You may be able to see the underside of the roof framing if there is an access hatch in the ceiling, possibly located in the garage or other areas. Otherwise if there is no documentation of the roof to wall connector, inspection of the connection may require some destructive means. From the interior, you will have to cut access holes into the interior wall or ceiling. From the extensive re-roofing project, there is an optimal opportunity to inspect and install additional hurricane ties if needed. Any corroded or damaged metal connectors should be replaced. For homes that precede the code requirement for hurricane ties where inspection of these concealed spaces is difficult or if it is unclear whether the home has hurricane roof to wall ties, it would be prudent to go ahead and add the hurricane clips on the exterior and paint them with the same color used for the wood framing.





3.3 WALL SYSTEM

Exterior walls need to be designed to resist the wind pressures on the wall surface, but also have to serve as a weather barrier. Wind-driven rain can penetrate through poorly sealed walls and cause mold or aesthetic damage to the interior walls and floors. This damage may seem minor, but remediation costs can be significant, especially if mold develops.

3.3.1 Wall Components

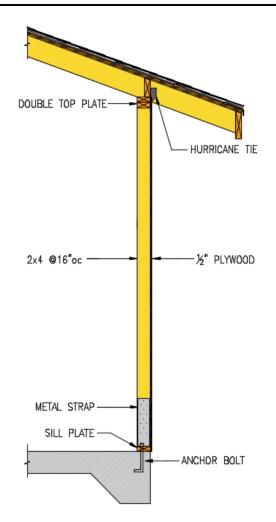


Figure 3.3-1: Typical wood wall section (left) and concrete wall section

3.3.1.1 Exterior Wall Covering

Wall coverings are the most exterior barrier against the weather and elements. Therefore, wall coverings are subject to much more damage from hurricane forces. If wall covering is blown away, the interior becomes vulnerable to water damage.

For wood-framed houses, wall siding may be used, which may or may not be plywood. FEMA publishes very specific instructions on how to properly install vinyl siding (FEMA P-499, Technical Fact Sheet No. 5.3). Wall sidings are now available with hurricane-rated performance. It is important to survey the edges of the siding on your home and make sure the trim members are in good condition. Once trim



members fail or if trim members are in a bad condition, the edge siding on your home will be more vulnerable to being peeled back in a hurricane.

Another type of wall covering is **EIFS**, which stands for exterior insulation and finishing system. This type of covering can be found on newer homes. There have been multiple cases showing failure of EIFS from hurricane forces. This is due to the lack of sufficient fastening of the insulating styrofoam panel to the wall studs. Unfortunately, there is no easy or cost-effective method to retrofit the system aside from having the entire covering stripped and replaced.

3.3.1.2 Building Paper or House Wrap

House wrap is a secondary barrier beneath the wall covering that keeps water out but has tiny perforations that allow the transmission of water vapor. This helps to keep the insulation and the framing from getting wet from the outside weather, but also allows the system to ventilate and dry if there is already moisture in the wall. It does not prevent windborne debris strikes from penetrating the wall.

3.3.1.3 Structural framing

The structural framing varies across different construction types. The framing provides the structure on to which all other components are attached. For single-wall construction, tongue-and-groove boards (T&G) are the primary structural framing members. T&G boards serve two purposes: supporting the weight of the roof above and resisting lateral forces, out-of-plane and in shear. For double-wall construction, the structural framing includes the 2x4 or 2x6 wall studs and the sheathing or siding.

3.3.1.4 Insulation

Well-insulated structures are able to maintain comfortable temperature levels more. Light-framed structures typically utilize fiberglass insulation "batts" laid between the studs. If water penetrates the wall system and wets the batt insulation, the insulation will need to be removed from the wall and replaced. Single wall construction does not employ any insulation in the wall system.

3.3.1.5 Interior Finish and Sheathing

For all construction types, the interior face of the wall is typically sheathed with gypsum board, or commonly referred to as drywall. Drywall serves as an aesthetic finish to the interior space and has some nominal fire resistive properties.

In wood construction, shear walls utilize structural grade plywood sheathing to achieve shear strength. Walls that have gypsum sheathing, mostly used for interior walls to divide rooms, usually do not contribute to the lateral resistance of the building and are typically not attached to the structural diaphragm. Single wall construction typically does not have interior finish or sheathing.



3.3.2 Single Wall Construction – Wall Retrofit

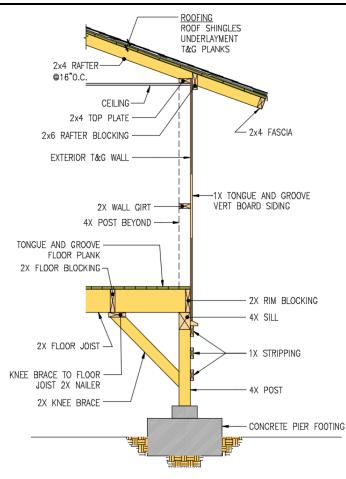


Figure 3.3-2: Typical single-wall construction

3.3.2.1 Tongue-and-Groove Boards

The walls of single wall houses have relatively lower out-of-plane capacity compared to conventional stud walls. Single-ply walls have to bend in their minor direction, which is weaker than bending in the major direction. These wall boards are typically redwood, which has good termite-resistant properties, but can eventually succumb to dryrot.

In certain later styles of single wall construction, a wall girt at the mid-height of the wall is provided for the additional stiffness by limiting the vertical span of the T&G boards. The girts are then supported by 4x4 or larger posts at each end. The wall girt can be located either on the interior or exterior of the building; when it is on the exterior, it is turned vertical and has the appearance of a horizontal continuous trim piece on the wall.

If the house has a gable roof, there may be a potential weakness in the connection of the gable roof edge to the top of the gable end wall. See Section 3.5.2 for more information on gable end wall retrofit.

3.3.2.2 Wall Retrofit

Because the walls are a major structural component as well as a major envelope component, it is still important to identify and strengthen potential weak points in the wall. Wall planks subject to moisture or

termite damage should be repaired or replaced. Nailed connections to the roof and floor framing should be inspected to assess any damage from excess moisture or termites.

3.3.3 Double Wall Construction – Wall Retrofit

To effectively implement a complete load path, a wall must be in good condition and be properly framed with connectors to transfer forces from the roof diaphragm into the foundation and ground. It also carries the wind uplift force on the roof down into the foundation anchorage.

The components that make up the wall are hard to inspect because they are normally covered up with architectural features. The decision to inspect the inside of a wall is normally preceded by the intent to do some renovation. Unless remodeling work is being done, any damage may go unnoticed and may not be remediated in time before disaster strikes. However, signs of deterioration of the coverings can indicate the internal members may also be affected.

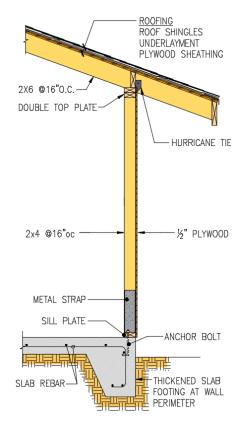


Figure 3.3-3: Typical double-wall construction

3.3.3.1 Top plates

On top of the wall studs are two 2x4s or 2x6s making up the "top plate" or the "double top plate". The top plate serves as a uniform support for the roof or second floor framing members, so the top of the top plate is level throughout the house or a specific space. The top plate distributes the loads from the level above to the wall studs. In a hurricane event, the two top plate members also serve as chord members, which resolves the high tension and compression loads that result from lateral loading on the diaphragm.

If the top plate is in a deteriorated state, either from termites or water, and fails to resist the hurricane loads, the diaphragm system will drastically lose capacity. This will lead to failures in other framing members and connections in the roof diaphragm and walls.

3.3.3.2 Wall studs

In typical load-bearing and shear walls, wall studs are primarily used to carry the gravity loads from the roof or the floor above. Wall studs are essential in supporting the wall sheathing, which makes the wall system rigid and strong enough to resist lateral, hurricane forces. Termite-damaged or rotted studs can be removed and replaced fairly easily. Wall studs are repetitive, so the absence of one stud for a short period of time will not compromise the entire wall system.

3.3.3.3 Wall Sheathing

Similar to roof plywood sheathing, wall sheathing stiffens and strengthens walls in order to transfer lateral forces to the foundation. Wall sheathing is the main component that resists the lateral shear force on a shear wall. In order to resist shear forces, the sheathing for at least one side of the wall has to be structural plywood. The nailing pattern of the sheathing influences the amount of capacity. Other wall coverings, such as gypsum, do not significantly contribute to the shear capacity of the wall.

Plywood sheathing in disrepair should be replaced with immediacy. Lack of sheathing can lead to shear failure and costly repair/replacement of the total wall assembly.

3.3.3.4 Sill Plates

The sill plate makes up the bottom perimeter of the wall and assists in framing the wall studs. The sill plate is also important in connecting the wall to the foundation or the wall below if one exists. The edge nailing of the wall sheathing is attached to the sill plate. Holdowns are typically spaced throughout the perimeter of the building.

The sill plate is susceptible to damage from termites and rot from excess moisture. Additionally, sill holdowns can face corrosion and can cause spalling in concrete or masonry.

3.3.4 Protection of Exterior Openings

Windows and doors are typically supported by more or larger structural members around the opening. Wood-framed windows have extra 2x4's or 2x6's that makes up the jamb on each side and a large header beam at the top. A window or door opening is still subject to high wind loads, so the extra framing members are provided to help transfer these forces to the roof and the ground.

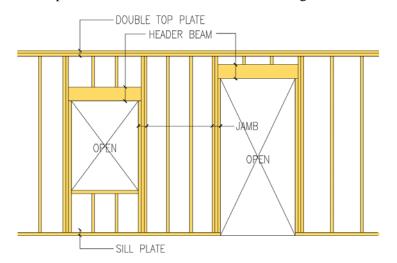


Figure 3.3-4: Typical window and door opening in double-wall construction

When window or door assemblies fail or are blown in from a hurricane, the house will be subject to higher internal pressures, known as **pressurization**. The exterior walls and roof of the house that are already enduring high external pressures will have to resist increased internal pressures if any openings are breached, as shown in Figure 3.3-5. For many older homes, this increases the risk of entire roof uplift or even structural collapse. For any category of hurricane, buildings are vulnerable to airborne debris and the property owner is advised to take extra steps to ensure that the windows, doors, and other large openings will not fail. Therefore, it is important that exterior openings are protected during hurricanes.

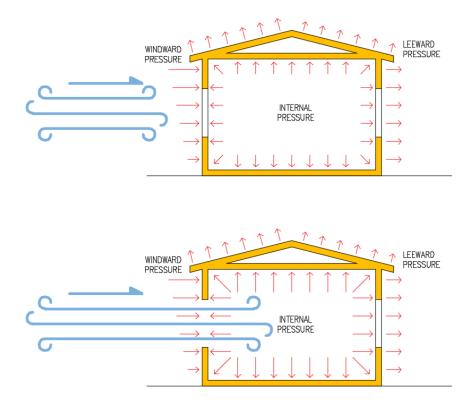


Figure 3.3-5: Example illustration of pressurization

3.3.4.1 Tape on Windows

Taping windows may seem like a common precaution, but it may actually increase the danger for anyone taking shelter in the house or nearby. The tape is applied to prevent window glass from shattering into tiny pieces. However, when taped, the window glass will break into much larger pieces and may turn into multiple sharp projectiles, which may increase the chances of serious injury.

3.3.4.2 Temporary Shutters

Temporary plywood can be installed over windows to protect the window opening from being breached by high wind forces or wind-borne debris. The plywood needs to be 5/8 inch to 3/4 inch thick and should be precut and pre-drilled with permanent corrosion-resistant hardware.

Temporary shutters should be attached to structural framing of the window or door. For single-wall homes, this can be identified by the 2x4 studs that frame around the openings. The structural framing is likely exposed either from the inside or outside. If the wall has exterior siding, then the structural framing will be likely be exposed on the inside. For double-wall homes, the opening may have a decorative

window trim on the inside and outside. Figure 3.3-4 shows the structural framing around the openings to assist the homeowner in finding a solid stud to fasten to.

For large openings, it is recommended to hire an inspector or structural engineer to make sure that the framing members are capable of transferring the loads to the upper and lower diaphragms. Alternatively, if the original drawings are available, review of the drawings may have information that an engineer can use to make an analysis of this capacity. It is important to make sure that the window or door assembly and the structural framing around the opening is strong enough to withstand hurricane forces.

Table 3.3-1: Fastener Red	wirements for Tem	porary Plywood Shutters
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	Maximum Fastener Spacing in inches			
Recommended Fastener Type	Panel Span up to 4 ft	Panel Span greater than 4 ft up to 6 ft	Panel Span greater than 6 ft up to 8 ft	
No. 8 Wood Screws with 2- inch embedment	16 inches	9 inches	6 inches	
No. 10 Wood Screws with 2-inch embedment	16 inches	12 inches	9 inches	
1/4" Lag Screw Anchor with 2-inch embedment	16 inches	16 inches	16 inches	

a. Fasteners shall be installed at opposing ends of the wood structural panel.

 Where screws are attached to concrete, masonry, or masonry/stucco, they shall be attached utilizing vibrationresistant anchors having a minimum withdrawal capacity of 500 pounds. Fasteners shall be located a minimum of 2-1/2 inches from the edge of concrete block or concrete.

c. Attachment in accordance with this table is applicable for buildings with mean roof height of 33 feet or less.

d. Source: WRD 2007 Specifications

3.3.4.3 Permanent Shutters

Storm panels are alternatives to temporary plywood shutters. Storm panels can be made up of different materials and are specifically designed to temporarily protect the window opening of a home. The convenience of these systems is that it comes with its own mounting hardware and are ready to deploy out-of-the-box. Permanent shutters are ideal for upper story windows, where it may be difficult to access to deploy temporary shutters during hurricane warnings. Permanent shutters come in different styles, shown in Figure 3.3-6. Because the installation is permanent, these shutters offer more aesthetic appeal. However, the attachment to the structural framing should be of the utmost concern. The shutters need to be able to withstand high wind pressures as well as windborne debris impact and be able to transfer such forces to the structural framing. Impact-resistant assemblies are designed to resist high wind pressures as well as windborne debris impact. These assemblies should be able to transfer the wind pressures to the home's structural framing.



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Source: FEMA P-499 Technical Fact Sheet No. 6.2

Figure 3.3-6: Types of permanent shutters

3.3.4.4 Impact-Resistant Assemblies

There are several types of impact-resistant glazing. Laminated glazing systems are made up of two panes of glass with a layer of film laminated between. The film is meant to serve as a barrier against water and wind if the glass panes break. After-market impact-resistive self-adhering films can also be installed on the inside surface of the glazing, along with a silicone edge sealant all around to adhere all edges of the film to the window glazing frame. Polycarbonate glazing is made from plastic resins and is much more resistant to impact than glass. It is also important to ensure that the installation involves window frame attachment to the jamb studs, header, and sill beam. This will create a complete load path from the window to the foundation and roof/floor diaphragm above.

It is important to verify that any assembly considered has passed standard testing procedures and is certified and approved by testing authorities. For Hawaii, ASTM E1996, an impact testing procedure, lists Hawaii under Wind Zone 1. To meet the criteria under E1996, an assembly to be installed in a typical residential structure must be able to resist a projectile, 2x4 lumber by 4 feet long, flying at 40 feet/sec or 27 mph. Many products on the market may advertise that they meet certain benchmarks, labeled under trademarked brand names. To avoid confusion, make sure that impact rated systems meet certification requirements under the American Society for Testing and Materials (ASTM) E1886 and E1996.

It is highly recommended that skylights are installed as an impact-rated assembly because protecting the opening is impractical. If a breach of a skylight does not lead to major structural damage, it will at least guarantee costly damage from flooding and water intrusion, as hurricanes winds are often accompanied

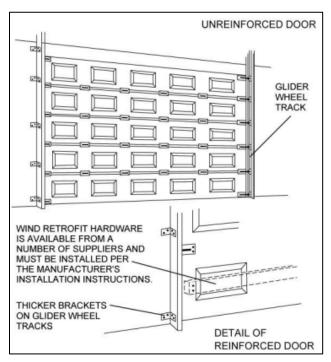


by heavy rain. Large openings, such as exterior sliding doors, are also recommended to be an impactrated system for the same reasons.

3.3.4.5 Garage Door Bracing

Garage doors are often the largest opening into a house or building. They are not designed to the same standards as conventional windows and doors because the garage is a low occupancy area and garage doors are lightweight in order to make it easier to raise and lower. Many garage doors may not be rated for hurricane performance. They are vulnerable to large deflections and this could eventually cause pressurization of the interior, increasing the lateral force and uplift on the garage structure. Keep in mind that currently, most buildings are designed for an enclosed building, so the design of the garage may not account for this increased load state.

Retrofit of the garage door can be done by reinforcing the door with horizontal girts. The girts are installed along each horizontal panel and the wheel track is reinforced with thicker metal brackets, as shown in Figure 3.3-5. Horizontal girts have the advantage of making the door stronger but still can remain clear of the existing track, keeping the door operable. (However, if the garage door relies on an automatic opener, the added weight from reinforcement may affect performance for a given power rating.)



Source: FEMA "Reinforce or Replace Garage Doors", March 2011

Figure 3.3-5: FEMA's illustration of a retrofitted garage door

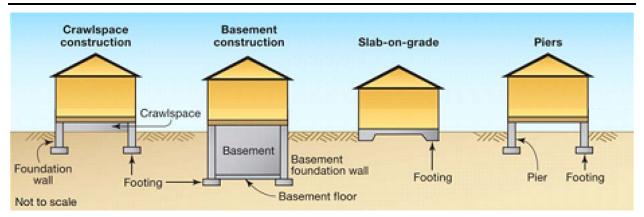
Temporary vertical girts may be more compatible for installation on your existing garage door, but may obstruct normal operation of the door. Mounting hardware to connect the vertical girts should be preinstalled and the vertical girts should be deployed when a hurricane warning is issued. Another alternative would be to provide temporary strapping connected to holdown anchors for the garage door, which can be deployed during the hurricane warning (the garage door is held down and won't operate).

If your home utilizes an open carport, see 3.5.1 Carports, Canopies, and Covered Walkways.

3.4 FOUNDATION SYSTEM

Vertical load-bearing elements, such as columns, posts, or walls, need to be supported at the ground level by a foundation system. In order for the soil to provide support for a structure, the foundation must spread the vertical load across a wide area. On an average day, a vertical element and foundation will resist weight of the building and small magnitudes of uplift and lateral loads caused by nominal wind forces. However, during a hurricane event, the connection of the vertical element to the foundation must have enough capacity to transfer lateral (horizontal) forces and other actions on the structure that normally are not present.

3.4.1 Anatomy of Foundations



Source: FEMA Hurricane Sandy Recovery Fact Sheet No. 2

Figure 3.4-1: Different types of foundations

A foundation system is typically built with concrete because concrete is a resilient material that performs well in soil. For example, concrete is not vulnerable to termite damage like wood and will not corrode like steel when embedded in soil. Concrete is also a very heavy material, which contributes to good wind uplift resistance. (When designing the foundation, engineers check the allowable bearing pressure of the soil or the capacity of the pile, designate the size of the footing and amount of steel reinforcement required, and check if the expected settlement meets building code requirements.)

Most modern residential structures are typically built with a slab-on-grade system or engineered masonry or concrete piers. Homes that are framed with concrete or masonry may utilize wall footings, spread footings, and grade beams.

For wood walls and posts, it is important to check if the base is damaged, either rotted from moisture or damaged by termites. The condition of the connections, such as the metal straps, nails, screws, etc., should also be checked. Weakened wood members will generally be able to serve their everyday purpose, but they will not be able to withstand their original design forces or higher. Similarly, for steel columns, the base of the column and base plate should be checked if there is section loss from corrosion and if remediation is necessary. Concrete and masonry are generally more resistant to corrosion, although cracks and signs of rust should be investigated.



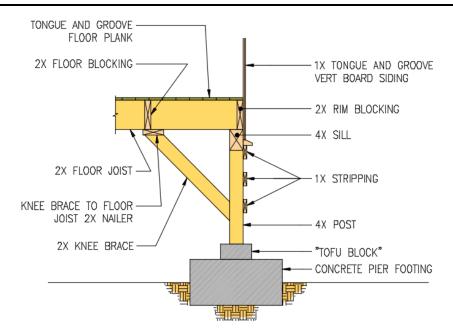


Figure 3.4-2: Typical foundation of a single wall house

The foundation system for older single wall homes often consist of a post and pier system with an elevated floor and a crawl space underneath. These are not engineered systems. The homeowner should check if there is a connection between the wood posts to the concrete block to provide uplift resistance. This connection is typically visible and can easily be inspected by the homeowner. The foundation system for single family homes typically consist of multiple isolated concrete blocks. In many cases, the posts supporting the house are not anchored to the concrete blocks.

3.4.2.1 WRD Option 4 Retrofit

The 2007 WRD Specifications detailed a retrofit that can be applied to typical single wall homes constructed on post and beam system with an elevated first floor. This retrofit resolves the major issue of single-wall homes not having adequate uplift resistance. As seen in Figure 3.4-3, WRD Option 4 involves pouring a new grade beam around the perimeter of the house and installing new holdown anchors to provide uplift resistance. The grade beam is poured against the existing foundation blocks and is also connected integrally with a dowel drilled into the existing footing. This allows the house above to effectively engage as many footings that are connected. Plywood sheathing is also added to brace the posts and to provide lateral stability during high wind events. Holdowns are also utilized to connect the perimeter floor beam to the grade beam every 4'-0" to provide tension and uplift capacity. Alternative designs by licensed structural engineers are permitted. Because this retrofit requires extensive amount of earthwork and concrete, a building permit will probably be required.

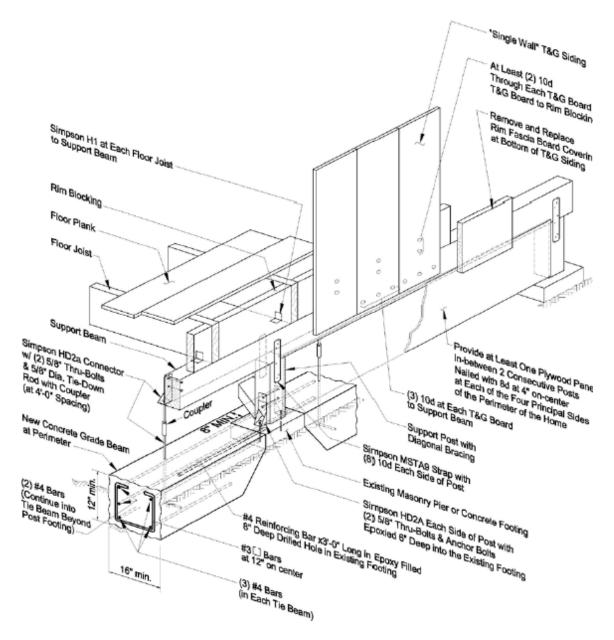


Figure 3.4-3: Typical foundation of single wall homes





3.4.3 Double Wall Construction – Foundation Retrofit

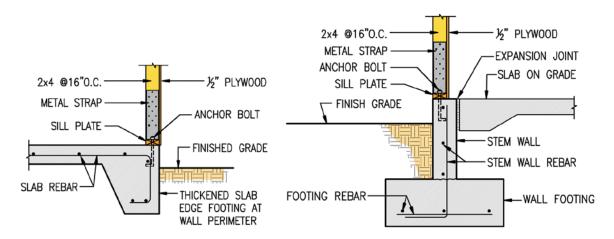
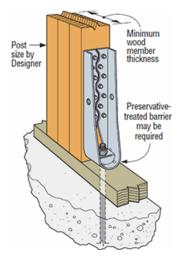


Figure 3.4-4: Thickened slab edge footing (left) & wall footing (right)

Foundation systems for conventional stud-framed residences typically consist of slab-on-grade with slab edge footings or wall footings. This foundation system has performed well in past hurricanes in other areas of the country. So, there has not been large demand in finding methods for retrofitting foundations for double wall houses, unless anchorages are missing. Instead, attention should be focused on the quality of the connection of the structure to the foundation.

The homeowner should identify areas that show signs of termite or moisture damage and check if the metal straps or holdowns are in good condition. Any anchor connections that show indication of the base concrete spalling should be brought to a contractor and the spall should be repaired immediately. If a concrete spall is detected, other locations that use the same connector may also be affected. Spalls are often linked to corrosion of the metal connectors. Construction drawings should indicate the type and the spacing of holdowns throughout the house. If any of these members are damaged, they should be removed and replaced.

There should also be an assessment done on flood risk. Because the first floor is typically not elevated for double wall homes, there is a greater risk of flooding if the house is located in a flood zone or if the site has poor drainage. Flood damage may greatly damage the interior of a house and will most likely require extensive, costly work to mitigate mold or moisture damage.



Source: http://www.strongtie.com/products/connectors/HDU-DTT2.asp

Figure 3.4-5: Anchor to wall footing or slab edge footing

3.5 OTHER COMMON STRUCTURES

Aside from the main home, there are other major components and structures that require assessment for hurricane performance. These include:

- 3.5.1 Carports, Canopies, and Covered Walkways
- 3.5.2 Gable End Wall Bracing
- 3.5.3 Safe Room

3.5.1 Carports, Canopies, and Covered Walkways



Source: Google Maps Street View (Honolulu)

Figure 3.5-1: Open carports in Honolulu

Many older carports consist of a lightweight roof and evenly spaced posts. These structures are vulnerable to complete uplift failure for the following reasons:

- they are fairly lightweight, have a considerable horizontal area, and are an open structure, which causes the carport to endure much higher pressures than the main structure or house
- older structures may not be anchored or braced properly
- they may be significantly deteriorated from wood rot or metal corrosion
- older structures most likely do not comply to current building code regulations

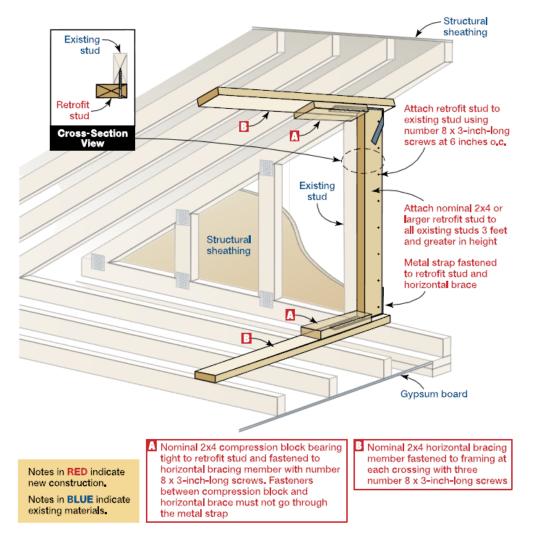
The roof-to-post connection should be inspected for damage or corrosion. For minor damage, affected members and connectors should be replaced. This may require shoring of the roof structure while the vertical structural members are being repaired. Please consult with a licensed contractor to ensure that the work is done safely and to avoid compromising the entire structure. Posts that are not anchored to a foundation should be retrofitted with an appropriate anchor connection. A structural engineer should be contacted to provide assistance with the retrofit details.

For structures with major deterioration, especially around the footings or roof connections, complete reconstruction is recommended. Complete reconstruction will not be as major of an endeavor compared to other types of structures because carports typically only consist of a few structural members. Opting to not retrofit increases the risk of compounding damage on to the house as well as endangers the occupants sheltering in the house.

3.5.2 Gable End Wall Bracing

For many homes, the upper gable wall is not constructed integrally with the lower wall. This causes the upper gable wall to undergo large deflections in a hurricane event, eventually detaching from the roof and wall below. Gable walls with ventilation openings (intended to keep the house cool) are exceptionally more at-risk because the opening occurs at a critical and vulnerable location. Houses with taller gables have greater risk than those with shorter gable walls. Shorter gable walls are less likely to fail because their vertical span is not as high.

In order to strengthen this weak point, bracing members have to be added, as shown in Figure 3.5-2. In order to prevent this failure, the existing studs should be reinforced with a new stud oriented perpendicularly to the existing sheathing. Additional horizontal bracing members are provided to engage the ceiling and roof members that are further back from the gable end, so that the load is not concentrated entirely at the gable end. Gable end wall heights over 16 feet are at high risk and require special attention by a professional structural engineer.



Source: FEMA P-804, pg. 4-19

Figure 3.5-2: Gable end wall retrofit by FEMA

3.5.3 Safe Room

The purpose of a safe room is to provide an accessible, reinforced shelter to be occupied at the onset of a hurricane. Safe rooms are designed to resist amplified wind pressures and windborne debris that the main structure would not be able to withstand.

Safe rooms should not be built in flood-prone areas. (ROH Chapter 16 Article 13). This includes coastal zones labeled with FIRM zone "V" or "A", flood zones defined by the FEMA SFHA map, and areas that can be affected by dam failure determined by the Department of Land and Natural Resources.

These are some of the requirements for a safe room:

- the maximum occupancy of the safe room is 8 persons and a minimum of 15 square feet of floor area must be provided per person, up to a maximum of 120 square feet
- the safe room must have two exits: one inward-swinging door and one impact-resistant operable window
- the space must be ventilated with two operable, impact-resistant vents providing one air change every 2 hours or 12 square inches of venting per person
- the ceiling/roof must be able to support any probable superimposed dead load from debris that will fall on the safe room, no less than 125 psf; the walls must also be able to support the heavily loaded roof
- the safe room structure should be impact-resistant per requirements of ASTM E 1996 Level D
- the construction of the a safe room will require a building permit and the constructed safe room requires an inspection by a certified building inspector

If you are planning a new home construction, you may be required to provide a safe room if your structure is classified as a partially enclosed structure. The following types of residential buildings require a safe room:

- Occupancy R-3, if it is partially enclosed structure
 - R-3 buildings are mainly single- or two-family homes, but also include buildings that provide accommodations for five or fewer persons for less than 24 hours a day (child care or senior care) and dormitory-type buildings for less than 16 people.
- Occupancy R-4 Residential Assisted Living Facilities
 - R-4 buildings provide assisted living care for more than five but not more than 16 people, excluding the staff (2006 IBC, Chapter 3)

The enclosure classification is a method in determining the internal pressure for which a structure must be designed. A partially enclosed structure is one that has both of the following:

- 1. Total areas of openings in a wall (or on one side) of a building is greater than the total area of all other openings by 10 percent.
- 2. Total areas of openings in a wall or on one side is greater than 4 square or 1 percent of the wall area and the percentage of total openings to total wall and roof area on all other surfaces is less than 20 percent.

There are additional requirements regarding telecommunication capabilities. See Appendix Section 4.15



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4.1 WIND RESISTIVE DEVICES

The following sections will detail the general WRD Specifications that were approved under the Loss Mitigation Grant Program. The Loss Mitigation Grant Program was active from 2006-2008 to provide homeowners with financial aid in strengthening their homes against hurricanes. Although the program is no longer active, the information below is helpful in defining an acceptable benchmark for new retrofit work.

4.1.1 WRD Option 1: Roof to Wall Uplift Restraint Ties at Roof Ridges and Roof Framing Members to Wall or Beam Supports

4.1.1.1 Uplift Resistance Capacity

Complying with WRD Option 1 will ensure continuous resistance to roof uplift along the roof perimeter. This entails installing a metal strap or connector to the roof member, either rafter or roof truss, to the support beam or wall. Uplift resistance of:

- 400 lb is required at each rafter-to-exterior wall connection, AND
- a minimum of 200 lb per feet required at the exterior perimeter.

If the roof span is greater than 24 feet, then the required resistance should be increased proportionally. This is equivalent to providing a net uplift resistance of 16.67 psf per square foot of roof area, discounting overhang areas. For gable end rafters, 1000 lb of uplift resistance are required at each end. For exterior support beams connecting to corner posts/columns, 2000 lb of uplift resistance are required. At door and window jambs, 800 lb of uplift resistance are required at each jamb.

4.1.1.2 Connection Requirements

A minimum of four to five 8d nails with at least 1.25 inches of penetration is required to connect the metal connector to the rafter/roof truss and to the support beam or the double top plate at the top of the wall or the wall stud. Hardware installation shall comply with the manufacturer's instructions.

For roofs with roof truss construction, comply with the requirements outlined in 4.1.1.1. For roofs with post and beam construction, connectors are required at each connection point, including roof rafter to roof beams, top of post to horizontal ridge beam, and post to beam connection at the exterior wall.

4.1.1.3 Corrosion Resistance

The connector must be corrosion-resistant, either stainless steel (316SS) or galvanized steel with zinc coating of 1.5 ounces or greater per square foot of surface area per ASTM A653. The nails or screws must be stainless steel for stainless steel connectors or ASTM A153 galvanized for galvanized connectors.

4.1.1.4 Roof-to-Wall Details

See Appendix 4.2.1 for prototypical details excerpted from the 2007 WRD Specifications.





4.1.2 WRD Option 2: Fastening of Roof Wood Sheathing or Roof Metal Decking for High Wind Uplift

4.1.2.1 General Requirements

The intent of WRD Option 2 is to ensure that the roof assembly performs well as a water barrier and as a structural diaphragm, capable of distributing loads to the structure's shear walls.

The following are general requirements of WRD Option 2:

- roofing materials, such as tiles, shakes, shingles, etc., shall be removed and replaced
- any damaged or rotted decking materials shall be removed
- secondary water barrier shall be installed, either with self-adhering polyethylene or rubberized asphalt underlayment, per manufacturer's instruction regarding the required overlap (lapped distance of adjacent sheets)
- Simpson MSTA18 or equivalent (18" long, 18 gauge metal straps) shall be installed at minimum of 48" on center along the ridge of the roof, at each rafter or roof truss
- For roofs with existing structural sheathing, the existing sheathing shall be inspected and damaged sheathing shall be replaced. If the existing plywood sheathing is approved to remain, additional fastening will be needed to match the required minimum spacing.
- For roofs with no existing structural sheathing, new structural sheathing will have to be installed.

See Appendix 5.2.1.2 for prototypical details excerpted from the 2007 WRD Specifications.

4.1.2.2 Houses with Wood Roof Decking

For houses with plywood roof decks, add additional 8d ring shank nails to achieve a net maximum spacing of 6 inches in the body of the plywood panel and along the edges of the panel into all truss, rafter, beam, or joist supports. See Figure 4.2.2-3.

For houses with continuous dimensional lumber roof decks, add additional 8d ring shank nails to achieve a minimum of two nails in each decking board at each supporting rafter or truss. See Figure 4.2.2-4.

4.1.2.3 Houses without Wood Roof Decking

If there is no existing decking, new plywood decking with a minimum thickness of 5/8" shall be installed. Provide 8d ring shank nails per the requirements outlined in 4.1.2.2. See Figure 4.2.2-1.

Alternatively, the roof coverings can be removed until the battens are exposed. The plywood decking should be secured to each batten with 2-1/2" screw at a maximum spacing of 12" along each batten. See Figure 4.2.2-2.

4.1.2.4 Houses with Metal Roofs

If corrugated metal roof is in good condition with at least 15 years of remaining life, add 8d nails with neoprene washers at every 3 inches along the metal deck edges, eaves, and ridges and at every 6 inches at every support in the field of the decking panel. See Figure 4.2.2-7.

The house shall be inspected for corrosion, termites, and dry rot.

Alternatively, consider removing the existing corrugated metal roof and installing the system outlined in 4.1.2.2.



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4.1.3.1 General Requirements

Under WRD Option 3, all openings in a structure must be protected per requirements of ASTM E1996-05, except for openings less than 2 square feet.

WRD Option 3 allows garage and roll-up doors to be applied for separately from the other openings in the main structure. See the ASTM E1996-05 document or the 2007 WRD Specifications for more information on the testing procedures. Open buildings, those with 80% of the wall gross surface area open, are not eligible for this grant and should be inspected by licensed structural engineer for custom retrofit.

4.1.3.2 Temporary Plywood Panels

The following are requirement for the installation of temporary plywood panels:

- Panels must be minimum of 5/8-inch thick and span a max of 6 feet.
- Panels shall be preservative-treated
- Panels shall be precut and pre-drilled to be ready to be deployed when needed. Attachment hardware needs to be permanently installed in the frame of the opening.
- Corrosion-resistant hardware must be used.
- See Table 3.3-1 for fastening schedule.
- See Section 4.2.3 for approved APA details. Details may need to be modified for other types of openings.

4.1.3.3 Impact-resistant glass systems

These assemblies consist of a clear plastic-like interlayer film sandwiched and heat bonded between two glass panes. The glass panes are specially treated and the window frames are specifically designed to meet impact and pressure loads. The assemblies are installed as complete units that include the glass and the frame.

4.1.3.4 Laminated films

To comply with the requirements of these specifications, the manufacturer or installer is required to prepare prototypical drawing details for the attachment of the device to various types of window openings and frames. Details need to show the securing of the glazing to the window frame. Finally, submittal of test data showing product compliance with ASTM E 1996 is required.



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In order to comply with these specifications, the foundation retrofit detailed in Section 4.2.4 must be installed along the entire perimeter of the house. See Section 3.4.2 for more information. Alternative designs directly prepared by a licensed professional structural engineer shall also be acceptable.

A building permit will be required for this work.

4.1.5 WRD Option 5: Hawaii Residential Safe Room Performance Specifications

4.1.5.1 Minimum Structural Engineering Criteria

- the ceiling/roof must be able to support any probable superimposed dead load from debris that will fall on the safe room, no less than 125 psf; the walls must also be able to support the heavily loaded roof
- 160 mph 3-second peak gust
- Site Exposure C
- Importance Factor and Directionality Factor of 1.0
- Gust factor of 0.85
- Topographic wind amplification (Kzt) in accordance with local county building code
- Main building that houses the safe room shall not provide any additional protection and shall be assumed to be destroyed in the hurricane event
- Foundation system designed and engineered by a structural engineer

4.1.5.2 ASTM E 1996 Level D Testing Criteria

- Debris Missile Size: 2x4 weighing $9.0 \text{ lb} \pm 0.25 \text{ lb}$, 8 feet $\log \pm 4$ inches
- Minimum Debris Impact Speed: 50 ft/sec or 34 mph
- Cyclic Air Pressure Testing: 35 psf inward and 45 psf outward

4.1.5.3 Compliant Wall Assemblies

The following are wall assemblies that comply with the Level D requirements of ASTM E 1996 (ROH Chapter 16, Article 13, Table 16-13.7b):

- ³/₄-inch plywood on wood studs at 16-inches on-center with #8 X 3-inch wood screws at 6-inches o.c.
- ³/₄-inch plywood attached to double studs at 16-inches o.c. with #8 X 3-inch wood screws at 6-inches o.c.
- 8-1/4" cementitious lap siding over 22ga sheet metal attached to 350S162-33 studs at 24" or 16" o.c.
- 8-1/4" cementitious lap siding attached to 350S162-33 studs at 24" o.c. studs with interior 3/4" ply interior sheathing
- 8-1/4" cementitious lap siding attached to 35US1b2-33 studs at 24" o.c. with 1/2" interior 22-gage sheet metal composite gypsum wallboard
- 8-1/4" cementitious lap siding attached to 2 x4 wood studs at 16" o.c. with 1/2" interior 22-gage sheet metal composite gypsum wallboard



- 8-1/4" cementitious lap siding attached to 2 x4 wood studs at 16" o.c. with 22-gage sheet metal and ½" interior gypsum wallboard
- Cementitious lap siding attached to 5/8 inch structural plywood on 2 X 4 wood studs @16 inches a/c.
- Cementitious-panel siding attached to 5/8 inch structural plywood on 2 X 4 or 362S-137-43 steel studs @ 16 inches o.c.
- EFS with ¹/₂-inch dens-glass gold exterior sheathing on 362S-137-43 steel studs @ 16 inches and ¹/₂-inch interior gypboard
- Interior or Exterior wall with laterally braced (sheathed) 2 x 4 wood studs at 16" o.c. with 22-gage sheet metal on either side attached directly to the studs
- Interior or Exterior wall with laterally braced (sheathed) 2 x 4 wood studs at 16" o.c. with 1/2" interior 22-gage sheet metal composite gypsum wallboard on either side attached directly to the studs
- 24 gage steel sheet (50 ksi) on girts
- 4-inch-thick concrete with reinforcing
- 6-inch CMU with partial grouting at reinforcing spaced at 24 inches o.c.
- 8-inch CMU with partial grouting at reinforcing spaced at 24 inches o.c.

4.1.5.4 Communications

The safe room is required to have a phone line and a telephone that only needs to be plugged into a phone outlet and does not require to be plugged in a power outlet. If the phone requires power, an Uninterruptible Power Supply (UPS) battery device must be available and operable.

4.1.5.5 FEMA In-Residence Shelter Designs

The WRD specifications also permit the design and construction of the FEMA designed safe rooms detailed in the FEMA guide P-320, "Taking Shelter from the Storm", published most recently in December 2014. However, the FEMA safe room is much more costly to build and exceeds Hawaii requirements.

4.1.5.6 Safe Room Registration

The safe room should be registered with the Department of Defense and County Civil Defense Agency with its Tax Map Key or GPS coordinates. The owner should also submit a standing waiver of evacuation so that the occupants are allowed to use the safe room during a hurricane instead of being asked to evacuate.





4.2 **PROTOTYPICAL DETAILS**

4.2.1 WRD Option 1: Roof to Wall Uplift Restraint Ties

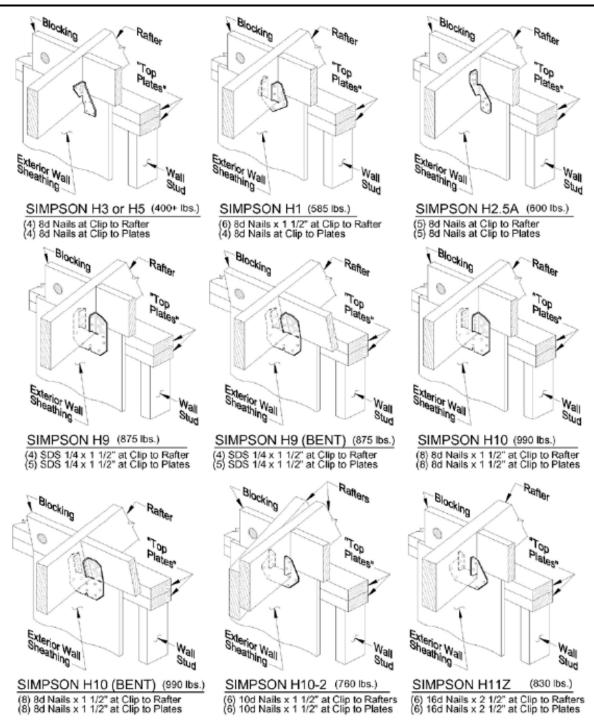


Figure 4.2.1-1: Roof to Wall Uplift Resistant Ties for Conventional Stud Wall (Double Wall) Construction





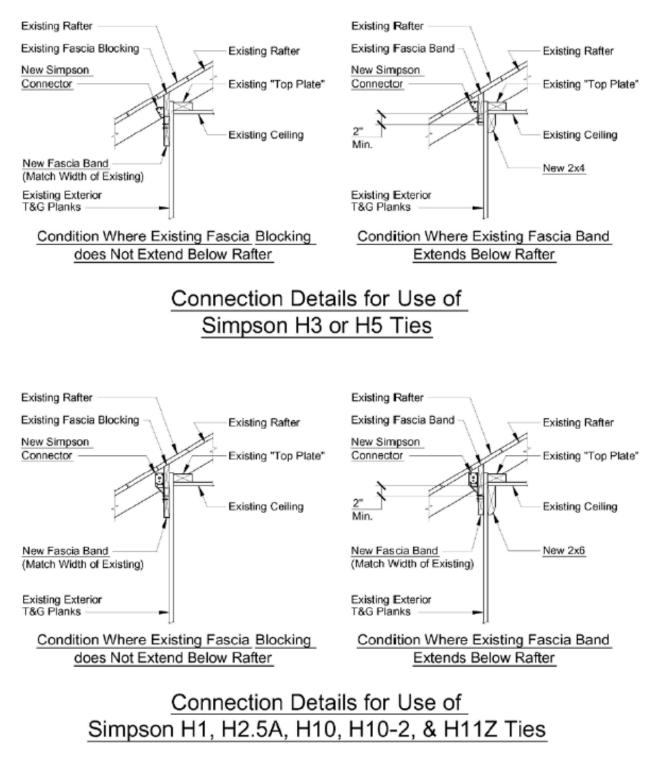
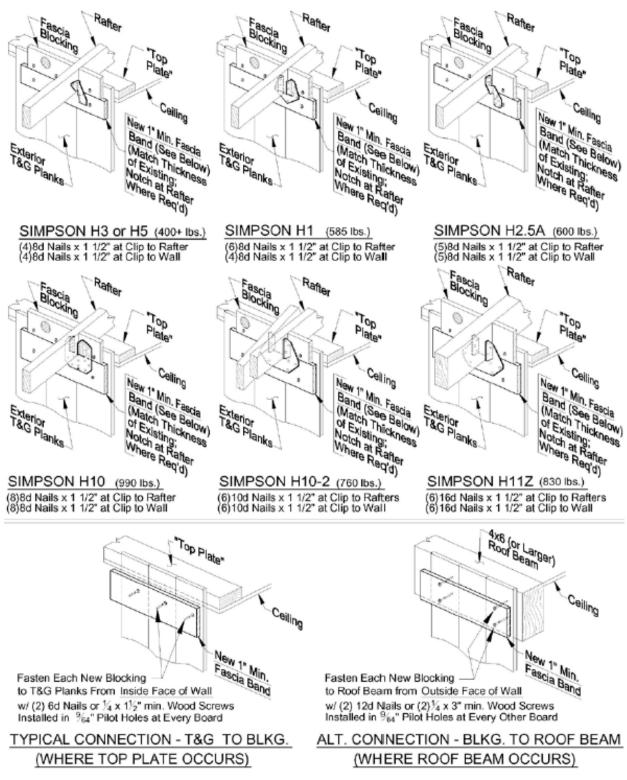
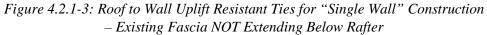


Figure 4.2.1-2: Roof to Wall Uplift Resistant Ties for "Single Wall" Construction











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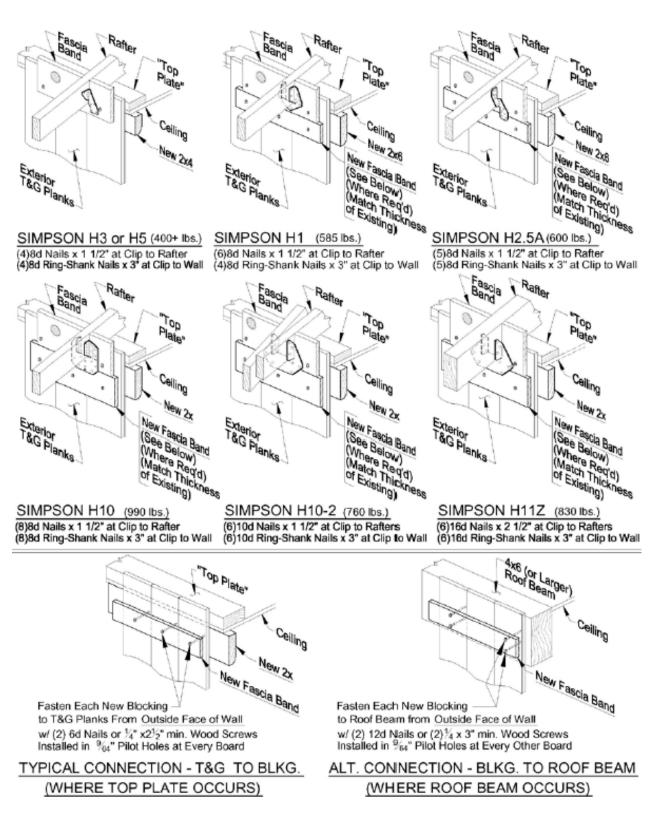


Figure 4.2.1-4: Roof to Wall Uplift Resistant Ties for "Single Wall" Construction – Existing Fascia Extending Below Rafter

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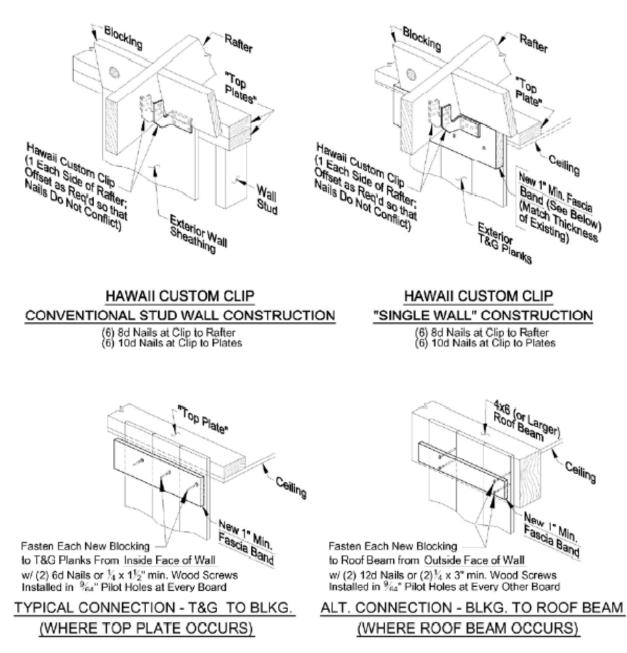


Figure 4.2.1-5: Roof to Wall Uplift Resistant Ties for Hawaii Custom Clips on Construction Where Rafter Spacing Does Not Exceed 24 Inches and Roof Span Does Not Exceed 24 Feet





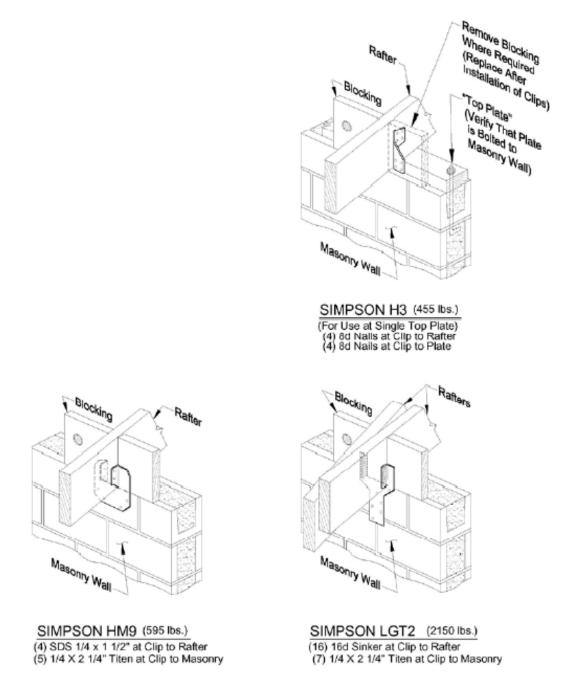


Figure 4.2.1-6: Roof to Wall Uplift Resistant Ties for Grouted Reinforced Masonry Construction



4.2.2 WRD Option 2: Fastening of Roof Wood Sheathing or Roof Metal Decking for High Wind Uplift

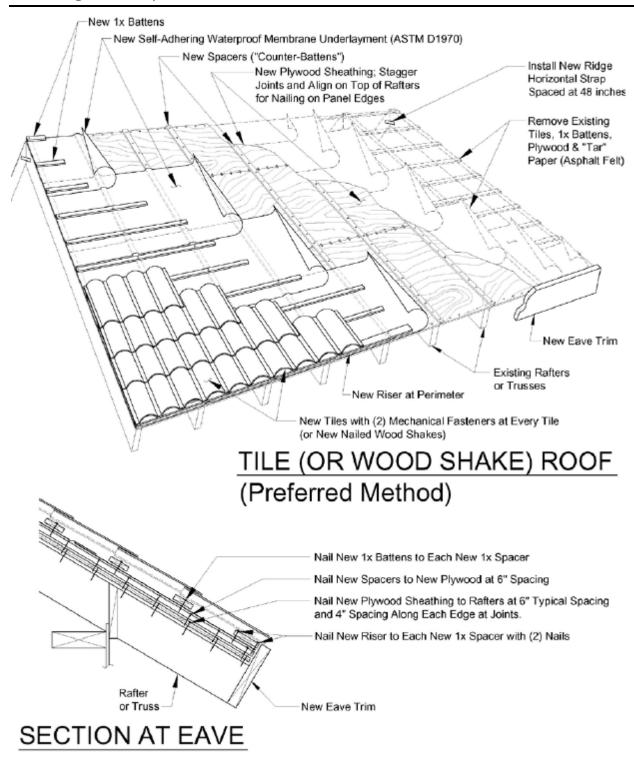


Figure 4.2.2-1: Preferred Upgrade of Structural Sheathing for Houses with Tile or Wood Shake Roofing

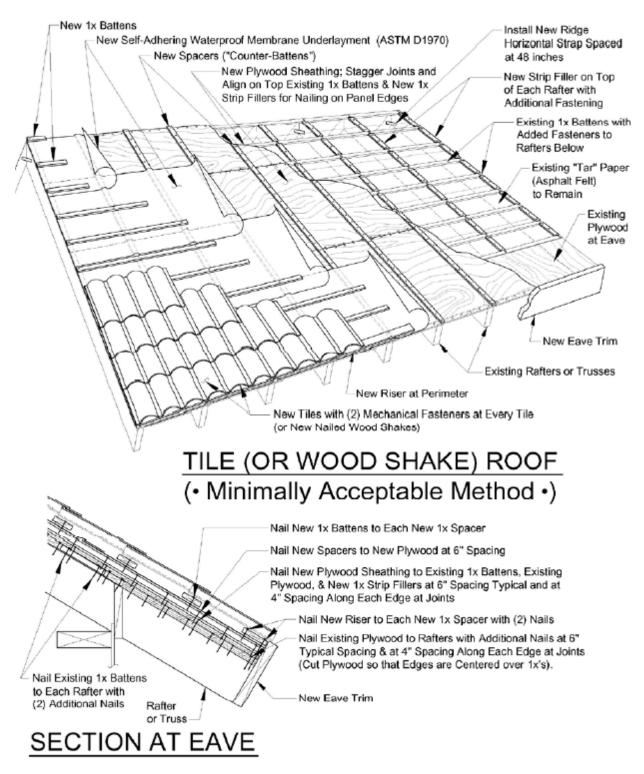


Figure 4.2.2-2: Minimally Acceptable Upgrade of Structural Sheathing for Houses with Tile or Wood Shake Roofing





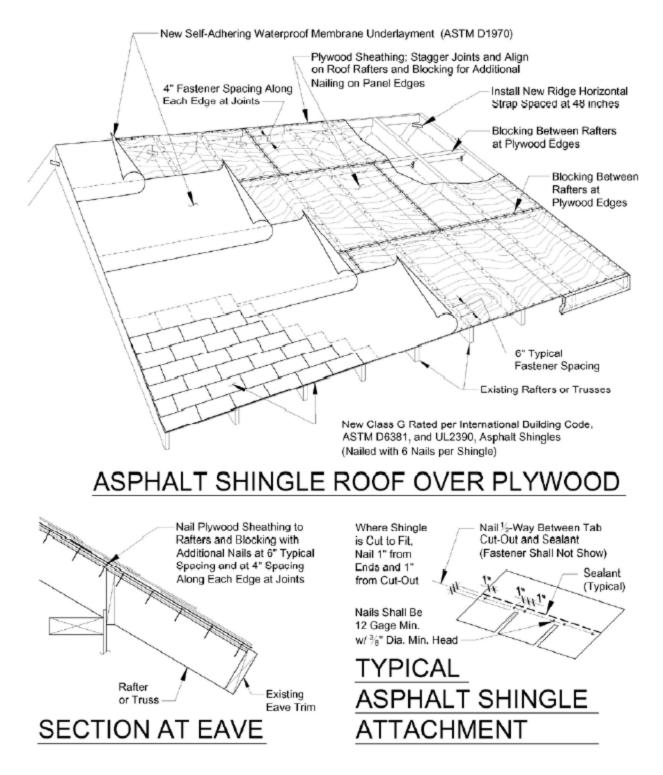


Figure 4.2.2-3: Upgrade of Structural Plywood Sheathing for Houses with Asphalt Shingle Roofing





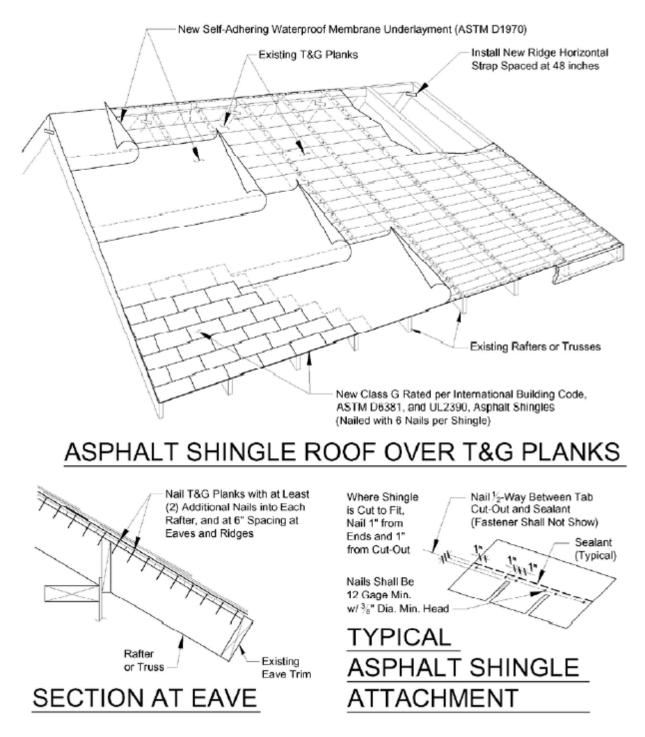


Figure 4.2.2-4: Upgrade of Structural Plank Sheathing for Houses with Asphalt Shingle Roofing





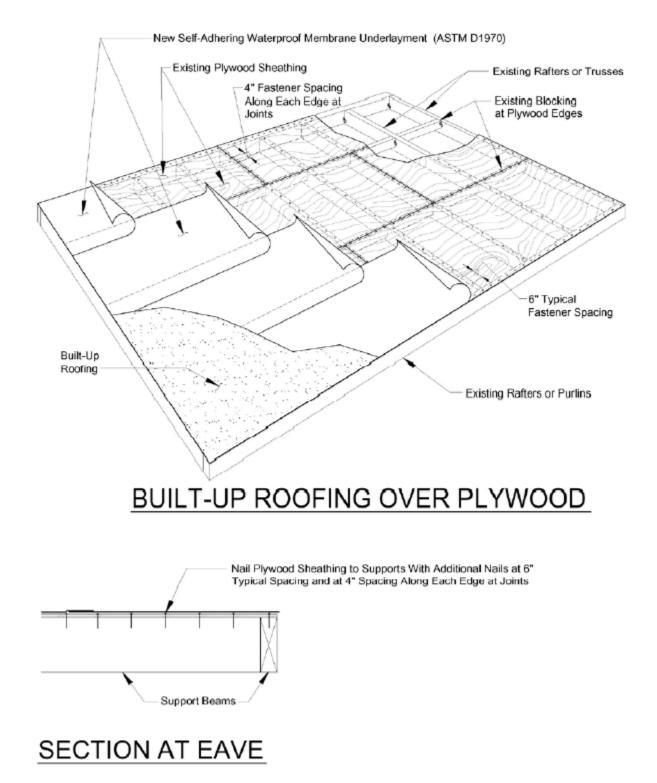


Figure 4.2.2-5: Upgrade of Structural Plywood Sheathing for Houses with Built-up Roofing



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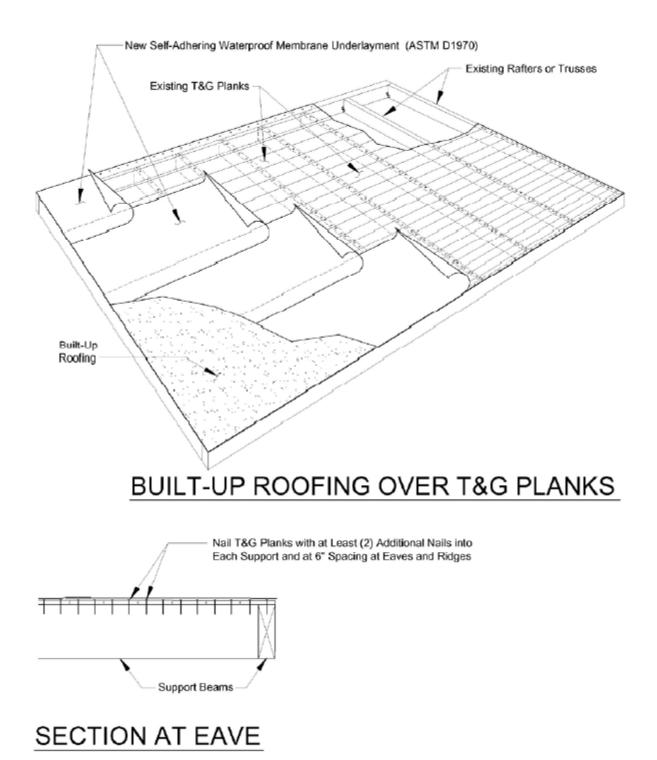


Figure 4.2.2-6: Upgrade of Structural Plank Sheathing for Houses with Built-up Roofing





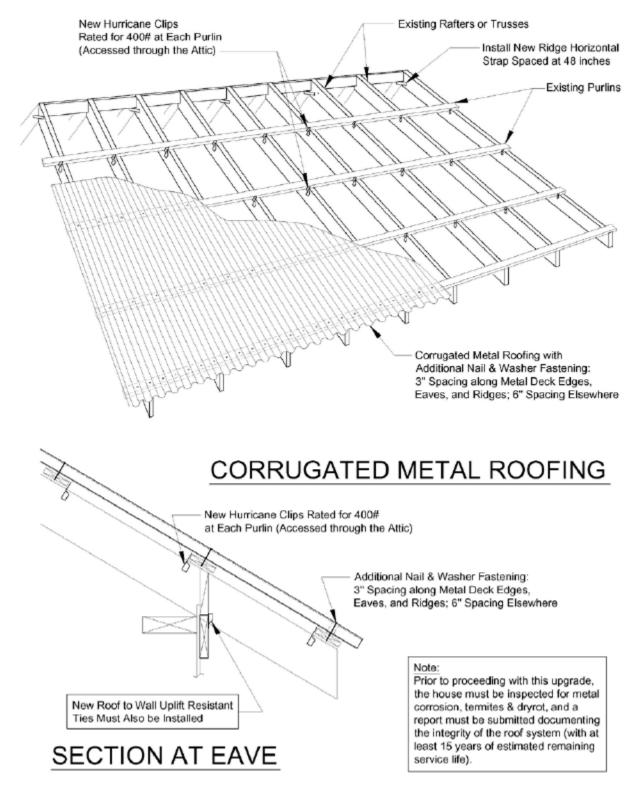
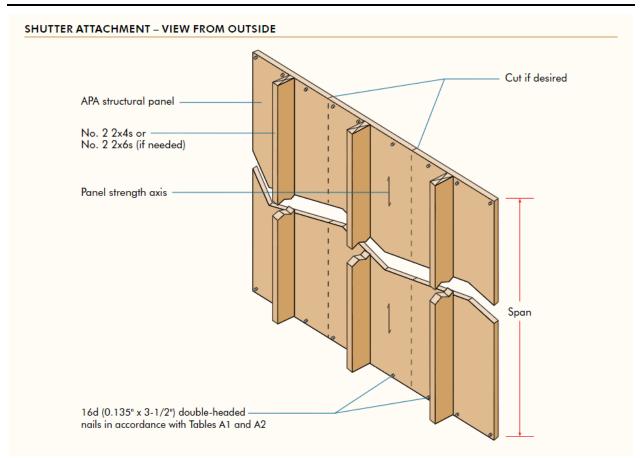


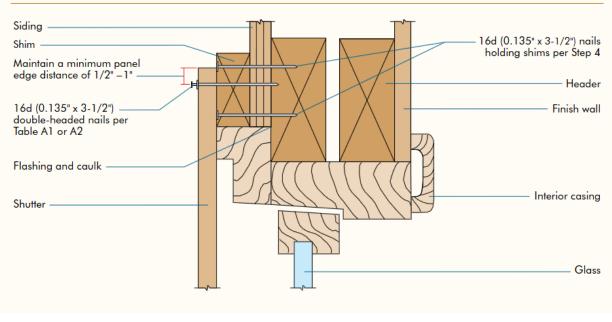
Figure 4.2.2-7: Upgraded Connections for Houses with Metal Roof Decking on Purlins and Rafter Trusses







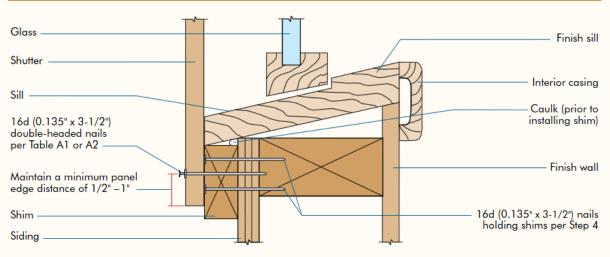
Source: From the Hurricane Shutter Design Guide from APA Form No. T450



SHUTTER ATTACHMENT - TOP

Source: From the Hurricane Shutter Design Guide from APA Form No. T450

SHUTTER ATTACHMENT – BOTTOM



Source: From the Hurricane Shutter Design Guide from APA Form No. T450



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4.3 STATE OF HAWAII WIND MAPS FOR THE 2010 STATE BUILDING CODE

Hawaii has adopted wind maps that are used to determine design loads on houses and buildings, based on the effect of topography on windspeeds. Accounting for the topographic effects that can amplify or diminish the windspeed, effective velocity maps are published as a part of the state or county's building code. They are available in pdf format at http://ags.hawaii.gov/bcc/building-code-rules/. The 2010 version of these state maps are shown here.





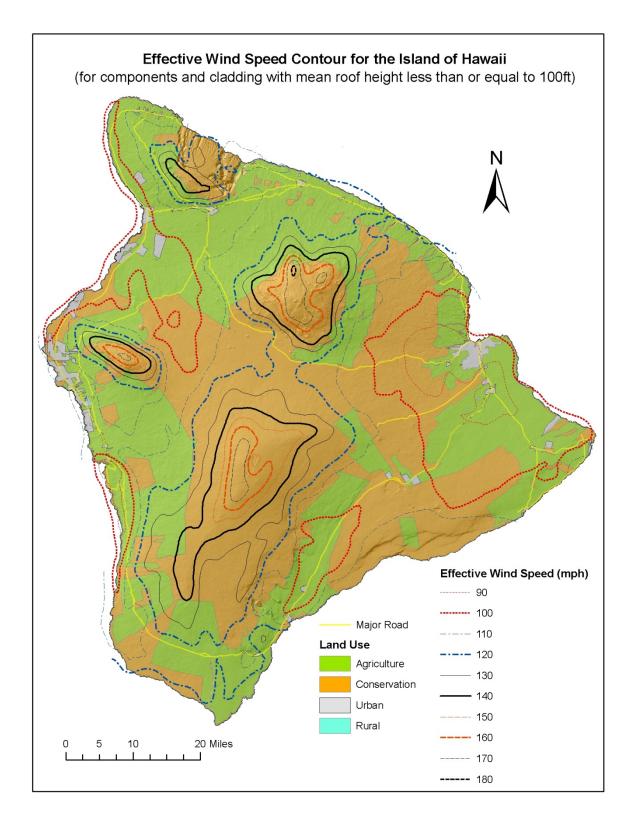
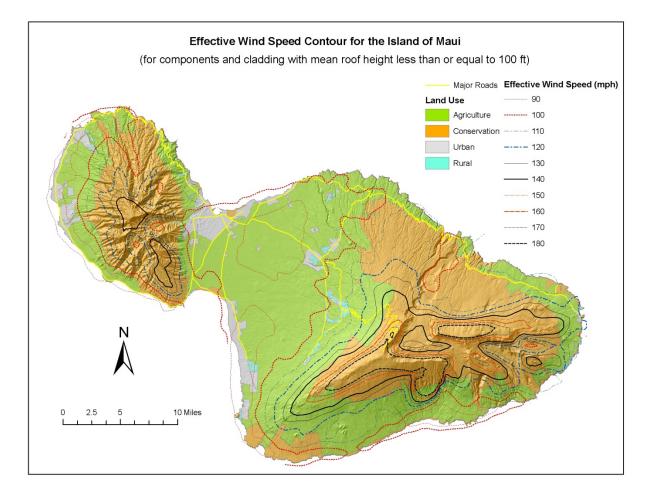


Figure 1609.3.2.2(a)

County of Hawaii Effective Wind Speed, V_{eff} , for Components and Cladding



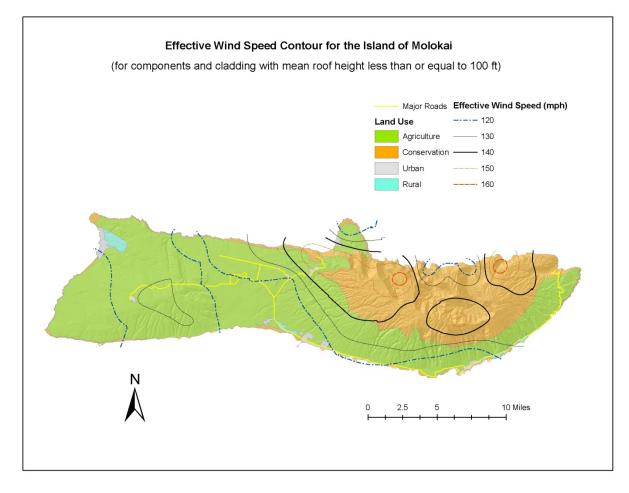


County of Maui, Island of Maui Effective Wind Speed, Veff, for Components and Cladding



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County of Maui, Island of Molokai Effective Wind Speed, V_{eff} , for Components and Cladding





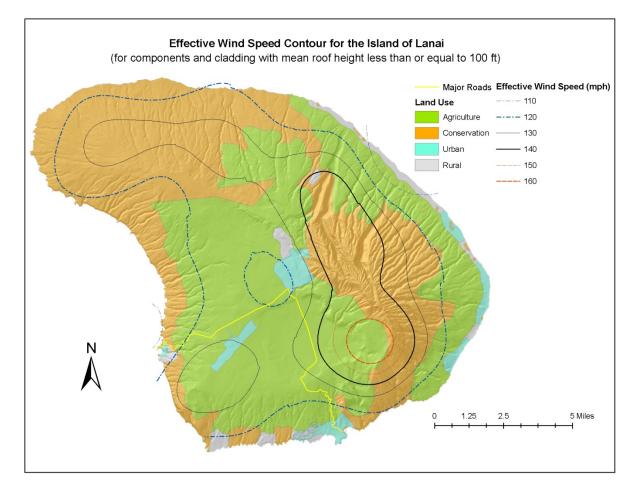


Figure 1609.3.2.2(d)

County of Maui, Island of Lanai Effective Wind Speed, Veff, for Components and Cladding





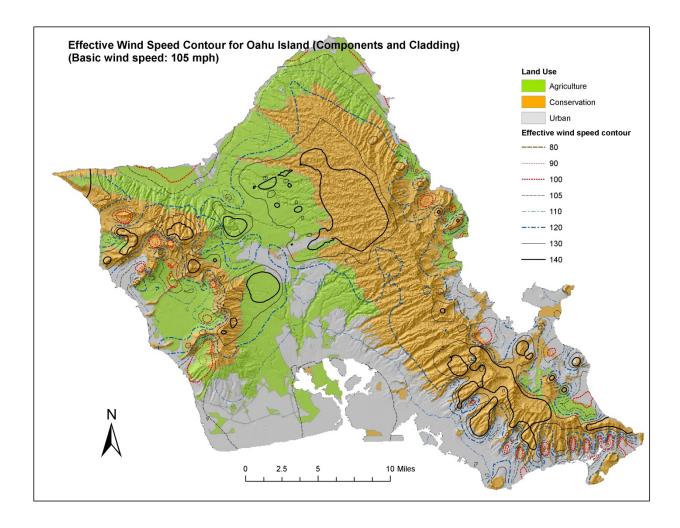


Figure 1609.3.2.2(e)

City and County of Honolulu Effective Wind Speed, Veff, for Components and Cladding



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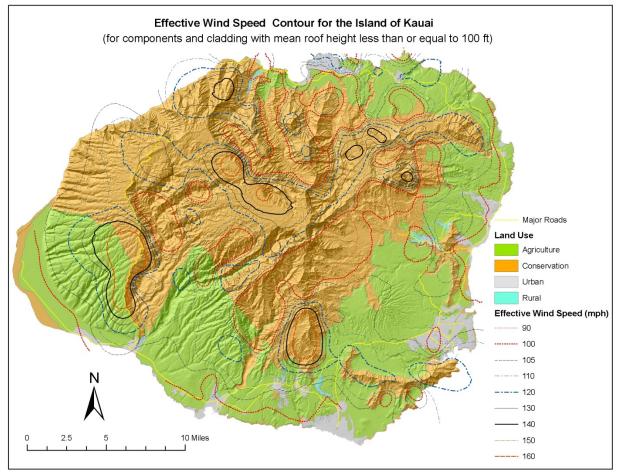


Figure 1609.3.2.2(f)

County of Kauai Effective Wind Speed, V_{eff} , for Components and Cladding





4.4 STATE OF HAWAII HURRICANE SHELTERS

To see a map of the nearest hurricane shelter to your home, go to:

https://portal.ehawaii.gov/residents/emergency-information/hurricane-shelters/

This website locates all the available hurricane shelters in the state of Hawaii. If the web address for this site changes, search for "Map of Hawaii Hurricane Shelters".





4.5 EMERGENCY CONTACTS

Department of Emergency Management – City and County of Honolulu 650 South King Street Honolulu HI 96813 Ph: (808) 723-8960 Website: http://www.honolulu.gov/dem Email: dem@honolulu.gov

Hawaii County Civil Defense Agency 920 Ululani Street Hilo HI 96720 Ph: (808) 935-0031 Website: http://www.hawaiicounty.gov/civil-defense Email: civil_defense@co.hawaii.hi.us

Kauai Civil Defense Agency 3990 Kaana Street, Suite 100 Lihue, HI 96766 Ph: (808) 241-1800 Website: http://www.kauai.gov/civildefense Email: civildefense@kauai.gov

Maui County Civil Defense Agency 200 South High Street Wailuku, HI 96793 Ph: (808) 270-7285 Website: http://www.mauicounty.gov/civildefense/ Email: civil.defense@mauicounty.gov

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