Spring 2019

Fire-Resilient Housing for Paradise, California

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FIRE-RESILIENT HOUSING FOR PARADISE, CALIFORNIA

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By

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SENIOR DESIGN PROJECT REPORT

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This thesis is dedicated to the people of Paradise. There is no question in our minds that the Town of Paradise will rebuild to become better than ever, due to the resilient spirit of the community. We are truly grateful for this opportunity to put our education to use for them.

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ABSTRACT

The intent of this project was to provide design recommendations to mitigate future wildland fire damage, with reference to the devastation incurred in Paradise, California, from the Camp Fire at the end of the 2018 fire season. The town of Paradise is uniquely positioned in a rural, heavily wooded, mountainous channel with few transportation routes, intensifying both the exposure to wind-aided wildland fire and the hindrance of evacuation and emergency response. The project scope included the structural design of a single-family residence and its non-structural material recommendations that can better withstand fire, as well as town-wide measures to improve preparedness. Though the recommendations of this report are based upon the most recent engineering knowledge and practice regarding structural fire resilience and community emergency preparedness, the Camp Fire proves human comprehension of nature's capacity for destruction will always be insufficient.

Keywords: fire mitigation, single-family residence, noncombustible design, emergency planning

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CHAPTER 1: Introduction

The intent of this project was to provide design recommendations to mitigate future wildland fire damage, with reference to the devastation incurred in Paradise, California, from the Camp Fire at the end of the 2018 fire season. The project scope included the structural design of a single-family residence and its non-structural material recommendations, as well as town-wide measures.

The Camp Fire (located in Butte County of Northern California) began at 6:30 am on November 08, 2018 the tail-end of the longest and most severe fire season in California state history. The region had only received three percent (3%) of its average autumn rainfall and experienced several windstorms in the days prior to the fire's ignition, compounding the region's vulnerability by distributing dry fuels over otherwise-non-combustible surfaces (Belles, 2018). Canyon gusts, high atmospheric pressures, and parched vegetation propelled the fire "football-field lengths within seconds," according to Cal-Fire spokesperson Scott McClean, spitting embers a quarter- to a half-mile ahead of the fire's body, according to Philip Rose, a member of the Paradise Fire Department who defended his town from the fire that would exede state records for speed, deadliness, and destructiveness (Rose, 2019). By noon on November 08, over half the Town of Paradise had been consumed in fire (Taylor, 2019). As of Sunday, November 11, there were 42 confirmed deaths, awarding the Camp Fire the dubious honor of most deadly fire in state history. As hundreds of evacuees spent Thanksgiving in a Walmart parking lot on November 22, the fire was 95% contained after seven (7) inches of precipitation aided firefighting efforts (CBS News, 2018). Three days later, containment reached 100%, marking the beginning of a long and arduous recovery process, with some 52,000 people displaced and 85 dead (Associated Press, 2018).

The town of Paradise is uniquely positioned in a rural, heavily wooded, mountainous channel with few transportation routes, intensifying both the exposure to wind-aided wildland fire and the hindrance of evacuation and emergency response. Estimates suggest monumental challenges in the rebuilding process, with 90% of the town's homes destroyed (Lillis, 2018). The Paradise community experiences generational poverty and minimal outside financial assistance, further exacerbating recovery efforts. Coordinating with governmental and private insurance agencies to lower costs for residents will be vital in ensuring community survival and improved resilience.

This design team intended to help the residents of Paradise rebuild their lives by providing housing stock improvement recommendations that can better withstand fire seasons to come in addition to improved town-wide preparedness. Fire response and resilience will be an ongoing concern in Paradise, but civil engineers have the opportunity to facilitate community prosperity through disaster planning and mitigation.

CHAPTER 2: Building Material Alternatives

2.1 Fire Rating Classification

In order for a house to be more fire resilient, materials that have higher fire ratings will be utilized in the design. It was not in the scope of this project to obtain an official fire rating on the proposed house design, due to high prices.

2.2 Materials

In the design process, materials were chosen based on fire resistiveness, credibility, and constructability. Primarily, fire resistiveness was prioritized when choosing the materials. To avoid problems of reliability with companies, materials were primarily chosen from the ICC-ES ("Reports Directory"). The ICC-ES is a nonprofit, "limited liability company that does technical evaluation of building products, component's methods, and materials." The "Reports Directory" of the ICC-ES website provides various materials that have been tested to meet various building codes.

From this selection, the siding, plaster, insulation, sheathing, fire tape/sealant, and all other aspects of the house were chosen. A problem encountered with this method is the lack of windows tested in the ICC-ES that are viable options for residential homes. Also, this limited list of material options disallowed for shopping for the least expensive options on the market. Choosing to prioritize legitimacy of companies over expediency, was a trade the team was willing to make since the cost of materials far exceeds the cost of any human life.

2.3 Wall Sections

A uniform wall section was utilized on all walls of this house. Research was conducted on various building materials and different design ideas. The design process began with various ideas, from cinder block walls to panelized construction. In the end, a detailed cross section was designed to optimize fire resistivity in the walls. This design was comprised of the following layers from interior to exterior: ⅝" Gypsum Board, 4" Steel Studs with Mineral wool insulation, ⅝" Gypsum Board, Vapor Barrier, and Fiber Cement Siding.

This design of the walls assumed the danger of fire comes from the exterior. The various layers are all ICC-ES approved and fire retardant in some capacity. The Mineral Wool is Rockwool Comfortboard 80 Mineral Wool Thermal Insulation Board ("COMFORTBOARD™ 80."). This insulation adds at least 15 minutes of run time, and is a noncombustible material that melts at 2150 degrees Fahrenheit ("COMFORTBOARD™ 80."). Siding on the outside is Hardieboard HardiePlank Lap Siding, which is also highly fire retardant, and when tested with wood cross section yields a one hour run time. Even the in between details, such as the 3M Fire tape used to seal, and the Tyvek Water and Vapor Barrier are all ICC-ES approved and specialize in being fire retardant quality.

2.4 Roofing

The roof is a steel truss structure. Similar to the walls, ICC-ES insulation and sheathing were chosen for the design. Lokseam Roof Panels will decor the outside of the steel roof, followed by mineral wool and then the structural steel. The insulation chosen was the same mineral wool as used in the walls, which was compressible. On top of the roof will be adhesive solar panels, Mia Sole Flex series. This flexible, thin film technology easily sticks to roofs and provides solar power for homes.

2.5 Windows and Doors

The ICC Evaluation Services Reports were used for determining a door for the house. The Special-Lite Sandstone Textured FRP/Aluminum Hybrid Door was chosen. The door and window selection was arguably the most difficult part of material decision due to various reasons. First, doors and windows that obtain higher fire ratings are most likely used in non-residential applications. Most glass companies through the ICC-ES that had a fire rating are also not aesthetically pleasing. Second, due to most of the windows/doors not being residential based, prices are sometimes higher or more difficult to obtain. Calls were made to numerous manufacturers, with no responses received and in the end a detailed spreadsheet was created to contrast the pros and cons of non ICC-ES products as well as ICC-ES approved products.

Tables 1 and 2 can be viewed below, with detailed explanation of pros and cons for each option. After comparing products wholistically based on aesthetics, fire-resistivity, price, and constructability, a final door and window product were chosen. The team decided on prioritizing fire resistivity over price since the cost of one human life is invaluable. The Special Lite door has an official 90 minute rating which is optimal for this design. Although expensive (still waiting on response with quote), the fiberglass door still is aesthetically pleasing without compromising the safety of the door. The window or glass chosen is from Saftifirst brand, also an ICC-ES approved glass. After calling the manufacturer, the company does in fact provide windows for residential projects including any size requests. The price is $300 per square foot, the most expensive of the window options, however, this window is rare. The Saftifirst brand has a two hour gel insulated within the windows that, if fire were nearby, would withstand the radiant heat for up to two hours. The company also includes installation with the pricing, which would expedite construction and lower associated construction costs. Most importantly, it is steel clad which performs well in fire. Compared to other potential window options, it was difficult to find non-vinyl windows that are not for aesthetics.

Table 1: Comparison of Potential Doors.

Brand/*Size*	**Type**	**Price**	**Pros**	**Cons**
Special-Lite 1 *Size Varies*	Sl-20	Per request	● Very durable ● 90 minute rating ● Fiberglass ● ICC-ES Approved	● Expensive ● Not Aesthetic
Fiberglass Door *36inx80in*	Home Depot	$430.91	● Cheaper ● Fiberglass	● No fire rating
Steel Door *32inx80in*	Home Depot	Per request	● 20 minute fire rated ● Steel door ● Prehung	● Wood Frame ● No price available
TrueDoors *Size Varies*	Steel Door	$275	● 3 hour fire rating ● Steel ● Aesthetically pleasing	● No ICC-ES approval
Mexin *40inx80in*	Steel Door	$150	● WHI approval ● Steel ● Aesthetically pleasing	● No ICC-ES approval ● Double doors

Table 2: Comparison of Potential Windows.

Brand	**Type**	**Price**	**Pros**	**Cons**
Saftifirst	Glazing General Contractor (GC)	$300/sq .ft	• Steel clad • Open for homes • ICC-ES approved • Gel for heat • Dual Paned	• Expensive • Glazing GC
Aluflam	Glazing GC	Per request	• Aluminum frame	• Glazing GC • Structural Glass
Steel Door *32inx80in*	Vinyl window	Varies	• Cheap • Accessible	• Unreliable

CHAPTER 3: Structural System Resilience

3.1 Architectural Layout

The structure's layout and sizing were chosen to be similar to the footprints and look of the homes before the fire. The single story structure is 1200 square feet with slight offsets of three (3) feet (ft) or five (5) ft on each of the four faces. The ceilings are 10 ft tall. The exterior walls extend past 10 ft tall in the areas on the north and south sides of the house that extend forward and backward from the central rectangular portion. There are two external doors located on the north and south walls.

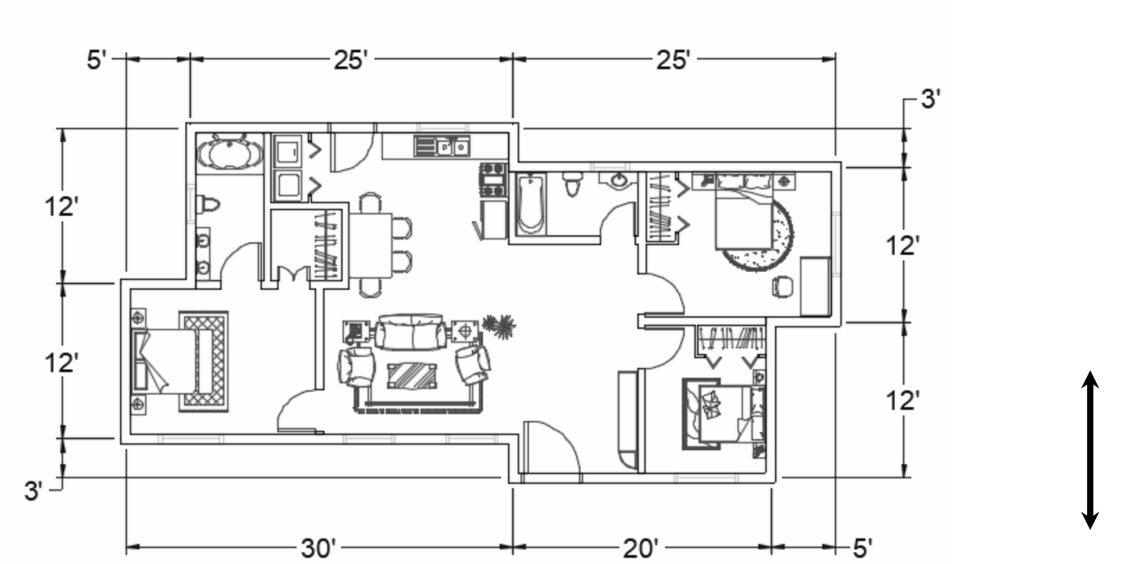

Figure 1: Floor Plan.

The major difference between the style of the previous houses and the current design is that there are no overhangs and there are a minimal amount of valleys on the roof. Overhangs are a likely area where embers will get trapped and begin turning into flames. Valleys are susceptible to accumulating debris that fuels fires. Too simplistic of a design, however, is not aesthetically pleasing and restricts variation from house to house. It was therefore decided to include a separate gable roof system of the east and west extensions, as in Section 3.3.

3.2 Wall Framing

Design with Cold Formed Steel (CFS) is similar to wood in that both are used as light-gauge framing systems. The stud spacing chosen was 24 inches (in.) on center (o.c.) based on the loading (both dead and live) from the roof. The typical wall section is an exterior, load bearing wall that is comprised of a top and bottom track with a stud (normal to the track) sandwiched in between. Other wall sections include window or door openings, corners, and areas where interior walls frame in to load bearing walls. See Section 3.5 for connection details. All wall framing members are 400S200-54 studs and are oversized for ease of constructability and to stay within safety thresholds. The gravity loads taken into account for the wall design are shown in Tables A-1 and A-2. (Appendix A: Structural Drawings)

3.3 Roof

As previously explained, the roof system did not include overhangs and was designed with minimal valleys. Figure 2 shows the general roof plan with a shallow pitch of 3:12. The apex lies at the centerline of the inner main rectangle of the structure's footprint. Likewise the ridges of the gable systems on the extended portions lie in the center of their respective extended sections.

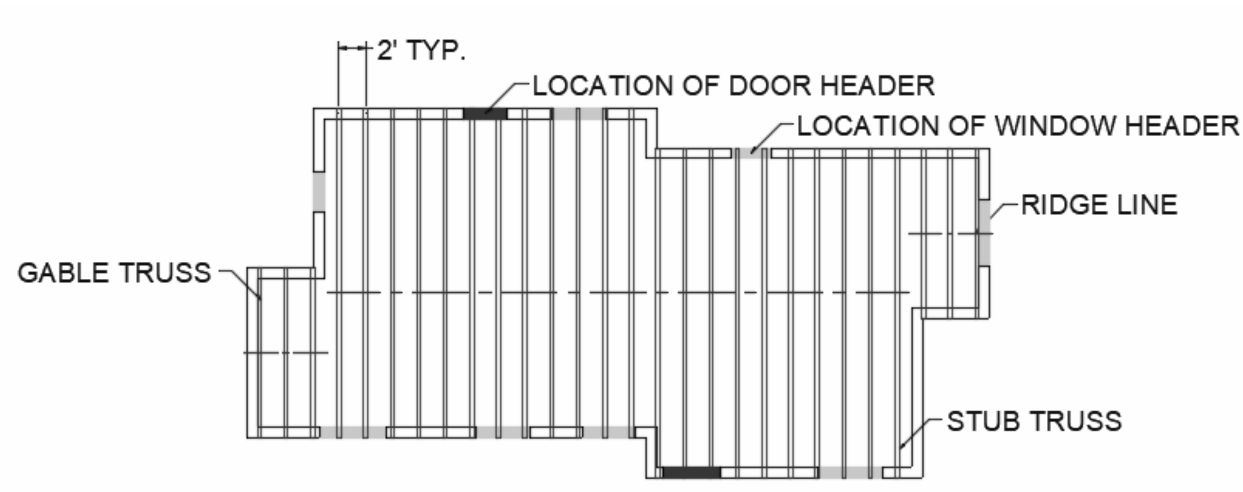

Figure 2: Roof Plan.

The roof truss system was comprised of two truss systems. Figure 2 shows the layout of the types of trusses and their locations. The "common truss" was larger in size and covers the majority of the structure, spanning 24 ft and 9 in. (Figure A-1). The "gable truss" system covered the east and west extensions (Figure A-2). All trusses were spaced at 24 in. o.c.

3.4 Foundation

The foundation was a standard concrete slab-on-grade and is shown in Figure A-3. The concrete was specified to have a minimum 28 day specified compressive strength (f'_c) of 2500 pounds per square inch (psi) per IRC 2012 Table R402.2. The slab was four (4) in. thick with 12 in deep footings at the edges. The footings had one No. 4 bar at the top and bottom of the footing and No. 3 vertical dowels with standard hooks on each end at 48 in. o.c.

3.5 Connection Details

The various elements of the structure had to be connected to form one coherent building. These connections included foundation-to-wall, wall-to-roof, and wall-to-wall connections, as well as a configuration to allow openings for doors and windows. Most connections are standard for CFS construction, but some details are designed specifically to enhance fire resilience.

Notice in Figure A-4 that the configuration of the studs in the corner seal the wall-to-wall connection. This detail would block the fire from entering from an area that would have otherwise been a potential weak point. The same idea—of addressing areas where fire is prone to enter the structure—rationalizes the use of a break shape over the edge of the roof truss (Figure A-7).

3.6 Lateral Bracing

The structure had to be braced against wind and seismic loads. The largest lateral load is the wind loads in the north-south direction, which is 16.7 kips (k). The wind load in the east-west direction is 8.2 k. The horizontal component of the seismic force is 2.4 k and the vertical seismic force is 3.1 k. The lateral design system was composed of tension strap bracing (Figure A-7). The member size calculations are found in Appendix A. The strap is 5 in. wide and 0.0329 in. thick.

CHAPTER 4: Community-wide Fire Resistivity

4.1 Property-level Resilience

Cal-fire offers adequate and appropriate information for property owners to maintain their parcel to reduce fire susceptibility, but dissemination and implementation could be improved. The team compiled existing infographics that ought to be disseminated to community members (Appendix B: Compilation of Infographics). The team recommends developing an infographic specifying which plants are most desired and least desired for defensible-space and drought/fire resistance capacity. Compiling existing infographics into one singular document could be beneficial, so long as comprehensibility was maintained. Additionally, Cal-Fire website http://www.readyforwildfire.org/ includes animated videos and other easily digestible information.

4.2 Town-wide Resilience

4.2.1 Alternative Energy Sources

The Camp Fire destroyed some 14,000 structures and will constitute a significant financial burden for any human party deemed responsible for its ignition (Paris, 2019). The largest utility company in California, Pacific Gas & Electric (PG&E), anticipates its infrastructure will be found liable for sparking the wildfire. In December 2018, California's Attorney General raised the possibility of criminal charges for failing to maintain its electrical infrastructure. By April 2019, the Butte County District Attorney joined in the state criminal investigation (Brekke, 2019). The unprecedented ferocity of this fire resulted from a confluence of conditions including weather, habitat, and the ever-increasing encroaching of human development into fire-prone regions so that any unlucky spark could engender a cascade of destruction. Of the 21 major fires in Northern California in 2017, 17 (80%) were caused by power lines, poles, and other equipment owned by PG&E (Johnson, 2018). This design team has found no evidence that PG&E is especially negligent in maintaining its infrastructure, but instead credits this disproportionate representation in wildfire liability with its largeness. Rather than suggest one particular utility company should be scapegoated, the inherent dangers of high-powered energy transmission across increasingly fire-prone rural terrain are evidenced in the 2017 fire season.

Regardless of the utility industry's increasing propensity to ignite unprecedented wildfires and the contributing environmental factors of which a utility company has no means of control, current legal precedent places PG&E economically responsible for the insurmountable costs of the Camp Fire devastation even without evidence of negligence (Penn, 2019). In anticipation of "billions of dollars in possible liabilities and nearly two dozen lawsuits from victims of the Camp Fire," PG&E filed for bankruptcy in January of 2019 in anticipation of (Paris, 2019). PG&E and other California utilities are requesting state permission to raise service rates for customers in order to implement safety improvements and offset wildfire financial risks (Penn, 2019). If legislators "make it harder for property owners to seek damages from utilities for wildfires," a PG&E spokesperson expressed willingness to reduce the requested rate, though opponents view both offers as "looking for a bailout by another name."

PG&E's bankruptcy argued that the "staggering debts" incurred by their negligently maintained power lines' sparking wildfires ought to negate its "high-priced renewable energy contracts" (Rogers, 2019). The executive director of a Sacramento non-profit, Center for Energy Efficiency and Renewable Technologies, fears California's green energy goals may be disrupted if not "wrecked" if PG&E's solar and wind contracts are broken. PG&E argues that requiring the company to comply with contracts it signed "over the past 15 years" places "those renewable energy companies ahead of other potential creditors, including wildfire victims."

Three months after initial evacuation, at the February 2019 Paradise Town Council meeting, community members laughed bitterly at the PG&E representative's clear intention to mitigate company liability more than to understand the pain suffered by the fire refugees. This is pointed out not to demonize the profit-driven company, but validate the community's dissatisfaction and distrust of external energy sourcing for the town's future. This engineering team recommends investigating alternative energy sourcing that could double as job-creating programs that could promote community cohesion. Adhesive solar paneling as described in section 2.4 would offset rural utility infrastructure requirements in the Town's proximity. Energy storage could be achieved by pumping water up any of the neighboring geographic inclines, to be returned as hydropower when necessary. The channelized terrain that exacerbated the Camp Fire's speed could prove to be a valuable wind farming opportunity. The Community Choice Aggregation (CCA) is offered in Butte County to governmental entities to purchase or generate electricity with PG&E delivering and maintaining services (Butte County, 2013). The feasibility study projects two percent (2%) savings to customers through the CCA. Though this program indirectly reduces fire exposure by slowing carbon emissions, the dangers of transmission lines persists with CCA energy transport. Burying transmission lines, where equipment malfunction would pose significantly less potential to ignite a wildfire, was a highly desirable option for community members at the February Council meeting for whom the increased upfront implementation cost pales in comparison to the monumental costs associated with 90% of the community's housing being reduced to ash.

4.2.2 Evacuation Plan

Philip Rose, engineer at the Paradise Fire Department (PFD), defended his town from the Camp Fire. In reflecting three months later, he cited the speed and scale of the blaze as unprecedented, saying, "within an hour and a half, most of the town had burned or was on fire, actively burning." Rose insisted his community had been preparing, and that the threat of wildland fire specific to the Paradise region had been well-researched, for decades, but nothing could have prepared them for the intensity of the Camp Fire. All things considered, this first responder was amazed that "we have only 85 deaths, while tragic as it is… we were expecting thousands" of dead, citing the "sheer luck and tenacity" of his fellow townsfolk in escaping the flames (Rose, 2019). One survivor Darrel Wilkins sat in his car with three hospital patients, "stuck in traffic along with thousands of others" as trees, structures and cars "exploded into flames" in front and around them (Arthur, 2019).

The unprecedented ferocity of the Camp Fire is best put into perspective through a comparative assessment of the deadliest wildfire in California history before it: the Griffith Park

Fire 85 years ago. On October 3, 1933, some 1,500 workers were widening roads in a ravine when they were sent to the ridge-top to extinguish a small brush fire that had started "in the canyon beneath the hill" (Harrison, 2015). In a sudden wind shift, 29 of the untrained firefighting men were trapped and killed by the flames. Similarly, the majority of citizens who perished in the Camp Fire's consumption of the Town of Paradise were trapped in grid-lock traffic as all 14 Town evacuation zones attempted to outrun the flames. Fireman Rose recalls truck after truck exhausting its water-tank as fire-fighting efforts resorted to containment as opposed to suppression - allowing neighbors' homes to burn down as resources were devoted to preventing the next home from catching fire.

The Town of Paradise had one of the most robust evacuation plans in the country (Arthur, 2019). Few feasible recommendations can be offered to more effectively evacuate all 27,000 residents on time scales comparable to that imposed by the Camp Fire. The geographic topography limits widening roads and even if doing so were feasible, designing a small town's transportation infrastructure to accommodate mass exodus would have tremendous negative consequences for community morale and aesthetic desirability.

4.2.3 Town-wide Defensible Space

Based upon regional climate models, the unprecedented conditions that facilitated the Camp Fire are expected to be the "new normal" (McDermid, 2018). As explained in section 4.2.2, transportation planning is severely limited in its ability/capacity to respond to fires, comparable to the Camp Fire, wherein whole towns must fully evacuate in less than hours. An alternative option that could prove more feasible, and psychologically acceptable, would be to augment the resilience of the Town's perimeter to prevent fire penetration and/or reduce the Town's susceptibility to the spreading of fire (see recommendations of Chapters 1 and 2). As evidenced in inspecting the aftermath of the Camp Fire, structures were often either untouched or completely reduced to ash (Taylor, 2019). Though the housing improvements outlined in this report are recommended based upon the most recent engineering knowledge regarding structural fire resilience, the Camp Fire proves human comprehension of nature's capacity for destruction will always be fallible. Once the exterior of the structure becomes penetrated (often from embers landing in gutters and starting small debris fires), all fire-resilience integrities became easily compromised. Under sustained heat, the noncombustible materials recommended in this report will inevitably melt, though they will not contribute to the fire. Likewise, perimeter resilience is a mitigation and not a cure to the Town's exposure to fire damage. With adequate thoughtful planning, a system could be designed, implemented and maintained to buffer the Town from intrusion by fire.

There is, of course, an inherently politically divisive element to such a system. It is impossible to not exclude some community-members and neighbors and that would likely undermine community cohesion. One solution would be to create a Town-wide tax that would pay for system maintenance and double as an insurance pool for community members whose homes may be lost in the future. Additionally, external insurance companies may soon begin to lower costs for communities taking innovative approaches to natural disaster resilience, if they do not already. The comparative reliability between these potential revenue streams emphasizes the human aversion to upfront costs and liability, which will prove to hamper all Town-wide emergency resilience system considerations.

Considering California's drought and the weighty politics often attached to water collection rights, waterless systems of fire suppression were first considered. Fire is a natural earth systems phenomenon requiring heat, oxygen, and fuel. Reducing the heat as a wall of fire moves in, spitting embers a quarter- to half-mile, was quickly deemed infeasible. Engineers design closed laboratory and technology spaces so that oxygen is removed from a contained space, immediately suffocating the detected flame. The scale of containment and implementation of such a system in the mountainous outskirts of the Paradise community is several magnitudes more complex than the typical lab, complicated further by the extreme danger of malfunction and the liability associated with a densely oxygenated pocket of air in the vicinity of conditions comparable to the Camp Fire. Emergency fuel reduction is performed by firefighters in the prioritization of containment over suppression. Robotic assistance could one day be of benefit to collect debris up to the point they are overtaken by fire or are somehow able to escape, but could easily encumber firefighters' expert judgment and life-protecting effort. Another waterless system alludes to the ultimate recommendation, as a physical barrier to the fire would most effectively slow the progression of fire without expensive on-going performance testing and maintenance. A wall made of fire-resistant materials would incur high upfront material and environmental costs, affect long-term runoff and wildlife patterns, and over time debris would collect in the proverbial corners of the wall, creating a fire ladder or other weak spot in the fire-slowing capacity of any wall system. Any fire higher, faster, or taller than the wall's design could catch first responders and evacuees by surprise or even trap the unlucky community member.

Physical reliability without ongoing maintenance costs could be achieved by developing a Town-wide defensible space, a cleared ring with a 100 ft minimum width according to Cal-Fire's property-level defensible space recommendations. The width of the space would be recommended larger with a design fire comparable to the Camp Fire, though the same aesthetic tradeoff as in section 4.2.2 is important for the community to keep in mind. The serviceability of the town perimeter could be improved by saturating the plant matter and debris with water as a temporary fire resistivity. Runoff could be collected and stored by the town to supplement other available water sources to be time-released by the evacuation system. The same treatment requirements as in a river would be appropriate to potentially land on slower-moving evacuee, provided the rate of discharge was gentle enough. This gentleness is a tradeoff with effectiveness against a raging firewall whose radiant heat can evaporate across great distance. The fastest release system can be modeled by exploding water to neutralize bombs, wherein distribution is difficult to target, alluding to a high propensity for unintended collateral damage. A ground deluge/sprinkler would reduce water evaporation as compared to elevated deluge/sprinkler, though extent of potential fuel saturation would also be reduced. The elevation support and sprinkler piping material fire resistivity would not be necessary if the system is expected to only function in anticipation of the fire, though its melting could complicate the post-fire cleanup process and the system potential to act as a fire ladder or contribute to the fire is of utmost importance to consider. The final water system considered is modeled after feudal castles' motes, wherein water would seep and flow out of the mote to saturate groundcover, though elevated potential fuels would be unaffected. The system could be segmented to reduce water demand, though determining where segments begin and end would require complicated political and engineering deliberations. The buildup of debris in the mote could aid or clog water distribution and aid fire penetration.

After looking into the topographic terrain of the town's boundary and considering the costs associated with ongoing maintenance and performance verification (Figure 3), an automated emergency water-release system is deemed infeasible. Creating a defensible space perimeter around the town is recommended, however, as it would aide firefighters in preventing future fires from entering the town and would foster community cohesion. Fire-resistant plant species could be preselected and available for community members to plant and cultivate. Individual families, school classes, and other local organizations would be allowed and encouraged to sponsor sections of the defensible perimeter.

The upfront cost of this defensible space plan includes clearing the land and a three (3) in. layer of compost (or combination of potting and topsoil) (BH&G, 2019). The Town's pine needles could be diverted to be used as a mulch, or bark chips from the trees removed post-fire for a longer-lasting mulch. Edible plants are not recommended due to potential contaminants from the fire as well as post-harvest plant waste representing a fuel source. Though community members would be encouraged to maintain the garden space, a small ongoing cost would be restocking approved plant seeds, occasional campaigns to encourage participation, and perhaps a paid maintenance team to facilitate preparedness during the peak fire season would be worth the cost of that municipal government job program.

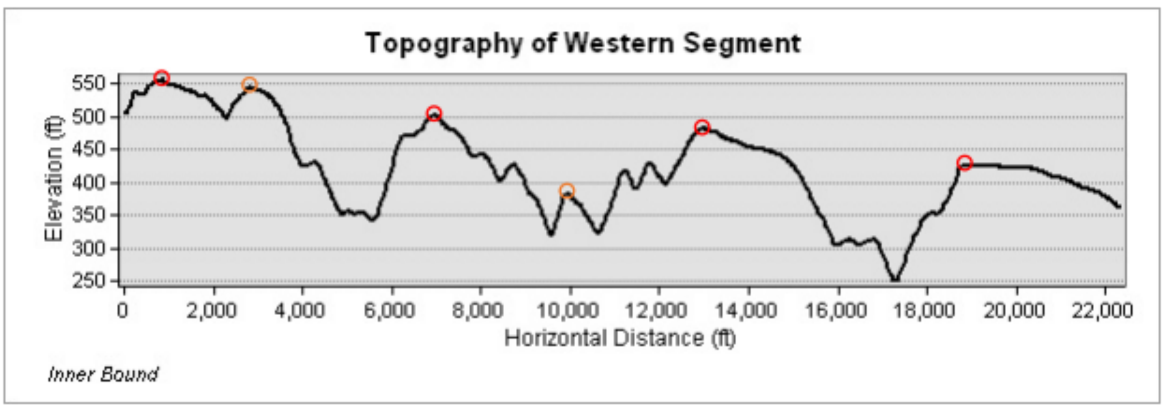

Figure 3: Approximately one-fifth (⅕) of the Town's perimeter would require a water supply and distribution system deemed unfeasible to adequately saturate fuels in the forested mountainous region as fast-moving fire approaches.

4.3 Natural Hazards, Aside From Fire

As with most regions, the Town of Paradise is at risk of a variety of natural disasters. The 2018 Camp Fire emphasized the town's exposure to wildland fire, and the majority of this project's scope seeks to mitigate that specific threat. By focusing on one risk, there is the potential to overlook other issues. On November 29, 2018, days after the Camp Fire, Butte County officials had to renew evacuation orders and deploy swift water rescue teams to save people from "heavy rain in a short period of time…the worst thing that can happen in the burn scar," meteorologist Craig Shoemaker noted (Nero, 2018). More variable extreme snow- and rainfall led to mudflows and runoff flooding Butte County roads in late January (Elias, 2019). The region's susceptibility to flooding and extreme windstorms ought to be considered, but the high risk of earthquake is of particular concern because of tectonic unpredictability. The United States Geological Survey (USGS) estimates a 49.7% chance of a major earthquake (magnitude 5.0 or greater) within 50 km (31.1 miles) of Paradise in the coming 50 years (Homefacts.com). There is low risk of tornado and radon[1] exposure, but the town is high on the ultraviolet (UV) Index. This last risk has community-level consequences on the health system (skin cancer, eye degeneration, immune suppression) and can be managed according to dermatological recommendations regarding sun exposure. The complicating factor of the town's UV risk is a tradeoff that must be considered in terms of fire exposure: adequate shade ought to be available to locals and tourists without creating fire ladders.

The slow-working UV risk is less relevant to the rebuild process than risk of earthquake because of the potentially catastrophic consequences of that natural hazard. According to Dr. Lucy Jones of Caltech, "There is no way to predict the time of when [California's next major quake] will happen, but that it will happen is an absolute certainty" (Hobson, 2017). Jones assures it is "extremely improbable" that an earthquake will be so large as to affect Los Angeles and San Francisco, but one triggering another is "extremely probable." While the people and infrastructure of the Town of Paradise will likely not be directly affected by a "Big One" affecting the Bay Area or Southern California, the economic and communication ramifications are likely to ripple across the state and globe (Stewart, 1992). The structural component of this project's house design takes into account earthquake loading, and Figure B-8 includes earthquake safety recommendations produced by www.ready.gov/earthquakes. The public ought to be aware of the building code's limitations: the majority of structures are designed to undergo irreversible damage without catastrophic collapse, to protect life safety with little to no consideration for the economic aftermath. Beyond encouraging individual citizen preparedness, the Town of Paradise could benefit from forming a Council Subcommittee explicitly dedicated to preparedness and response to the myriad natural threats.

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[1] A cancer-causing gas formed by the natural radioactive decay of uranium in the earth's crust. For more information, see https://www.homefacts.com/radon/California/Butte-County.html.

4.3.1 Disaster Response in Sonoma County, a Case Study

After the extreme flooding of 2019 turned towns to islands, Sonoma County supervisor Lynda Hopkins expressed certainty that the community would "pull together" and become stronger as they had through previous disasters, namely the 2017 Tubbs Fire, whose title of most destructive fire in California history was usurped by the 2018 Camp Fire (O'Dowd, 2019). Hopkins continued: "In many ways, we now feel like we are ground zero for the impacts of climate change" due to the region's more severe fire and flood seasons projected for the summer and winter, respectively. She was confident the Office of Recovery and Resiliency (ORR), formed after the 2017 wildfire devastation, will aide the County's response to the 2019 flood season.

The ORR collaborates with various County departments and agencies, cities and other jurisdictions, nonprofits, and other community stakeholders, resulting in a strategic document approved by the Board of Supervisors, after public comment, "to serve as a vision and approach for how Sonoma County will recover and emerge more resilient" ("Recovery Framework," 2019).The ORR is "tasked with exhaustively pursuing and coordinating all available" funding, submitting quarterly progress reports to the Board, meeting regularly with community partners, and implementing the preparedness communications Outreach Plan ("Recovery Progress," 2019). The County also has departments titled Fire Operations and Training Division, Fire Prevention, Fire and Emergency Services, and Emergency Management Division that are, respectively, tasked with training volunteer responders; preventing the outbreak of fires in unincorporated areas; protecting the environment from the negative impacts of fire; and the planning, coordination, and mitigation of county-wide emergencies ("Departments & Agencies," 2019). Comparatively, Butte County has a Fire Department, Office of Emergency Management, and Water and Resource Conservation Department. These departments may accomplish all the County-level preparedness that Sonoma County's four existing divisions and the ORR address. Either way, augmenting the County structure would be outside the control of the Town of Paradise, though they could lobby the County to augment the Town's local support structures. Commissioning an evaluation of their County's preparedness is encouraged to better inform the Town Council of the extent of their external support relative to that offered by Sonoma County. A more apt comparison for Paradise to assess its preparedness is Santa Rosa, the largest city in Sonoma County. Considering Santa Rosa is almost seven (7) times more populous than Paradise, the Town cannot be expected to achieve the same level of preparedness, but can adapt its structures as desired.

The Santa Rosa Fire Department (SRFD) is organized such that, in addition to overseeing the Operations, Administration, and Prevention Bureaus that perform typical city firefighting functions, a City Emergency Preparedness Coordinator is under the jurisdiction of the Fire Chief ("Strategic Plan"). A "cross section of personnel from all ranks" of the SRFD produced a Strategic Five Year Plan, to be revised and refined annually, in order to address the "ever-increasing demands for fire and life safety services" facing the City. Through the Emergencies subset of the Fire Department, the City has produced Continuity of Operations and Emergency Operations Plans (COOP and EOP, respectively) to ensure essential government functions can respond flexibly and efficiently in future disasters ("Emergency Preparedness"). The City has Community Engagement and Economic Development Departments that are not currently incorporated into the Town's list of Departments. These functions, as related to response and recovery, could be handled by a Preparedness subset of the Town's Fire Department or an independent Preparedness Department that would consist of a cross-section of volunteers from the Town's existing governing structure.

Supervisor Hopkins pointed to the County's efforts to reduce its climate footprint as an indirect means of responding to Sonoma County's exposure to myriad natural disasters. This indirect tactic is relevant to the scope of this project in terms of the tradeoff between fire-resistant materials that incur higher emissions and the cumulative effect of emissions on climate intensifying the propensity for extreme weather, with fire in particular for the counties of Northern California (Clarke, 2015). Emissions reduction is closely tied to disincentivizing the Californian preference for (sub)urbanized sprawl, as opposed to multi-story planning.

4.4 Maintaining a Small-Town Atmosphere While Avoiding Sprawl

After the 2017 Tubbs Fire destroyed more than 5,000 homes in Sonoma County, the governments of Santa Rosa and Sonoma were under pressure to rebuild in wildfire-prone areas due to the already-severe housing shortage (Sommer, 2018). California's decade-old zoning rules did not require fire-resilient building standards for almost 40% of the destroyed structures. In the rebuild, some homeowners took on the added cost of meeting those standards under no legal obligation, and others did not. As climate change makes California's wildfires more extreme, local leaders' decisions will affect lives for decades to come. Santa Rosa City Councilmember Julie Combs expressed interest in developing programs (funded by governments or neighbors), similar to those related to flood risk, to offer homeowners buy-outs, so they need not rebuild if they determine the emotional or economic burden of potentially reliving the ordeal to be too great for them. Considering 21 of the 22 homes built to the most recent wildfire codes were destroyed by the Tubbs fire, it is clear that risk can be reduced but not eliminated.

The Tubbs fire exacerbated an already inadequate housing market in Santa Rosa. The City expedited permit processing and reduced impact fees to incentivise home-building in the downtown core, but it cannot eliminate the market for single-family residences on the outskirts where wildfire risk is highest. Combs was the lone vote against allowing a 237-unit townhome development on a hillside that burned in the Tubbs fire, explaining "I just think we need to not put more sleeping people in a fire hazard area" and warning that the new development sets the precedent for a sprawling rebuild. The same pressure to approve developments in remote areas faces the entire Sonoma County and California as a whole, as high density housing is considered less desirable. Combs cites the "strong emotional pull to get what you lost back" that was also evident in the Town of Paradise. This issue is further complicated by the Paradise community's fear of metamorphosing a suburb or city atmosphere in place of its characteristic tight-knit small town aura before the Camp Fire's devastation. Building up inherently threatens to urbanize the Paradise aesthetic, so architectural design will be integral to balancing safe building practices with the community's ambiance. Leavenworth, WA, is a small town that attracts tourism through its quaint architectural themes that mask its low-rise hotel and condo complexes. Similar architectural efforts could facilitate a higher density town center and incentivize tourism without corrupting the small-town character that attracts so many locals to make the Town of Paradise their home.

4.4.1 Mitigation Cannot Eliminate Risk

Since 2000, California has experienced fifteen of its twenty largest wildfires in recorded history (Milman, 2018). Wildfires require more than ignition to wreak havoc, and until recently, the speed and direction of winds as well as fuel and terrain conditions acted as natural suppressants. In the modern era (1970-present), temperatures in the Western United States are increasing at double the global average rate. PFD Engineer Rose was confident that fire had not jumped the canyon in well over one hundred years. As evidenced in the most recent California fire season, the frequency and severity of fires has increased as drought and "the ceaseless drive to populate fire-prone areas" compound the threat of economic damage and environmental trauma (Clarke, 2015). The president of California Professional Firefighters, Brian K. Rice, cites parched vegetation, high winds, and low humidity as catalysts for what the State Senate president pro tem Toni Atkins recognizes as the "new normal" of massive wildfires as "every bit the same kind of disaster as earthquakes, hurricanes and other natural disasters that confront states across the country." The impacts of climate change are inextricably linked to the global propensity for wildfires and are already evident in California. If the Camp Fire truly represents the soon-to-be typical fire, the Paradise Fire Fighters interviewed are at a loss as to how to balance economic and aesthetic concerns with mitigation efforts in ensuring minimal dry fuel loads at the Town's outskirts and interior. The combination of large-scale fires and rapidly increasing temperatures may convert much of the forestland into shrub and drought-adapted ecologies that naturally sequester less caron, creating a feedback loop to further climate change. Management and suppression efforts tend to be less effective under extreme weather conditions (Kitzberger, 2017). Wildfires are a global Earth system process both integrating and influencing climatic and ecosystemic conditions. Every year, the smoke from the wildfires ravaging these forests is "visual testimony" of this massive release of carbon that will only spur warming trends. As temperatures continue to warm and drought persists in frequency and intensity, the traditional strategy of "one-size-fits-all fuel management" will be less and less effective in reducing fire risk (Clarke, 2015). Communities large and small will have to rethink where to build and with what materials, how to "tweak our presence in ways that won't worsen the firescape, that nudge both city and countryside toward greater resilience," because as ASU professor Stephen Pyne described, fire "doesn't, really doesn't, care about our pain," our preferences, or our tweets (Milman, 2018).

Conclusions

In assessing the aftermath of the Camp Fire in the Town of Paradise, homes built in accordance with the 2008 strengthened CA Building Code for fire-prone regions had a better rate of survival. The comparison is undermined by the sample sizes, as 51% of the 350 post-2008 homes and 18% of the 12,100 pre-2008 homes escaped fire damage (Kasler, 2019). One family's guest house and backyard sheds were reduced to ash while the house survived with "a couple of warped window frames, a partially charred down spout and a stubborn smoky smell inside," emphasizing the unpredictability of wildfire patterns. The average construction date for Paradise housing stock is decades older than 2008, adding high retrofit costs to the already-expensive rebuild process. The housing recommendations delineated in Chapters 1 and 2 exceed the 2008 fire-prone code and are expected to increase resilience and mitigate exposure to fire, but cannot eliminate all risk.

Landscaping according to the Cal-Fire defensible space recommendations and the selection of locally adapted plant species aid firefighters in containment and suppression efforts. A town-wide defensible space would offer firefighters additional options for site staging and prescribed burns to create fire breaks and stop or slow fire's progression into the Town, where structural density and property-owner interests limit the efficacy of achieving adequate defensible space to contain and suppress fire within Town boundaries. Climatic conditions are expected to continue to exacerbate the Paradise region's propensity for extreme wildfire, but reducing the demand for external energy sources would eliminate some exposure given the disproportionate representation of neglected rural power lines serving as ignition sources in the 2017 Northern California fire season as well as the Camp Fire (Johnson, 2018). Evaluating neighboring municipal and county-level fire preparedness methods and structures could be illuminating for the Town Council to ensure no gaps exist in the community's on-going fire readiness. A designated Resiliency Councilmember or Subcouncil could facilitate Camp Fire recovery as well as response to future natural disasters, fire or otherwise.

Though the recommendations of this report are based upon the most recent engineering knowledge regarding structural fire resilience, the Camp Fire proves human comprehension of nature's capacity for destruction will always be fallible. Once the exterior of the structure becomes penetrated, often from embers starting small debris fires in gutters, all fire-resilience integrities became easily compromised. The noncombustible materials recommended in this report will inevitably melt, though they will not contribute to the fire.

According to Cal Fire, as many as three million homes lie within the various "fire hazard severity zones" around the state (Kasler, 2019). Daniel Gorham, a former firefighter and U.S. Forest Service researcher working for a South Carolinian Insurance Institute, points out that "California is leaps and bounds ahead of other parts of the country… on the forefront" of U.S. fire preparedness, and the California legislature is working toward retrofit subsidization programs and additional improvements. Increasing fire exposure is a serious nationwide problem affecting engineering, economics, politics, emergency response, and transportation industries. The Town of Paradise has lost the luxury of abstract preparedness, but are themselves resilient and ready to go above and beyond regional, state, and national minimums to rebuild their community.

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Appendix A

Structural Specifications

Table A-1: Roof and Ceiling Loads.

No.	**Material**	**Load (psf)**
1	Truss System	1.17
2	LokSeam	1.25
3	LP FlameBlock (7/16”)	1.4
4	Mechanical duct allowance	5
5	Mineral wool insulation (2")	1.33
6	LP FlameBlock (7/16”)	1.4
	Total	**11.55**

Table A-2: Exterior Wall Loads.

No.	**Material**	**Load (psf)**
1	Gypsum Board (5/8")	2.75
2	Mineral wool insulation (2")	1.33
3	Structure (362S162-97)	1.85
4	Furring channels (150F125-33)	0.44
5	Fiber Cement Siding HardiPlank® Lap Siding	2.4
	Total	**8.76, say 10 psf**

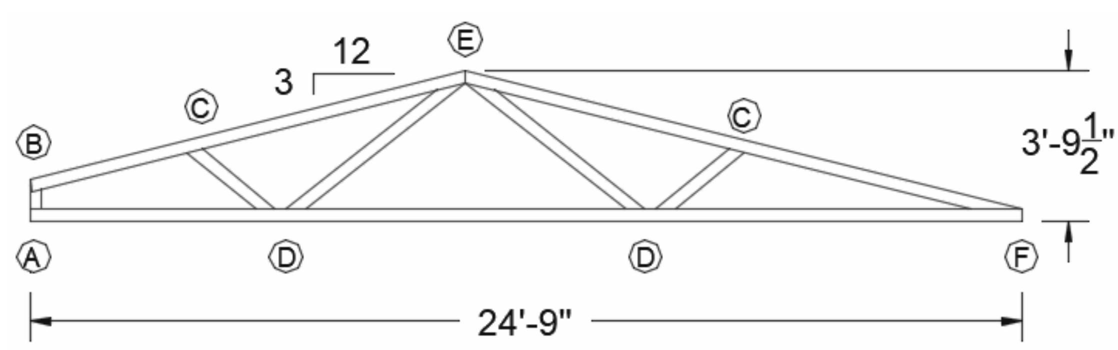


Figure A-1: Common Truss Dimensions.

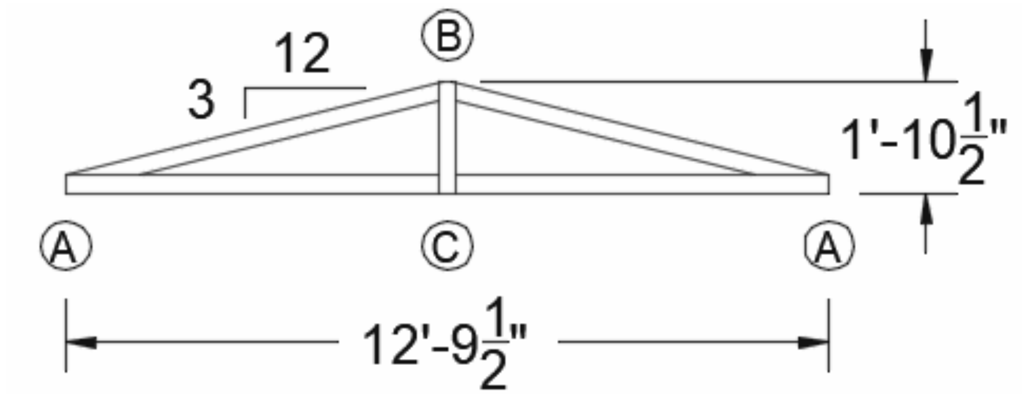


Figure A-2: Gable Truss Dimensions.

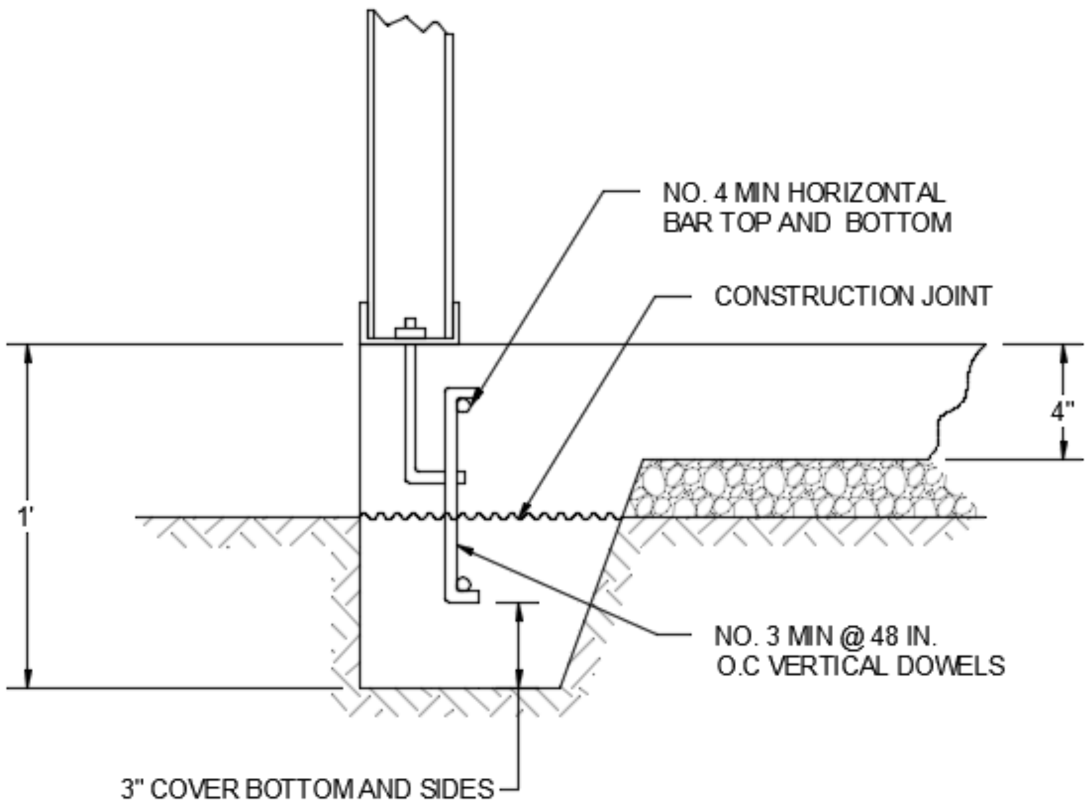


Figure A-3: Thickened Edge Slab.

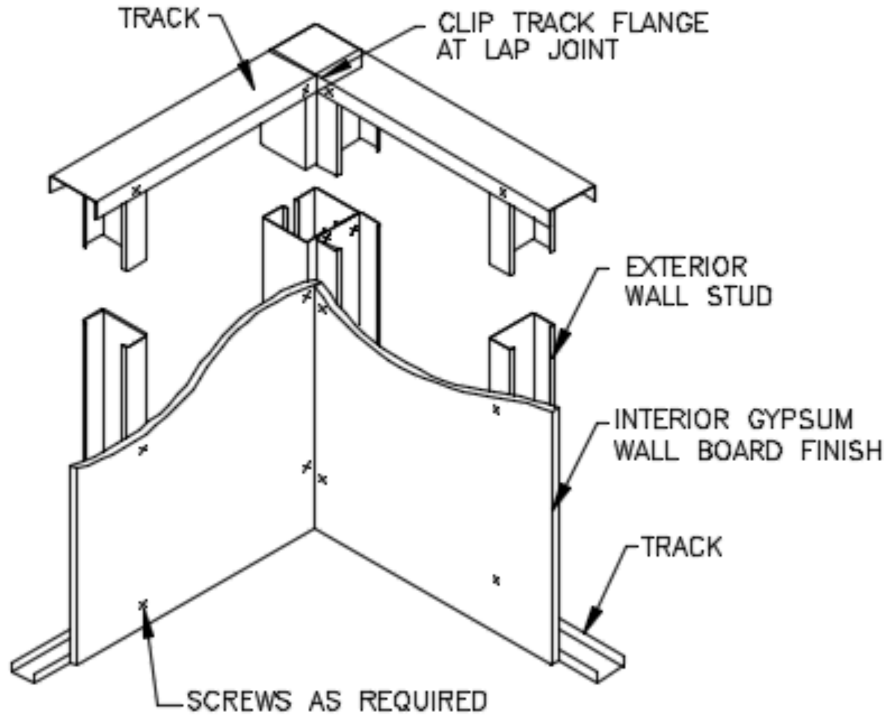


Figure A-4: Wall-to-Wall Corner Connection Perspective View.

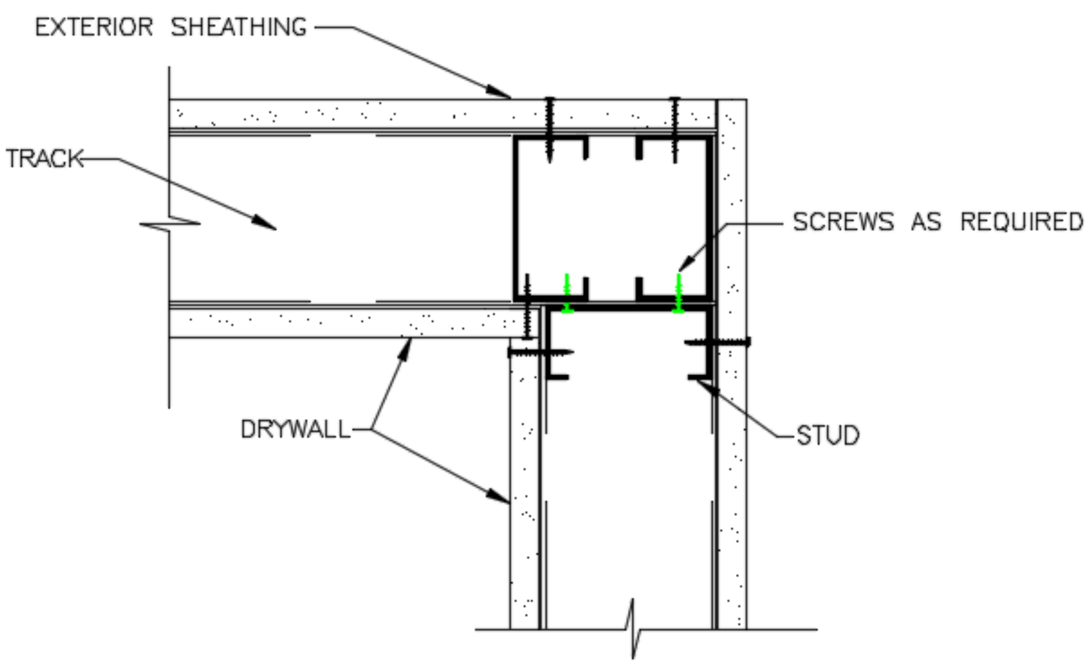


Figure A-5: Wall-to-Wall Corner Connection Plan.

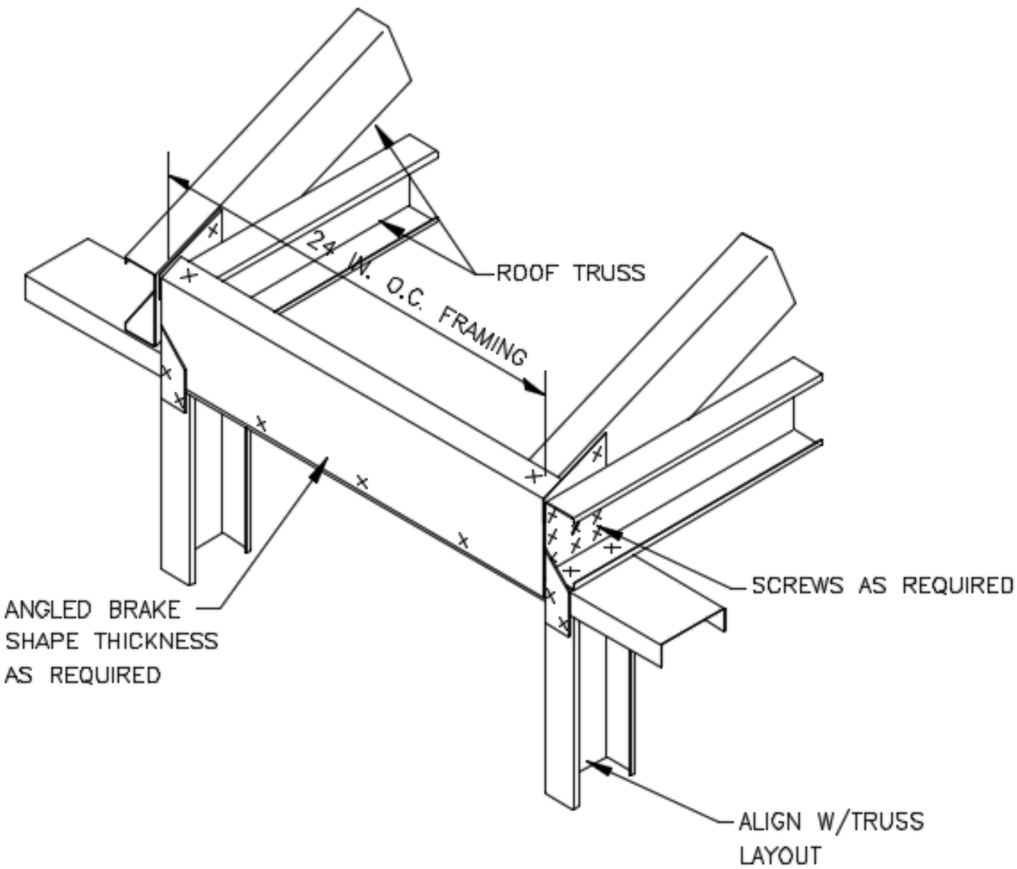


Figure A-6: Brake Shape Detail.

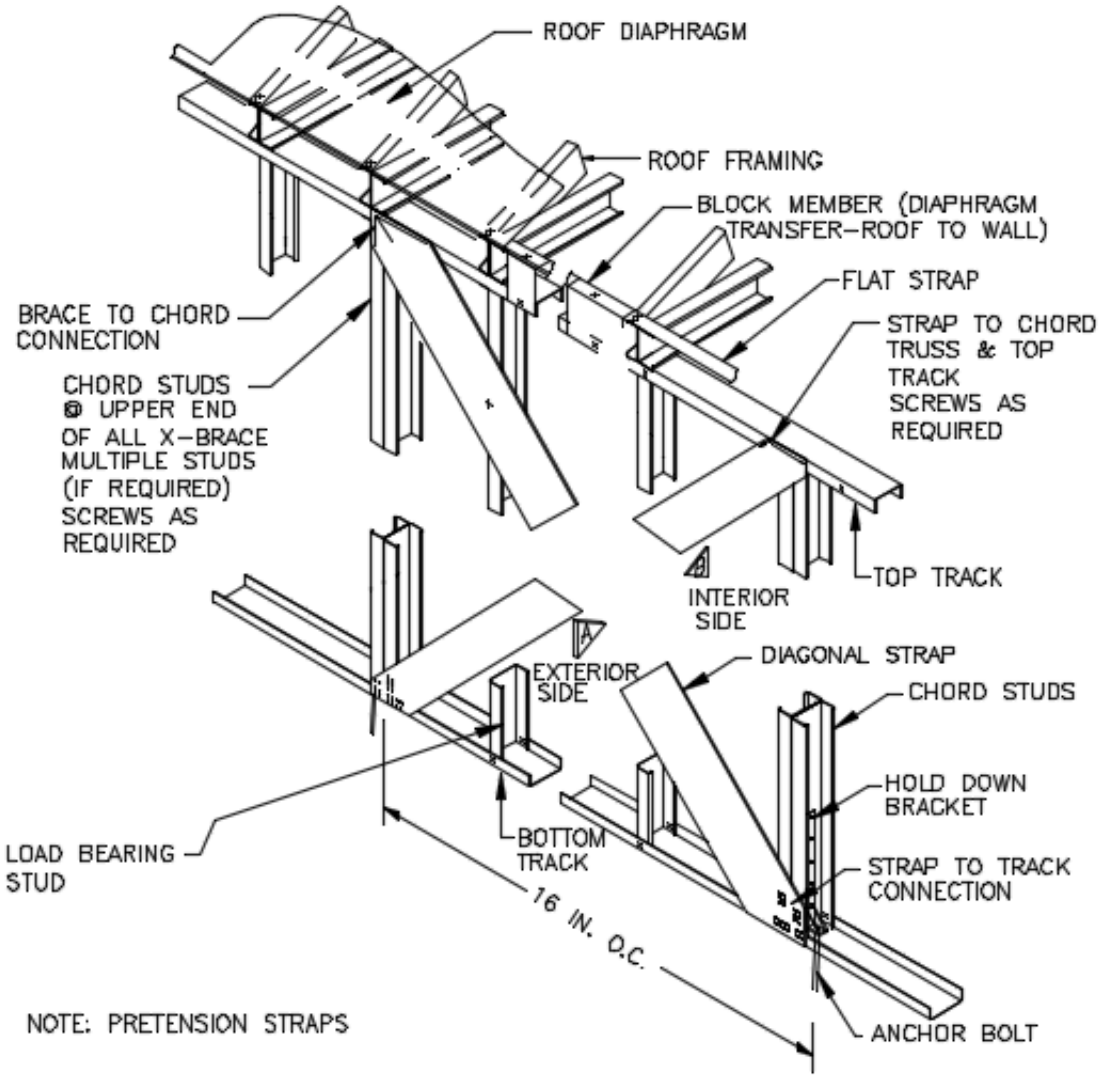


Figure A-7: Tension Only Bracing Against Lateral Loads.

Structure Loads

This document calculates the basic loads applied to the structure based on the floorplan.
It calculates Dead, Live, Seismic, and Wind Loads.
Variables that need an input are highlighted in blue. Outputs are highlighted in yellow.

LAYOUT

Plan

$A := 1200ft^2$	Area
$P := 164ft$	Perimeter
$L := 55ft$	Length
$B := 27ft$	Width
$Ht := 10ft$	Height

Roof

$p := 3$	Roof Pitch
$Rf := \frac{p}{12} \cdot (Ht + 0.5ft) = 2.625\,ft$	Top of Wall to Roof Apex
$\Theta := atan\left(\frac{p}{12}\right) = 14.036 \cdot deg$	Roof Angle

Walls

$Th := 8.75in$	Exterior Thickness
$th := 6.625$	Interior Thickness

ROOF TRUSS

Common Truss

$S_B := B + 2Th = 28.458\,ft$

$Sp := B - 3ft + 2 \cdot Th = 25.458\,ft$ Truss Span

$Tr := 45ft$ Transverse Span

$r := 3$: 12 Roof Slope

$\Theta = 0.245$ Roof Angle

$sp := 24in$ Spacing

Use section: 362S162-33

$Wt := 0.89 \frac{lb}{ft}$ Unit Weight of Member

Member	*Length (ft)*	*Weight (lb)*
A - B	$ab := \frac{r}{12} \cdot (S_B - Sp) = 0.75\,ft$	$w_{ab} := Wt \cdot ab = 0.668\,lb$
B - E	$be := \dfrac{\frac{S_B}{2} - (S_B - Sp)}{\cos(\Theta)} = 11.575\,ft$	$w_{be} := Wt \cdot be = 10.302\,lb$
E - F	$ef := \dfrac{\frac{S_B}{2}}{\cos(\Theta)} = 14.667\,ft$	$w_{ef} := Wt \cdot ef = 13.054\,lb$
A - F	$af := Sp = 25.458\,ft$	$w_{af} := Wt \cdot af = 22.658\,lb$
A - C	$ac := \sqrt{\left[\frac{ef}{2} \cdot \cos(\Theta) - (S_B - Sp)\right]^2 + \left(\frac{ef}{2} \cdot \sin(\Theta)\right)^2} = 4.483\,ft$	$w_{ac} := Wt \cdot ac = 3.989\,lb$
D - E	$de := \sqrt{\left(\frac{S_B}{3 \cdot 2}\right)^2 + \left(\frac{S_B}{2} \cdot \tan(\Theta)\right)^2} = 5.929\,ft$	$w_{de} := Wt \cdot de = 5.277\,lb$
C - D	$c_d := \sqrt{\left(\frac{S_B}{3}\right)^2 + \left(\frac{ef}{2}\right)^2 - \frac{2 \cdot S_B}{3} \cdot \frac{ef}{2} \cdot \cos(\Theta)} = 2.964\,ft$	$w_{cd} := Wt \cdot c_d = 2.638\,lb$

$W_{t1} := w_{ab} + w_{be} + w_{ef} + w_{af} + w_{ac} + 2w_{de} + 2w_{cd} = 66.5\,lb$ Total Weight per Truss

$No_1 := \frac{Tr}{sp} + 1 = 23.5$ Number of Trusses

$Common := W_{t1} \cdot No_1 = 1562.752\,lb$ Weight of Common Truss System

King Post

$S_B := 12ft$

$Sp := 12ft$ Truss Span

$Tr := 10ft$ Transverse Span

$r := 3$: 12 Roof Slope

$\Theta = 0.245$ Roof Angle

$sp := 24in$ Spacing

Use section: 362S162-33

$Wt := 0.89 \frac{lb}{ft}$ Unit Weight of Member

Member	*Length (ft)*	*Weight (lb)*
A - A	$aa := Sp = 12\,ft$	$w_{aa} := Wt \cdot aa = 10.68\,lb$
A - B	$ab := \frac{\frac{Sp}{2}}{\cos(\Theta)} = 6.185\,ft$	$w_{ab} := Wt \cdot ab = 5.504\,lb$
B - C	$bc := ab \cdot \sin(\Theta) = 1.5\,ft$	$w_{bc} := Wt \cdot bc = 1.335\,lb$

$W_{t2} := w_{aa} + 2 \cdot w_{ab} + w_{bc} = 23.024\,lb$ Total Weight per Truss

$No_2 := \frac{Tr}{sp} + 1 = 6$ Number of Trusses

$King := W_{t2} \cdot No_2 = 138.142\,lb$ Weight of King Truss System

$$\frac{(Common + King)}{A} = 1.417 \frac{lb}{ft^2}$$

DEAD LOADS

Roof and Ceiling

No.	*Material*	*Load*
1	Truss System	$rc1 := 1.42psf$
2	LokSeam	$rc2 := 1.25psf$
3	LP FlameBlock (7/16")	$rc3 := 1.4psf$
4	Mechanical duct allowance	$rc4 := 5psf$
5	Mineral wool insulation (2")	$rc5 := 1.33psf$
6	Lp FlameBlock (7/16")	$rc6 := 1.4psf$

$$rc_{total} := rc1 + rc2 + rc3 + rc4 + rc5 + rc6$$

$$rc_{total} = 11.8 \cdot psf$$

Exterior Wall

No.	*Material*	*Load*
1	Gypsum Board (5/8")	$ew1 := 2.75psf$
2	Mineral wool insulation (2")	$ew2 := 1.33psf$
3	Structure (362S162-97)	$ew3 := 1.85psf$
4	Furring channels (150F125-33)	$ew4 := 0.44psf$
5	Fiber Cemnt Siding	$ew5 := 2.4psf$

$$ew_{total} := ew1 + ew2 + ew3 + ew4 + ew5 = 8.77 \cdot psf$$

$$ew_{load} := ew_{total} \cdot Ht$$

$$ew_{load} = 87.7 \cdot plf$$

Interior Wall

No.	*Material*	*Load*
1	Gypsum Board (1/2")	$iw1 := 2.2psf$
2	Mineral wool insulation (2")	$iw2 := 1.33psf$
3	Structure (362S162-97)	$iw3 := 1.85psf$

$$iw_{total} := iw1 + iw2 + iw3$$

$$iw_{total} = 5.38 \cdot psf$$

LIVE LOADS

Area	*Load*
Roof	$q_{roof} := 20psf$
Ceiling	$q_{ceil} := 10psf$
Floor	$q_{floor} := 40psf$

SEISMIC LOADS

$S_S := 0.634$

$S_1 := 0.266$

$S_{DS} := 0.547$

$S_{D1} := 0.331$

$T_L := 16$

$R := 6.5$

$I_e := 1.0$

$$H := Ht + \frac{Rf}{2} = 11.313\,ft$$

$$C_s := \frac{S_{DS}}{\left(\frac{R}{I_e}\right)} = 0.084$$

Weights

$$W_{floor} := ew_{load} \cdot P = 14382.8\,lbf$$

$$W_{roof} := rc_{total} \cdot A = 14160\,lbf$$

$$W := W_{floor} + W_{roof} = 28542.8\,lbf$$

Base Shear

$$V_s := \frac{C_s \cdot W}{1000}$$

$V_s = 2.402\,lbf$

Vertical Earthquake Load

$$E_v := \frac{0.2 \cdot S_{DS} \cdot \left(rc_{total} \cdot A + ew_{load} \cdot P\right)}{1000} = 3.123\,lbf$$

WIND LOADS

$K_z := 0.85$

$K_{zt} := 1.0$

$K_d := 0.85$

$V := 110\text{mph}$

$q_z := 0.00256 \cdot K_z \cdot K_{zt} \cdot K_d \cdot V^2 \cdot \left(\frac{\text{hr}}{\text{mi}}\right)^2 \cdot \text{psf} = 22.38 \cdot \text{psf}$

$G := 0.85$

$GCpi := 0.18 \qquad -GCpi = -0.18$

$Cp_{ww} := 0.8$

$Cp_{lw} := -0.3$

$Cp_{wr1} := -0.5 \qquad Cp_{wr2} := 0$

$Cp_{lr} := -0.5$

$Pw := q_z \cdot G \cdot (Cp_{ww} - Cp_{lw}) - q_z \cdot -GCpi = 24.954 \cdot \text{psf}$

$Pw_e := \text{if}(Pw > 16\text{psf}, Pw, 16\text{psf}) = 24.954 \cdot \text{psf}$

$Prw := q_z \cdot G \cdot Cp_{wr2} - q_z \cdot -GCpi = 4.028 \cdot \text{psf}$

$Prl := q_z \cdot G \cdot -(Cp_{lr}) - q_z \cdot -GCpi = 13.54 \cdot \text{psf}$

$Q := (Prw + Prl) \cdot \sin(\Theta) = 4.261 \cdot \text{psf}$

$Q_e := \text{if}(Q > 8\text{psf}, Q, 8\text{psf}) = 8 \cdot \text{psf}$ Equivalent Horizontal Load

$W_x := L \cdot H \cdot Pw_e + L \cdot Rf \cdot Q_e$

$W_x = 16.681 \cdot \text{kip}$ X-Direction Wind Loads

$W_y := B \cdot H \cdot Pw_e + B \cdot Rf \cdot Q_e$

$W_y = 8.189 \cdot \text{kip}$ Y-Direction Wind Loads

Design of Wall Stud

Determines if given beam satisfies limit states.
Loads, section porperties, and spport conditinos are given.

Properties for 400S200-54

$R := 0.0849in$

$t := 0.0566in$

$F_y := 50ksi$

$E := 29500ksi$

$A_g := 0.5in^2$

$I_x := 1.292in^4$

$I_y := I_x$

$r := R + 0.5t = 0.113 \cdot in$

$s := 24in$

$h := 10ft$

$w_d := 7.1klf$

$w_l := 12.3klf$

$w := 1.2w_d + 1.6 \cdot w_l = 28.2\,klf$

Moment and Shear Demand

$$\Delta := \frac{h}{480 \cdot in} = 0.25$$

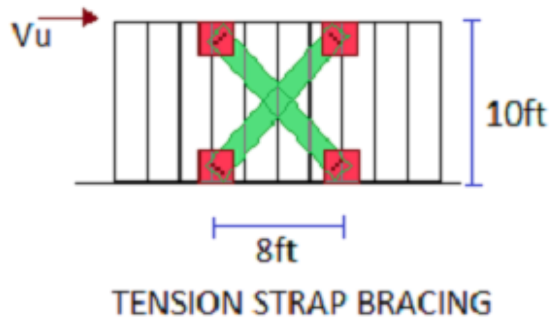
$$I_{xmin} := \frac{5 \cdot w \cdot h^3}{384 \cdot E \cdot \left(\frac{1}{480}\right)} = 860.339 \cdot in^4$$

$$M_u := \frac{w \cdot h^2}{8} \qquad M_u = 4230 \cdot kip \cdot in$$

$$V_u := \frac{w \cdot h}{2} \qquad V_u = 141 \cdot kip$$

Tension Only Strap Bracing

Determines width of strap bracing adequate for sesimic loads.



Properties

$t := 0.0329in$

$w_{strap} := 8ft$

$F_y := 33ksi$

$h := 10ft$

$V_u := 1.80kip$

$\phi := 0.9$

$$F_{strapx} := \frac{w_{strap}}{\sqrt{h^2 + w_{strap}^2}} = 0.625$$

$$F_{strap} := \frac{V_u}{F_{strapx}} = 2.881 \cdot kip$$

Failure Mode: Yield

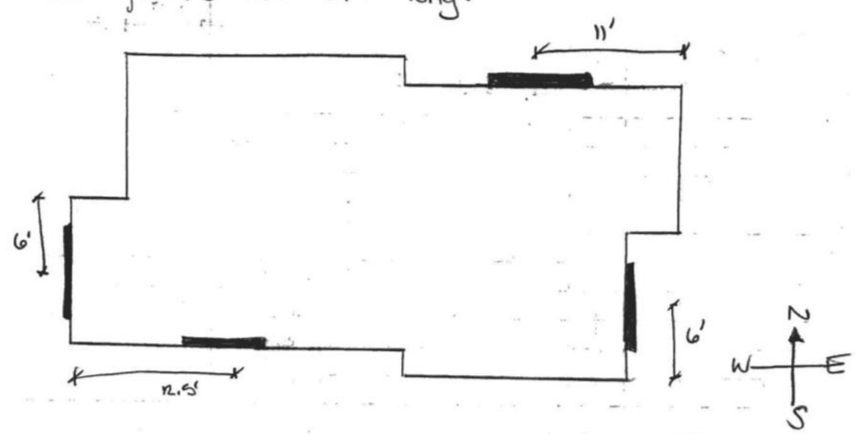
$$w := \frac{F_{strap}}{\phi \cdot t \cdot F_y}$$

$w = 2.949 \cdot in$

use w = 5"
assume min (3) no. 10 screws across strap width

LOCATION OF STRAP BRACING:

- ▬ represents lateral bracing.
- dimension measures to center of bracing.
- all systems are 8 ft long.



→ Location of bracing was chosen in areas where no door or window openings existed.

Appendix B

Compilation of Infographics

Figure B-1: Defensible Space Flyer, accessible at https://calfire.ca.gov/communications/downloads/fact_sheets/DefensibleSpaceFlyer.pdf.

WHEN CREATING DEFENSIBLE SPACE, KEEP THESE SAFETY TIPS IN MIND:

- All equipment with an internal combustion engine must be equipped with an approved and operable spark arrestor.
- Metal blades striking rocks can create sparks and start fires. Use caution.
- To protect water quality and habitat do not remove vegetation associated with water, avoid using heavy equipment near waterways and do not clear vegetation near waterways to the bare mineral soil. Keep soil disturbance to a minimum.

OTHER HINTS TO SECURE A LEAN, CLEAN AND GREEN ZONE:

- Select less flammable plants for your Lean, Clean and Green Zone:

  Shorter plants (less than 2 feet) are safer than taller ones.

  If kept green, herbaceous plants (grass and non-woody flowers) are better choices than shrubs and trees.

  If planting shrubs and trees, choose deciduous (trees that shed their leaves) ones over evergreens. Avoid planting juniper, pine and palms.
- Remove tree limbs that are touching the house or deck, or are within 10 feet of the chimney. If limbs are encroaching on overhead lines, contact your telephone or power company for removal.
- Use hard surfaces (concrete, stone, asphalt, brick, etc.) in your landscaping.
- Clear ALL flammable vegetation from within 10 feet of propane tanks.

YOUR RESPONSIBILITY:

California law (PRC 4291) requires property owners and/or occupants to create 100 feet of DEFENSIBLE SPACE around homes and buildings.*

YOUR GOAL — TO CREATE A:

Lean, Clean and Green Zone

An area of 30 feet immediately surrounding your home.

Reduced Fuel Zone

The fuel reduction zone in the remaining 70 feet (or to the property line).

**Compliance to PRC 4291 is required by any person who owns, leases, controls, operates or maintains a building or structure in or adjoining any mountainous area, forest-covered lands, brush-covered lands, grass-covered lands or any land that is covered with flammable material and is within the State Responsibility Area. PRC 4291 requires 100 feet of Defensible Space (or to the property line if less than 100 feet) from every building or structure that is used for support or shelter of any use or occupancy.*

Owner, lessee or operator must also comply with all existing environmental protection laws and must obtain all necessary permits. Contact your local resource or planning agency officials to ensure compliance with federal, state and local requirements.

Figure B-2: Page 2 of Defensible Space Brochure, accessible at https://calfire.ca.gov/communications/downloads/fact_sheets/2007DefSpaceBrochure.pdf.

TWO ZONES MAKE UP THE REQUIRED 100 FEET OF DEFENSIBLE SPACE:

1. Lean, Clean and Green Zone

An area of 30 feet immediately surrounding your home.

2. Reduced Fuel Zone

The fuel reduction zone in the remaining 70 feet (or to the property line).

COMPLY WITH THE LAW AND HELP SAVE YOUR HOME BY CREATING DEFENSIBLE SPACE.

Follow these guidelines:

1. Create a Lean, Clean and Green Zone

Remove all flammable vegetation and any dead or dying plants within 30 feet of each building or structure.

You may keep single trees or other vegetation that are trimmed of all dead and dying foliage and are well pruned and maintained.

2. Decrease Fuel in the Reduced Fuel Zone

Surface litter consists of fallen leaves, needles, twigs, bark, cones, pods, small branches, etc. Remove loose surface litter so it does not exceed a depth of three inches.

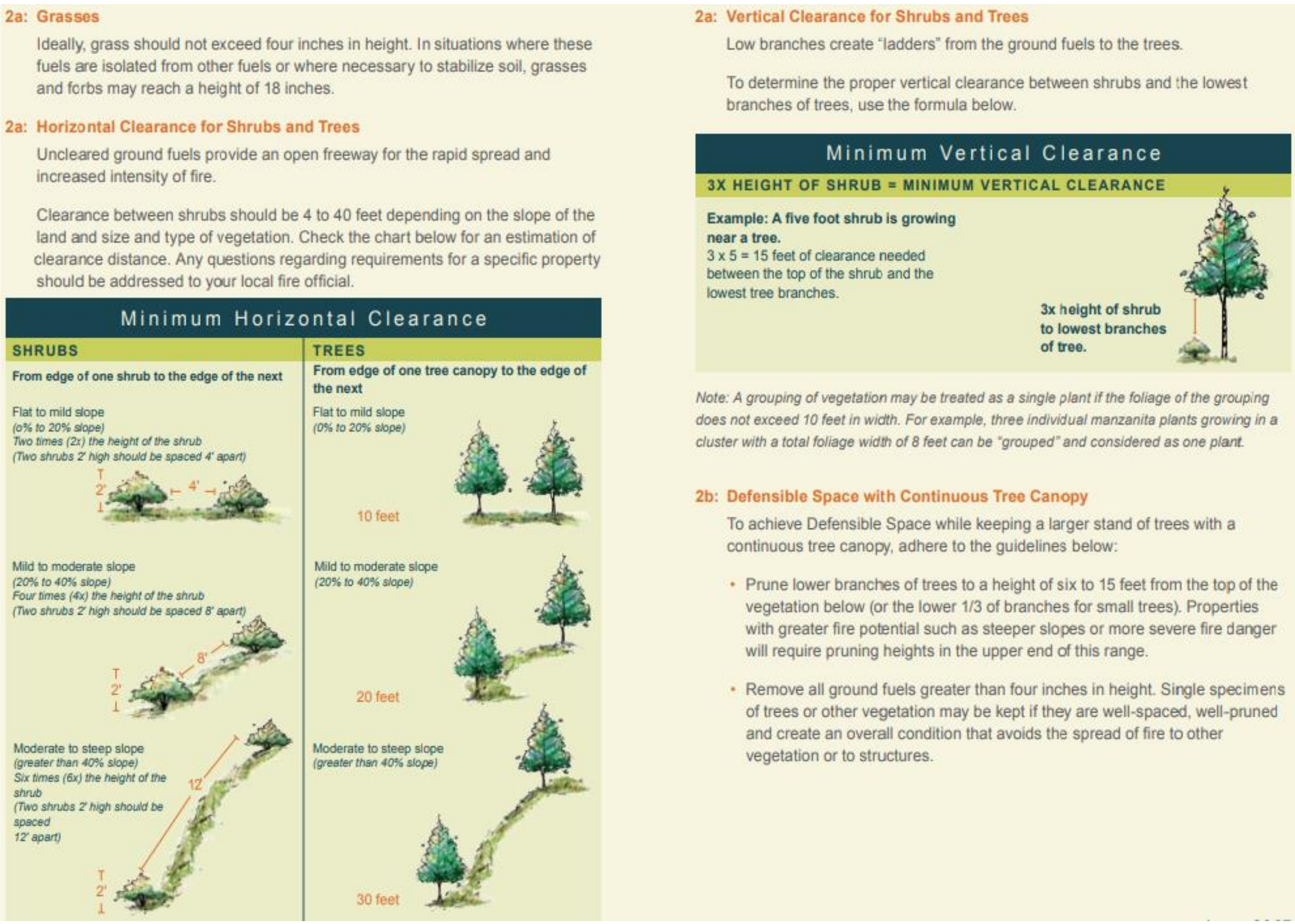
Make It Safe: Logs, Stumps and Snags

- All logs and stumps should be removed unless they are embedded in the soil. If you keep an embedded log, remove nearby vegetation.
- A standing dead tree (snag) may be kept for wildlife providing there is only one snag per acre, and if the snag were to fall, it would not reach buildings or structures and would not land on roadways or driveways.

Provide Fuel Separation and Treatment

- Guidelines for fuel treatment as published by CDF are designed to reduce the spread of wildfires.
- Choose option 2a or 2b. The best option for your property will be based on its characteristics (slope, vegetation size, vegetation type-brush, grass, trees, etc. — and other fuel characteristics). Properties with greater fire hazards will require larger separation between fuels. For example, a property on a steep slope with larger vegetation will require greater spacing between trees and shrubs than a level property that has small, sparse vegetation.

Figure B-3: Page 3 of Defensible Space Brochure, accessible at https://calfire.ca.gov/communications/downloads/fact_sheets/2007DefSpaceBrochure.pdf.



2a: Grasses

Ideally, grass should not exceed four inches in height. In situations where these fuels are isolated from other fuels or where necessary to stabilize soil, grasses and forbs may reach a height of 18 inches.

2a: Horizontal Clearance for Shrubs and Trees

Uncleared ground fuels provide an open freeway for the rapid spread and increased intensity of fire.

Clearance between shrubs should be 4 to 40 feet depending on the slope of the land and size and type of vegetation. Check the chart below for an estimation of clearance distance. Any questions regarding requirements for a specific property should be addressed to your local fire official.

Minimum Horizontal Clearance

SHRUBS	TREES
From edge of one shrub to the edge of the next	From edge of one tree canopy to the edge of the next
Flat to mild slope (0% to 20% slope) Two times (2x) the height of the shrub (Two shrubs 2' high should be spaced 4' apart)	Flat to mild slope (0% to 20% slope) 10 feet
Mild to moderate slope (20% to 40% slope) Four times (4x) the height of the shrub (Two shrubs 2' high should be spaced 8' apart)	Mild to moderate slope (20% to 40% slope) 20 feet
Moderate to steep slope (greater than 40% slope) Six times (6x) the height of the shrub (Two shrubs 2' high should be spaced 12' apart)	Moderate to steep slope (greater than 40% slope) 30 feet

2a: Vertical Clearance for Shrubs and Trees

Low branches create "ladders" from the ground fuels to the trees.

To determine the proper vertical clearance between shrubs and the lowest branches of trees, use the formula below.

Minimum Vertical Clearance

3X HEIGHT OF SHRUB = MINIMUM VERTICAL CLEARANCE

Example: A five foot shrub is growing near a tree.
3 x 5 = 15 feet of clearance needed between the top of the shrub and the lowest tree branches.

3x height of shrub to lowest branches of tree.

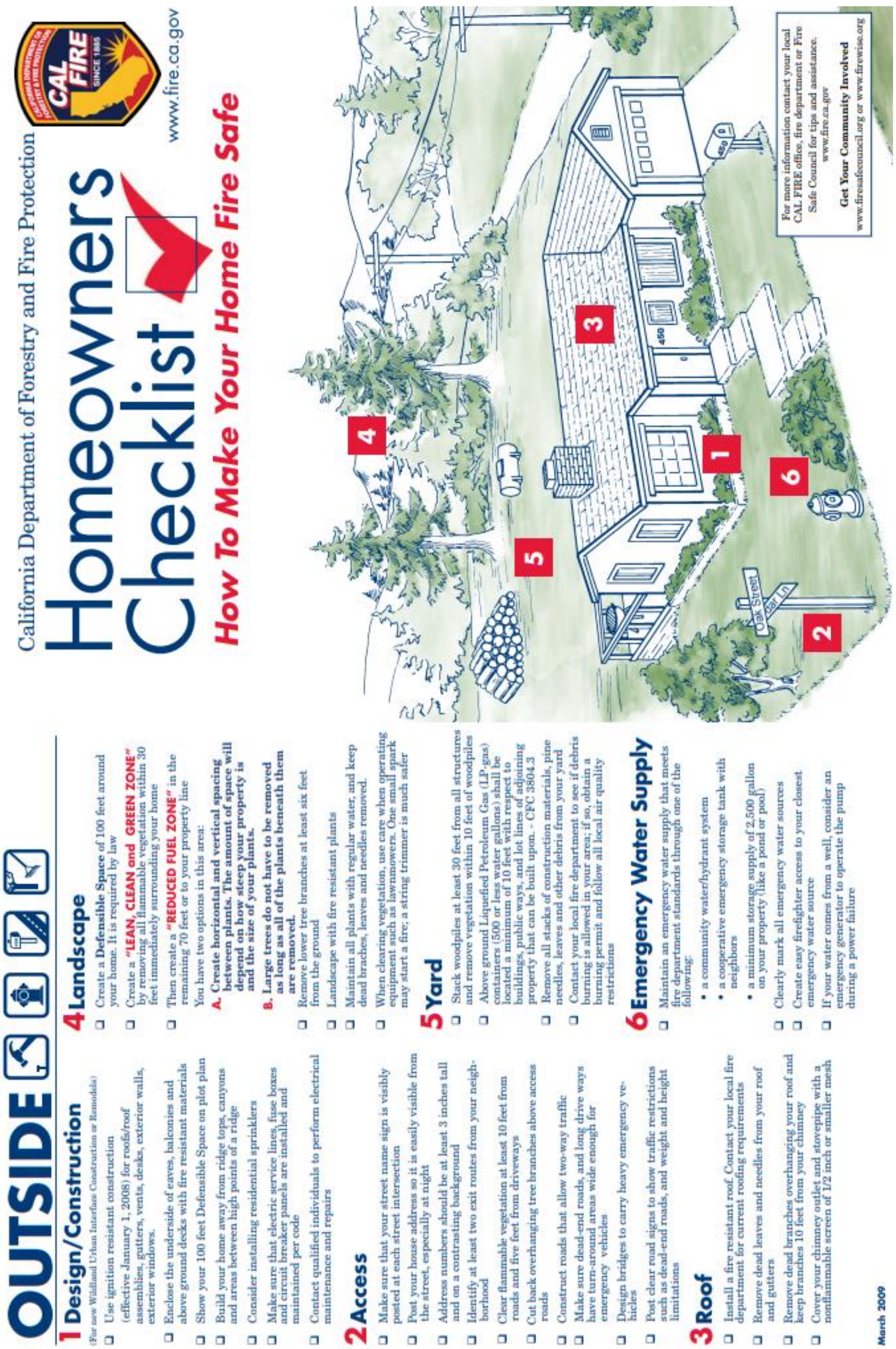
Note: A grouping of vegetation may be treated as a single plant if the foliage of the grouping does not exceed 10 feet in width. For example, three individual manzanita plants growing in a cluster with a total foliage width of 8 feet can be "grouped" and considered as one plant.

2b: Defensible Space with Continuous Tree Canopy

To achieve Defensible Space while keeping a larger stand of trees with a continuous tree canopy, adhere to the guidelines below:

- Prune lower branches of trees to a height of six to 15 feet from the top of the vegetation below (or the lower 1/3 of branches for small trees). Properties with greater fire potential such as steeper slopes or more severe fire danger will require pruning heights in the upper end of this range.
- Remove all ground fuels greater than four inches in height. Single specimens of trees or other vegetation may be kept if they are well-spaced, well-pruned and create an overall condition that avoids the spread of fire to other vegetation or to structures.

Figure B-4: Last Page of Defensible Space Brochure, accessible at https://calfire.ca.gov/communications/downloads/fact_sheets/2007DefSpaceBrochure.pdf.


OUTSIDE

1 Design/Construction

(For new Wildland Urban Interface Construction or Remodels)

- ❑ Use ignition resistant construction (effective January 1, 2008) for roofs/roof assemblies, gutters, vents, desks, exterior walls, exterior windows.
- ❑ Enclose the underside of eaves, balconies and above ground decks with fire resistant materials
- ❑ Show your 100 feet Defensible Space on plot plan
- ❑ Build your home away from ridge tops, canyons and areas between high points of a ridge
- ❑ Consider installing residential sprinklers
- ❑ Make sure that electric service lines, fuse boxes and circuit breaker panels are installed and maintained per code
- ❑ Contact qualified individuals to perform electrical maintenance and repairs

2 Access

- ❑ Make sure that your street name sign is visibly posted at each street intersection
- ❑ Post your house address so it is easily visible from the street, especially at night
- ❑ Address numbers should be at least 3 inches tall and on a contrasting background
- ❑ Identify at least two exit routes from your neighborhood
- ❑ Clear flammable vegetation at least 10 feet from roads and five feet from driveways
- ❑ Cut back overhanging tree branches above access roads
- ❑ Construct roads that allow two-way traffic
- ❑ Make sure dead-end roads, and long drive ways have turn-around areas wide enough for emergency vehicles
- ❑ Design bridges to carry heavy emergency vehicles
- ❑ Post clear road signs to show traffic restrictions such as dead-end roads, and weight and height limitations

3 Roof

- ❑ Install a fire resistant roof. Contact your local fire department for current roofing requirements
- ❑ Remove dead leaves and needles from your roof and gutters
- ❑ Remove dead branches overhanging your roof and keep branches 10 feet from your chimney
- ❑ Cover your chimney outlet and stovepipe with a nonflammable screen of 1/2 inch or smaller mesh

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4 Landscape

- ❑ Create a **Defensible Space** of 100 feet around your home. It is required by law
- ❑ Create a **"LEAN, CLEAN and GREEN ZONE"** by removing all flammable vegetation within 30 feet immediately surrounding your home
- ❑ Then create a **"REDUCED FUEL ZONE"** in the remaining 70 feet or to your property line

  You have two options in this area:

  A. Create horizontal and vertical spacing between plants. The amount of space will depend on how steep your property is and the size of your plants.

  B. Large trees do not have to be removed as long as all of the plants beneath them are removed.
- ❑ Remove lower tree branches at least six feet from the ground
- ❑ Landscape with fire resistant plants
- ❑ Maintain all plants with regular water, and keep dead braches, leaves and needles removed.
- ❑ When clearing vegetation, use care when operating equipment such as lawnmowers. One small spark may start a fire; a string trimmer is much safer

5 Yard

- ❑ Stack woodpiles at least 30 feet from all structures and remove vegetation within 10 feet of woodpiles
- ❑ Above ground Liquefied Petroleum Gas (LP-gas) containers (500 or less water gallons) shall be located a minimum of 10 feet with respect to buildings, public ways, and lot lines of adjoining property that can be built upon. - CFC 3804.3
- ❑ Remove all stacks of construction materials, pine needles, leaves and other debris from your yard
- ❑ Contact your local fire department to see if debris burning is allowed in your area; if so, obtain a burning permit and follow all local air quality restrictions

6 Emergency Water Supply

- ❑ Maintain an emergency water supply that meets fire department standards through one of the following:
  - a community water/hydrant system
  - a cooperative emergency storage tank with neighbors
  - a minimum storage supply of 2,500 gallon on your property (like a pond or pool)
- ❑ Clearly mark all emergency water sources
- ❑ Create easy firefighter access to your closest emergency water source
- ❑ If your water comes from a well, consider an emergency generator to operate the pump during a power failure

California Department of Forestry and Fire Protection

Homeowners Checklist

www.fire.ca.gov

How To Make Your Home Fire Safe

For more information contact your local CAL FIRE office, fire department or Fire Safe Council for tips and assistance.
www.fire.ca.gov

Get Your Community Involved
www.firesafecouncil.org or www.firewise.org

Figure B-5: Homeowners Checklist for Outside Fire Mitigation, accessible at https://calfire.ca.gov/communications/downloads/fact_sheets/Checklist.pdf.

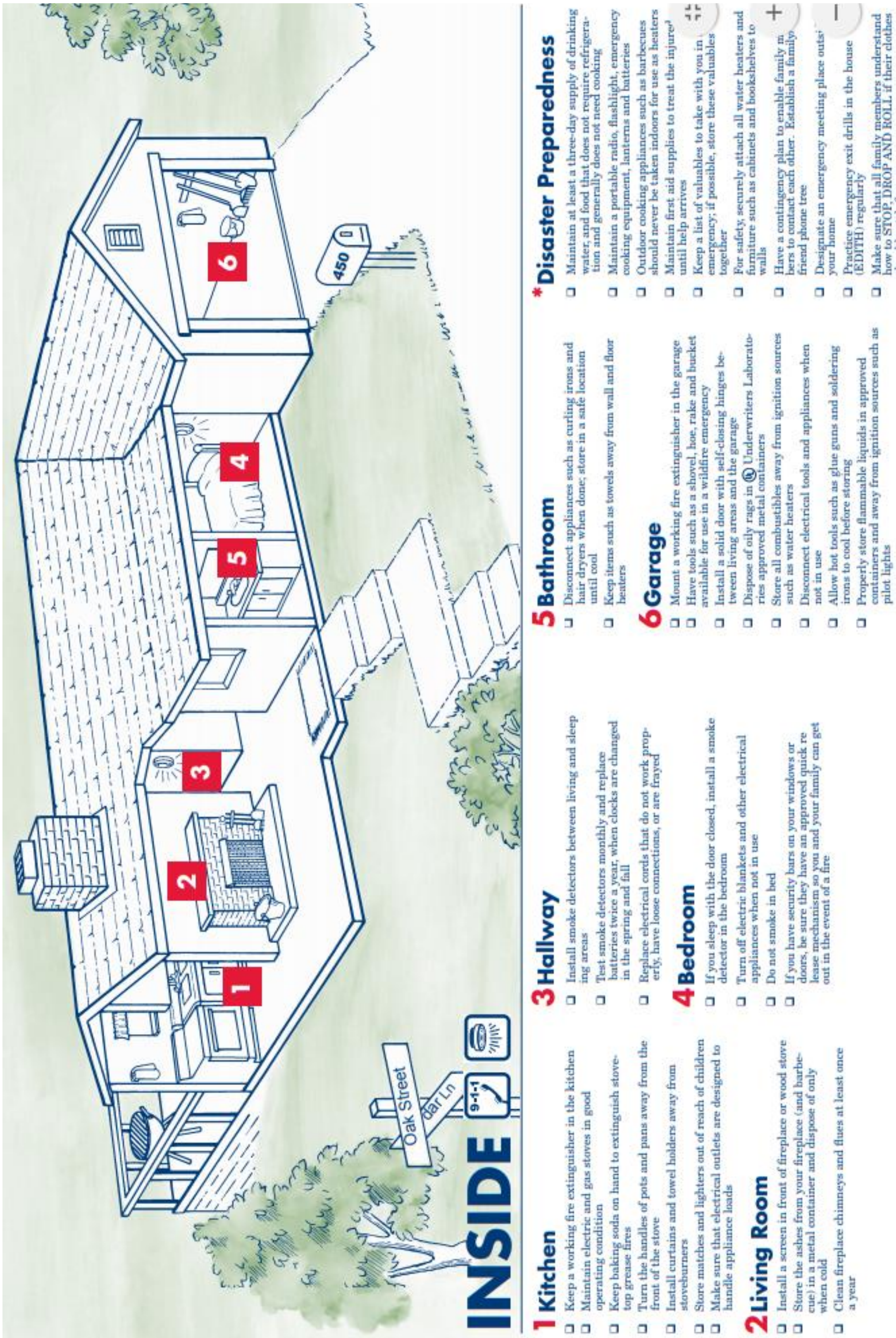

Figure B-6: Homeowners Checklist for Outside Fire Mitigation, accessible at https://calfire.ca.gov/communications/downloads/fact_sheets/Checklist.pdf.

How to Use This Guide

The plants in this guide are alphabetized by their scientific or botanical name, which is followed by the common name.

Below the plant name, you'll find a series of icons that gives a quick indication of the special needs and some qualities of each plant.

The text with each plant gives additional information that should help you to make the best selection to meet your landscape needs.

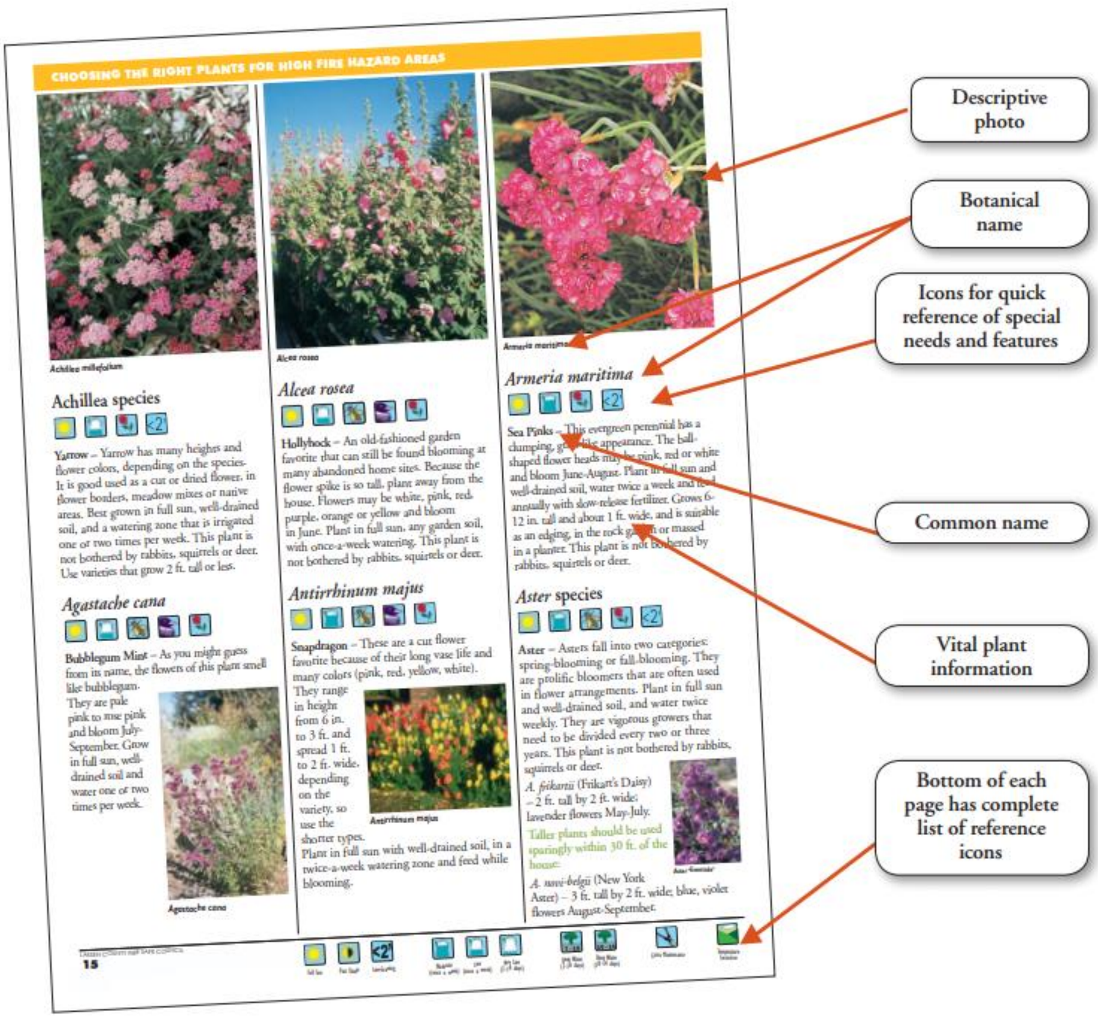

Figure B-7: Excerpt of 62-Page Landscaping Plant Guide for Northeastern California, accessible at http://www.lassenfiresafecouncil.org/wp-content/uploads/2011/01/Lassen-Fire-Safe-Council-NECal-LandscapePlantGuide.pdf. Additional Plant Information available at https://www.calflora.org//.

Prepare NOW

- Secure items, such as televisions, and objects that hang on walls. Store heavy and breakable objects on low shelves.
- Practice **Drop, Cover, then Hold On** with family and coworkers. Drop to your hands and knees. Cover your head and neck with your arms. Crawl only as far as needed to reach cover from falling materials. Hold on to any sturdy furniture until the shaking stops.
- Create a family emergency communications plan that has an out-of-state contact. Plan where to meet if you get separated.
- Make a supply kit that includes enough food and water for at least three days, a flashlight, a fire extinguisher, and a whistle. Consider each person's specific needs, including medication. Do not forget the needs of pets. Have extra batteries and charging devices for phones and other critical equipment.
- Consider obtaining an earthquake insurance policy. Standard homeowner's insurance does not cover earthquake damage.
- Consider a retrofit of your building to correct structural issues that make it vulnerable to collapse during an earthquake.

Figure B-7: Excerpt of earthquake preparedness recommendations, accessible at https://www.ready.gov/earthquakes.