Working Paper 2020-2

APPLIED HOUSING RESEARCH INITIATIVE
School of Public Affairs & Civic Engagement
San Francisco State University

The Seismic Performance of Tiny Homes: A Comparative Analysis of a Representative Shed and an IRC Tiny Home

Arturo Dominguez Escalante and Dr. Jenna Wong

Oct. 28, 2020

The PACE Applied Housing Research Initiative (AHRI) seeks to expand faculty research on housing to make PACE a central hub where students, policy makers, practitioners, and other housing leaders can come together to examine and understand housing policy issues in the Bay Area and beyond. AHRI provides a platform for introducing innovative solutions to affordable housing problems through activities such as supporting faculty and student research, offering a practitioner (co)-taught course on housing, and hosting an annual Distinguished Speaker Lecture. Seed funding from Merritt Community Capital Corporation for AHRI is greatly appreciated.

Abstract

With nearly 25% of the nation's homeless population living in California, the availability of affordable housing is a major concern and focal point. In many cities, the use of small or tiny homes for homeless housing is increasing. These homes provide a living space that is smaller than 600ft^2. These structures have found increasing popularity throughout the state with various cities modifying municipal code to allow increased development. The cost of a tiny home can vary depending on the design complexity. In some cases, commercially available sheds that are typically used for storage are being used as a tiny home. However, many of the cities impacted by high homeless populations are located in high seismic regions such as the San Francisco Bay Area. As such, this raises the question, how seismically safe are tiny homes? This study evaluated two tiny home models based on a representative shed and a design following the International Residential Code. It evaluates similarities and differences in the designs and the resulting influence on the performance of the structures under earthquake loading. Both models performed comparably with the weakest link in their designs being the connection between the structure and its foundation. In all the models and scenarios considered, the forces at the base of the structure exceeded the design values indicating damage could occur. These observations suggest that work is needed to conduct experimental tests and additional computational models to improve the design guidelines for these light weight structures. The housing crisis impacting California now will continue to be a major challenge for the generations to come. It is essential to bring local officials, policy makers, and engineers together to discuss the best practices for addressing our housing challenges in ways that are not just cost-effective but most importantly designed to protect during natural hazards such as earthquakes.

The Seismic Performance of Tiny Homes: A Comparative Analysis of a Representative Shed and an IRC Tiny Home

Arturo Dominguez Escalante[1] and Dr. Jenna Wong[2]

October 28, 2020

INTRODUCTION

The lack of affordable housing throughout the state of California and especially the Bay Area is a major policy concern. The need is so pressing that Governor Newsom in January 2020 created a new $1B housing fund to fight homelessness (State of California, 2020). Although only 1% of California's population is homeless, this 1% represents nearly 25% of the nation's homeless (Bendix, 2019). Governor Newsom's proposal relies on camper trailers and there are numerous programs throughout the state (publicly and privately funded) using tiny homes and even tuff sheds for homeless housing. For example, in Oakland, CA, $200k was raised via private funds to purchase and install nearly 20 Tuff Sheds[3] for "temporary" homeless housing (Graham and Lempres, 2018). In Berkeley, the non-profit organization Youth Spirit Artwork has a plan to build over 100 tiny homes for homeless youth over the next ten years (Orenstein, 2020). In Stockton, CA, 20.5% of the city's population lives below the federal poverty line prompting change to the municipal code allowing for the construction of tiny home villages (US Census, 2019). In real estate listings, there is an increasing number of sheds being rented out as housing units in San Francisco and San Diego. All of these efforts are the result of a growing demand for housing that is far out-pacing the construction of new affordable units.

A tiny home has a square footage typically under 600 square feet and may include not only a kitchen but bathroom as well (Figure 1a). These homes generally have wooden frames with siding made of wood, aluminum, or metal sheathing. They can be constructed in a matter of days without complicated foundational work making them an attractive housing system (but potentially seismically detrimental) for areas with shortages. The municipal codes or design

[1] Arturo Dominguez Escalante, Graduate Student/SF State Scholar in Civil Engineering, School of Engineering, San Francisco State University, adoming1@sfsu.edu; This project was completed as part of Arturo Dominguez Escalante's undergraduate capstone project and the foundation for his Master's Thesis with Professor Jenna Wong supervising as his faculty advisor. Arturo is a member of the SF State Scholars Program offering motivated students an accelerated pathway to a graduate degree.

[2] Jenna Wong, Ph.D., Corresponding Author/Assistant Professor, School of Engineering, San Francisco State University, jewong@sfsu.edu

[3] A Tuff Shed is a brand associated with a robust line of shed products and other manufactured buildings. Due to their visibility at popular home improvement stores and their own establishments, their sheds are typically referred to by their company name.

guidelines used depend on the construction site as well as temporary versus permanent usage goals.

Sheds are the most economical approach to creating a tiny home as many products such as Tuff Shed (Figure 1b) can be easily erected in a few days for around $5,000. Tiny homes constructed from the ground up can cost upward to $60,000 depending on the complexity of the interior design. These more complex homes also take a significantly longer construction time. In either case, this is a significantly lower cost compared to the current median house price of $533,500 in California according to Zillow (Zillow, 2020).

Tiny homes built in the backyards or another site on the lot/land of a larger primary housing unit are deemed auxiliary dwelling units (ADUs). In a recent report by the Terner Center for Housing Innovation (2020), the financing process of ADUs was discussed extensively due to the lack of financing available for them. Given that these ADUs have shown to help reduce overcrowding, provide new rental income and decrease home equity, there is increasing interest to increase their presence in all communities, especially in lower-income areas. Due to the substantial cost of an ADU, approximately $167k in California homeowners in economically stable communities are more likely to build ADUs. Organizations such as the Casita Coalition (2020) are working with policy makers to change the state's ADU laws and increasing the accessibility of ADU construction. These efforts support the vision to bring an ADU to every single-family home to increase housing accessibility, especially in affluent areas that lack diversity and affordability.

Beyond the immediate need to house the growing homeless and low-income populations, the COVID-19 situation has introduced a new interest in using tiny homes and sheds. With the increased number of family members working and learning from home, there is a need for increased space with many finding their backyards as a source of escape to work and relax. For example, a local shed company saw a 50% increase in customers with 95% of them planning to use the shed for a purpose other than storage (KTVU, 2020). Additionally, these customers are paying between $5k and $18k for these new structures. These tiny homes can be categorized as ADUs.

These tiny homes and sheds make a significant impact on the physical and psychological health of their owners but there is one major consideration that has yet to be addressed. How seismically safe are they?

Figure 1. Examples of (a) Tiny Home (Angst, 2020) and (b) Tuff Shed (Kendall, 2018) being used for homeless housing.

In the Bay Area alone, 2 million people live on or close to the Hayward Fault, the site of the next predicted major earthquake (USGS). With the evolution of tiny homes, the International Residential Code (IRC, 2017) has updated their codes to include details for tiny homes. In reviewing the literature, however, only a single study was found out of Australia that looked at their wind performance (Calluari and Alonso-Marroquin, 2017). None have actually done any computational or experimental studies to understand the seismic performance and reliability of these structures to inform code guidelines.

Objective

The objective of this study is to establish a fundamental understanding of the seismic performance of tiny homes by evaluating a home built according to the International Residential Code (IRC) and a representative shed used in the Oakland program (i.e., Tuff Shed).

Methods

Civil/structural engineers are challenged with the task of designing buildings and structures without being able to create full-scale prototypes as done with most products in mechanical, electrical, or computer engineering. Instead, there are three ways that Civil engineers can identify the potential performance of their designs: 1) data from actual events, 2) experimental tests, and 3) computer models. Data from actual events is difficult to garner as large magnitude earthquakes do not occur frequently (thankfully!) and cannot be directed to a specific city or region of interest. Although there is information available across the world about how certain structures perform, this information must be filtered based on the construction date, the codes followed, and the general design approach used as structural engineering has evolved very rapidly especially in the past 100 years. As a result, experimental tests are the next best way to test a structure for an earthquake scenario. Scaled or full-scale structures are constructed at experimental test facilities located at several universities throughout U.S. that are equipped with shake tables. These tables can replicate earthquake excitations to allow engineers to observe and record data on how much displacement, force, and acceleration is experienced throughout the structure. These tests also can record via video and audio media damage at various locations. Experimental tests are the closest approach to a prototype that civil engineers can create. However, these tests are rare as they are expensive and time-intensive. As a result, the majority of the designing community relies on computer models. Software development has allowed engineers to take physical models of structures and recreate them on computers. These models are driven by physics, experimental tests, and real events to allow engineers to apply loads and even earthquake excitations to predict the level of damage incurred. As these models are more cost and time-efficient, computer modeling is the first step taken typically in an earthquake analysis.

For this reason, this project used RISA3D, a well-known structural analysis program in the industry. This product is fine tuned for timber structures and implements physics-based models along with numerical methods to allow for the prediction of structural behavior under loadings and earthquake simulations. To properly study structures, there are typically several scenarios considered including a base study from which comparisons can be made. Comparisons allow engineers to understand the differences and potential similarities present in the structures and provide the context from which the results should be evaluated. When conducting these computer simulations, engineers look at a variety of measurements in the structure including displacements and forces. The displacements tell us how much movement occurs and can be compared against tables that define code limits to ensure the building does not collapse. The forces in the structure give insight into the capacity of the materials and general design approach.

To achieve this objective, this study examined two models: 1) a Representative Shed and 2) a Tiny Home designed per the International Residential Code (IRC, 2017). The Representative Shed is a based on the sheds used in the Oakland program discussed earlier. The IRC is the guideline for new residential buildings outlining the minimum criterion for safe housing. However, in addition to the IRC, there are site specific restrictions or criteria that must be satisfied. As the study uses a Representative Shed based on those used in Oakland, CA, the IRC design is created in accordance with the local municipal codes. For example, one of Oakland’s standards is a minimum of 120 square feet for a dwelling unit. A practicing engineer was consulted for peer review to ensure the IRC Tiny Home was as representative of an actual residential design as possible.

To characterize their seismic performance, nonlinear time history analyses were conducted using the accelerations from an actual earthquake event. In this case, the El Centro ground motion from the 1940 Imperial Valley earthquake was used. This earthquake is a moderate earthquake that is used extensively in earthquake engineering studies as a baseline case for analysis. From these analyses, the displacements and forces at various points in the structure are recorded and analyzed to identify their performance in the event and whether they met the IRC requirements for safe housing.

Computer Models

In creating the computer models, numerous details needed to be defined as discussed below.

Representative Shed

This model shown in Figure 2 is 8 feet wide and 15 feet long. The roof's pitch height measures 2 feet from the top of the wall. The roof's members are designed to be trusses, structural members that carry force only along the central axis putting the member into tension or compression. These members have pinned connections rather than rigid connections. The reason for the pin like connection is due to the steel plate and bolts connected to each pair of the roof trusses which does not produce a fully rigid connection. The roof truss members are 2x4 pieces of Douglas Fir Larch lumber. An example wall segment is shown in Figure 3. The walls are sheathed or covered the same as the IRC model but use single (not double) sided wood and 15/32-inch thick with 10d nails spaced 6 inches apart. Wall studs or the vertical members are spaced at 24 inches. In the shed, there are various openings to allow egress as well as natural lighting as shown in Figure 2. The wall segments are meshed in regions to allow for the software to identify all these wall elements as a single system and prevent unrealistic behavior due to the openings. For the shed foundation, a flat mat slab of reinforced concrete is used. There is one element of the model that is simplified from the physical model due to software restrictions. For a real shed, the current practice is to place the shed on top of a concrete slab or footings without any connections made between the structure and foundation. However, RISA 3D does not allow for structures to be analyzed without any anchoring. As a result, typical anchors (Simpson Tie Downs and Chord Straps) were applied to the model connecting the shed walls to the foundation. In future studies, this idealization will be better addressed understand the potential slippage that may occur as many shed structures are placed onto the slab with no anchoring.

The main details to notice are the studs spacing for the shed and sheathing. The studs are spaced 24 inches on center and are farther apart than the IRC model which would increase structural flexibility especially since these sheds also typically have sheathing only on the exterior. The dimensions for the wall's openings are estimated and only have openings in the front and back side of the walls. The other two sides of the structure does not contain any openings like the IRC model. The dimensions for the openings are provided in Table 1.

Table 1. Dimensions of Openings for Representative Shed

Opening	Width x Height
Door	3 ft x 6.67 ft
Front Windows	2.67 ft x 2 ft
Back Window	4 ft x 2.67 ft

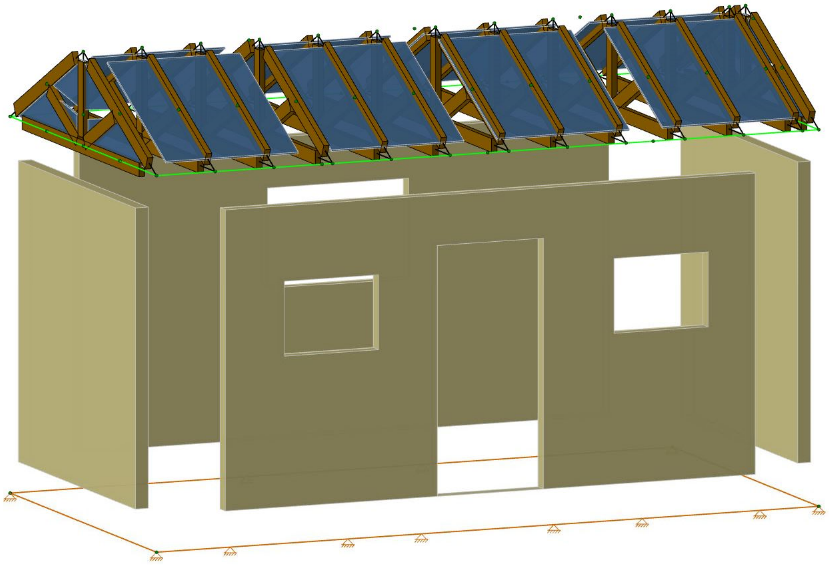

Figure 2. 3D Model of Tuff Shed

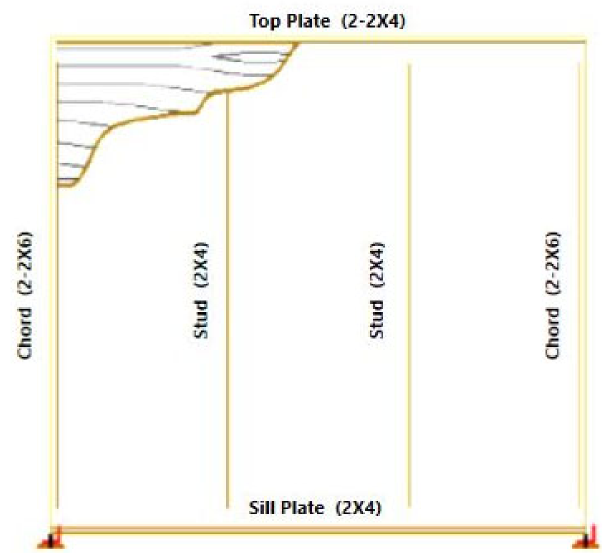

Figure 3. Example Tuff Shed Wall

IRC Tiny Home

The IRC Tiny Home is designed to be comparable in size and material to the Representative Shed as shown in Figure 4. Unlike the Representative Shed, the IRC Tiny Home uses 2x6 lumber for the rafters to provide space for ventilation installation per industry standard. The walls are sheathed using single- and double-sided wood that is 15/32-inch think with 10d nails and 6 inches spacing to meet the American Wood Council deflection limits (American Wood Council, 2017). An example wall segment is shown in Figure 5. The walls have fewer windows reflective of municipal codes designating minimum wall space between openings. The wall studs or the vertical members are spaced at 16 inches apart. The Tiny Home is anchored to the foundation in a similar fashion as the Representative Shed. Table 2 summarizes the dimensions of window and door openings.

Table 2. Dimensions of Openings for IRC Tiny Home

Opening	Width x Height
Door	3 ft x 6.67 ft
Front Windows	2 ft x 2.67 ft
Back Window	5 ft x 2.67 ft

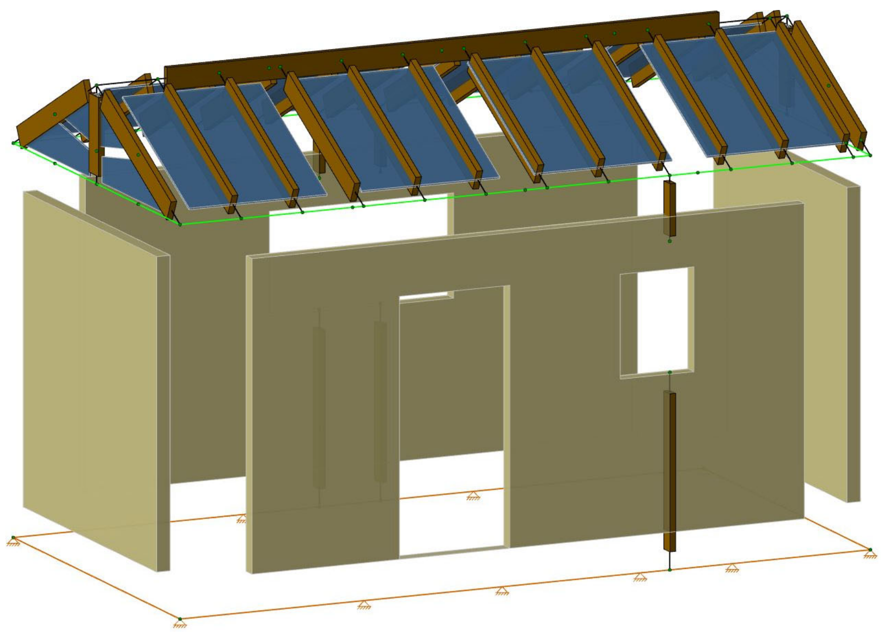

Figure 4. 3D Model of IRC Tiny Home

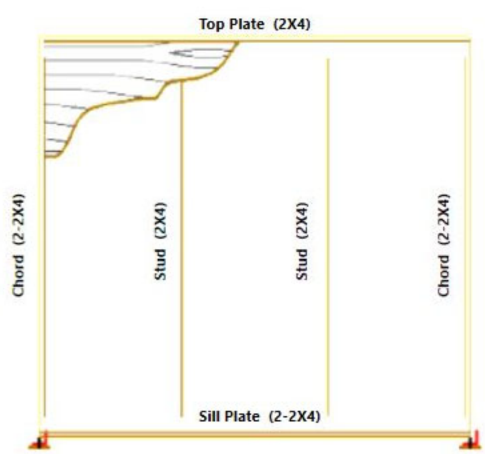

Figure 5. Example IRC Tiny Home Wall

Loads

In structural models, many types of loads or forces can be placed onto the system. These can include self-weight, live load (to account for transitory forces), snow, rain, etc. For these models, self-weight is the only load considered but there is a variation in loading between the two models. As shown in Table 3, there are various loads added to the structure which follow the load path shown in Figure 6. In all structures, loads must find their way to the ground. The self-weight for the Representative Shed is 6.3 psf (pounds per square foot). For the IRC model, its weight is more than twice at 15 psf. The reason for the heavier weight on the IRC structure is due to the practical stance of what a standard home would have. The weights applied were those provided by our consulting engineer. The number could range depending on the type of roofing materials used but an average value was used. This load is applied directly to the system by defining the member's weight as well as applying a factor to the loadings per the ASCE 7-16 (American Society of Civil Engineers, 2017) to account for safety.

Table 3. Load Breakdown

Type of material	IRC (psf)	Tuff Shed (psf)
Roofing	4	2
Sheathing	2.3	2.3
Rafters	1.5	0.9
Ceiling Joists	1.1	1.1
Insulation	1.0	-
Mech/Elec.	1.0	-
Ceiling GWB	2.3	-
Misc.	1.8	-
Total	**15**	**6.3**

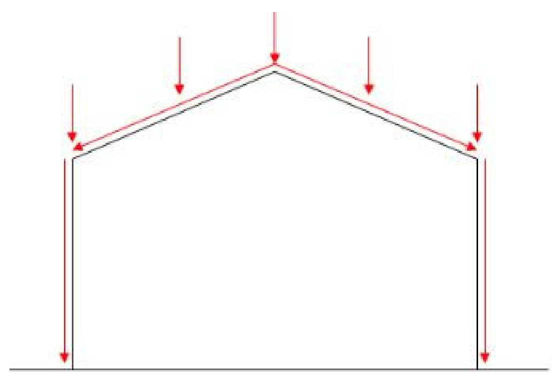

Figure 6. Example Load Path (The Student Engineer, 2011)

RESULTS

Using this computer model, there were various stages to our analysis. A systematic approach is necessary to check the computer model against the physical system. This allows engineers to ensure that the model is represented as accurately as possible.

Weight

The first step in the analysis is to calculate the weight of the structure. The reason for calculating the overall weight is to double check this value against hand calculations. The total weight of the structures is shown in Table 4 below.

Table 4. Seismic Weight of the Two Models

Representative Shed	2.29 kips
IRC Tiny Home	4.4 kips

Fundamental Period

The next step is to understand the dynamic properties of the structures. Every structure moves like a wave when excited by a force and as such can be defined by quantities such as periods or the time in between wave cycles. These periods tell engineers the relationship between the mass and stiffness of the structure. Periods are directly proportional to mass and inversely proportional to stiffness. Table 5 summarizes the fundamental or longest period of the structure's wave like behavior. The Representative Shed's period is shorter than the IRC shed, however, the values are very comparable. This is due to the balance between the decreased stiffness of the Shed and the increased mass of the Tiny Home. This suggests that there should be similarities in dynamic response to applied forces such as earthquakes.

Table 5. Information from the Fundamental Mode for the Two Models

Model	Frequency (Hz)	Period (sec)
Representative Shed	10.53	0.095
IRC Tiny Home	8.035	0.124

Ground Motion Analysis

The next step is to test these structures using an earthquake motion. This analysis is done by importing a ground motion time history which is a recording of accelerations over a period of time measured at a specific location during an earthquake. The ground motion used for this analysis is the 1940 Imperial Valley Earthquake recorded at the El Centro station (Figure 7). This motion is a moderate earthquake that has a peak acceleration of 0.32g or 10.3 ft/s^2 where g is the gravitational constant 32.2 ft/s^2. This earthquake lasted for approximately half a minute. Before this analysis can be conducted, there is one other component of the model to consider and that is damping. Damping is the decrease in structural oscillation due to the dissipation of energy via heat, noise, and deformation to relieve the stress applied to the structure. This damping can be natural due to the material properties or enhanced using special devices. In this case, only material damping is considered. There are various ways that damping can be modeled in a structure but 5% Rayleigh damping was used as it is a common approach (Chopra, 2012). This type of damping is based on a mathematical formula that defines a specific level of damping at certain points of the wave-like response.

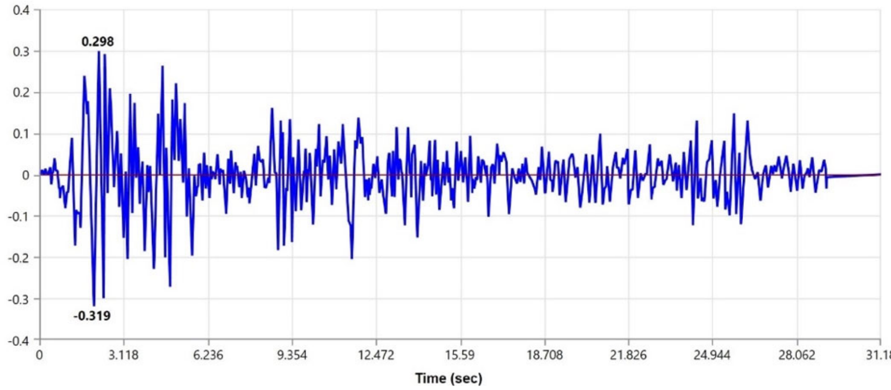

Figure 7. El Centro Ground Motion Acceleration Time History

There are two directions to test the model's response: the first direction is the transverse side or x-direction (short side) and the second direction is the longitudinal side of the model or y-direction (longest side). The motions were applied separately to closely examine the variation in behavior of each side of the structure given the various differences in the openings and dimensions of the wall.

To understand how well the structures performed, displacements were recorded at the top of the wall and at the roof along with shear forces at the base. These shear forces are forces created parallel to the ground due to the earthquake movement. Maximum results for the two directions are summarized in Tables 6 and 7 below.

Table 6. Max Responses from El Centro Ground Motion (x-direction)

Model	Base Shear	Displacement Top of the wall	Displacement Roof
Representative Shed	3.33 Kips	0.141 in	0.146 in
IRC Tiny Home	2.89 Kips	0.083 in	0.087 in
% Difference	15.2 %	69.9 %	67.8 %

Table 7. Max Responses from El Centro Ground Motion (y-direction)

Model	Base Shear	Displacement Top of the wall	Displacement Roof
Representative Shed	3.28 Kips	0.150 in	0.158 in
IRC Tiny Home	3.09 Kips	0.093 in	0.103 in
% Difference	6.2 %	61.3%	53.4 %

There are a number of observations to draw from these results. Firstly, the overall magnitudes of the displacements are rather small. This is reflective of the relatively stiff structures. Secondly, in comparison against code drift limit of 0.97 inches, both models perform exceptionally well. Thirdly, the differences between the two models' displacements is rather large in terms of absolute percentages but as these are low magnitude displacements this is not concerning. It does show that the increased flexibility of the Shed does lead to higher displacements in the structures with a higher influence in the y-direction (or long direction) excitation. In terms of the base shears, the code defines a design shear based on the weight of the structure and a seismic response coefficient that accounts for the structure's importance and location. In calculating this value, it was found that the design shears of the Representative Shed and IRC Tiny Home are 0.69 kips and 1.32 kips, respectively. This is significantly lower than the shears observed in Tables 6 and 7. This presents the case that there could be significant damage at the base or even movement in this plane.

To push this system further, the El Centro ground motion accelerations were multiplied by a factor of three to represent an earthquake with a peak acceleration of 0.96g or almost 32.2 ft/s^2. This acceleration can be comparable to what is felt on some roller coasters with a high drop point. The results from this increased seismic event are tabulated in Tables 8 and 9.

Table 8. Max Responses from El Centro Ground Motion (Peak Ground Acceleration = 0.957g, x-direction)

Model	Base Shear	Displacement Top of the wall	Displacement Roof
Representative Shed	10.0 Kips	0.422 in	0.439 in
IRC Tiny Home	8.64 Kips	0.249 in	0.261 in
% Difference	15.74 %	69.5 %	68.2 %

Table 9. Max Responses from El Centro Ground Motion (Peak Ground Acceleration = 0.957g, y-direction)

Model	Base Shear	Displacement Top of the wall	Displacement Roof
Representative Shed	10.06 Kips	0.458 in	0.483 in
IRC Tiny Home	9.26 Kips	0.279 in	0.309 in
% Difference	8.6 %	64.2 %	56.3 %

In comparison to the original motion, there are several trends to observe. Firstly, the percentage difference between the Shed and IRC models is comparable. However, the magnitudes of the displacements are more significant in this scaled motion. Here the Shed experiences maximum displacements around 0.5 inches compared to maximum values around 0.3 inches for the IRC model. In terms of the structure's drift limits, the models once again are well within the limit even for this heightened earthquake. In terms of the base shears, the base shears increasing accordingly with the increased seismic activity which will present increased concern given the design shear of the structure. Based on this study, the two structures perform comparably with neither showing increased seismic performance as they both exceed the design base shear. The weak link in the designs is the connection between the structure and its foundation.

CONCLUSIONS

With increasing housing needs and inadequate levels of new housing development, rapid deployment of tiny homes will be sought to as a potential solution. Although some cities see this is a temporary solution such as Oakland's homeless Tuff Shed program, others are looking to them as the permanent resolution as in Stockton. However, there is the question of how to best approach the use of tiny homes or any auxiliary dwelling unit for human occupancy, from a safety perspective.

The use of commercially available sheds like Tuff Shed, is a quick solution to creating a tiny home. They are definitely more cost-effective and readily available compared to a tiny home built from the ground up. As this study showed there are differences in the way that a shed is designed compared to a code-compliant tiny home. These differences arise from the spacing of vertical members and the detailing of the structure to accommodate typical housing features such as insulation and mechanical/electrical elements. The dynamic properties of the Shed and IRC Home are very similar. In examining their dynamic responses, these models showed that the structural systems themselves perform comparably. They both do not exceed any code limits for maximum drifts in either earthquake scenario. However, the base shears for all models and earthquake scenarios exceeded the design values. This means that there needs to be additional work done on investigating the connections between the structures and the foundation. The current anchorage system was optimized using the currently available software in industry. However, this study has found that there are limitations to this software given that it is not a direct match to the current approach of leaving the structure and foundation unconnected and also may not be able to properly optimize the connections for such light structures.

There is more room for future work on this topic. One of the major assumptions made in this study was the fact that the Shed and IRC Home were anchored to their foundations. In typical situations, sheds are not anchored. The lack of physical connection needs to be better understood both from an experimental test and computational model. The limitations of current industry software present a major challenge to allowing practicing engineers to better replicate the behavior of these structures. Secondly, there is the question of how well will these systems perform under nonstructural reviews or reviews examining how the structure's contents (e.g. furniture) behave under an earthquake. In the Representative Shed model, given that there are no electrical or mechanical systems, there is a question of how would lighting be provided and how will occupants create light especially at night. Given the hollow nature of these sheds, there is a question of how will hanging lights or elevated lighting stands perform under seismic events. Will they cause additional loads on the structure increasing their potential for damage? Will they have a higher potential for falling and potentially injuring occupants? Even the use of bunk beds to maximize the number of occupants needs to be considered. These are details that need to be better observed and analyzed to improve the approach to using these sheds and tiny homes for continuous or long-term human occupancy. It is very possible that these issues can be easily rectified by adding some structural features to their designs. Most importantly, this work will help in the development of design guidelines for these structures.

Overall, the use of tiny homes for housing is going to become more prevalent with time. With the movement to improve ADU financing and increase their presence in low-income communities, California cities in expensive metropolitan regions will find themselves looking to tiny homes as a feasible solution to their housing needs. With this in mind, this work needs to be done carefully to create designs that are cost-effective, can be easily and rapidly constructed, and most importantly, provide safe living spaces. It is through policy changes that all of this can be achieved. It is a partnership between local leaders, policy makers, and engineers that can help create resilient communities to serve and meet the challenges of the generations to come.

Acknowledgements

The authors are grateful for the peer review and design guidance provided by Elliot House, consulting engineer and SFSU Alum. We also thank Dr. Ayse Pamuk and the Applied Housing Research Initiative for their support of this project.

References

American Society of Civil Engineers (2017). *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.* American Society of Civil Engineers. ASCE/SEI 7-16. Digital Copy.

American Wood Council (2017). *National Design Specification (NDS) for wood Construction.* American Wood Council. 2018 Edition. Digital Copy.

Angst, M. (2020). San Jose opens first tiny home community for formerly homeless residents. Retrieved from: https://www.mercurynews.com/2020/02/27/san-jose-opens-first-tiny-home-community-for-formerly-homeless-residents/.

Bendix, A. (2019). *California's homelessness crisis is spiraling out of control. These mayors want to solve it with tiny homes, trailers, and floating apartments.* Retrieved From: https://www.businessinsider.com/california-mayors-homeless-crisis-tiny-homes-2019-6.

Calluari, K.A., Alonso-Marroquin, F. (2017). *Structural analysis of an off-grid tiny house.* In Proceedings of Off-Grid Technology Workshop.

Casita Coalition. (2020). *Small homes, big potential.* Retrieved From: https://www.casitacoalition.org/Chopra, A. (2012). *Dynamics of Structures: Theory and Applications to Earthquake Engineering.* Pearson Education Inc. Fourth Edition. Digital Copy.

Graham, D., & Lempres, D. (2018). *Oakland's Tuff Shed Program, by the Numbers.* Retrieved From: https://www.eastbayexpress.com/SevenDays/archives/2018/10/16/oaklands-tuff-shed-program-by-the-numbers.

International Code Council (2017). *2018 International Residents Code (ICC).* Retrieved From: https://codes.iccsafe.org/content/IRC2018/copyright.

Kendall, M. (2018). *Homeless greet Oakland's new Tuff Sheds with hesitation, hope.* Retrieved From: https://www.mercurynews.com/2018/05/08/homeless-greet-new-tuff-sheds-with-hesitation-hope/.

Orenstein, N. (2020). *A colorful 'tiny house village' for youth is opening in Oakland.* Retrieved From: https://oaklandside.org/2020/08/05/youth-spirit-artworks-tiny-house-oakland/.

State of California. (2020). *Governor Newsom Previews $1 Billion in Budget Proposal to Jump-Start New Homeless Fund and Provide Behavioral Health Services, Signs Order to Accelerate State Action to Fight Homelessness.* Retrieved From: https://www.gov.ca.gov/2020/01/08/governor-newsom-previews-1-billion-in-budget-proposal-to-jump-start-new-homeless-fund-and-provide-behavioral-health-services-signs-order-to-accelerate-state-action-to-fight-homelessness/

Terner Center for Housing Innovation. (2020). *Reaching California's ADU Potential: Progress to Date and the Need for ADU Finance.*

The Student Engineer. (2011). Loads paths. Retrieved from: https://thestudentengineer.wordpress.com/2011/05/10/loads-paths/.

U.S. Census (2019). *U.S. Census Bureau QuickFacts: Stockton city, California.* Retrieved From: https://www.census.gov/quickfacts/stocktoncitycalifornia.

USGS. *Earthquake Hazards of The Bay Area Today.* Retrieved From: https://earthquake.usgs.gov/earthquakes/events/1868calif/virtualtour/modern.php.

Zillow. (2020). *California Home Prices & Home Values.* Retrieved From: https://www.zillow.com/ca/home-values/.