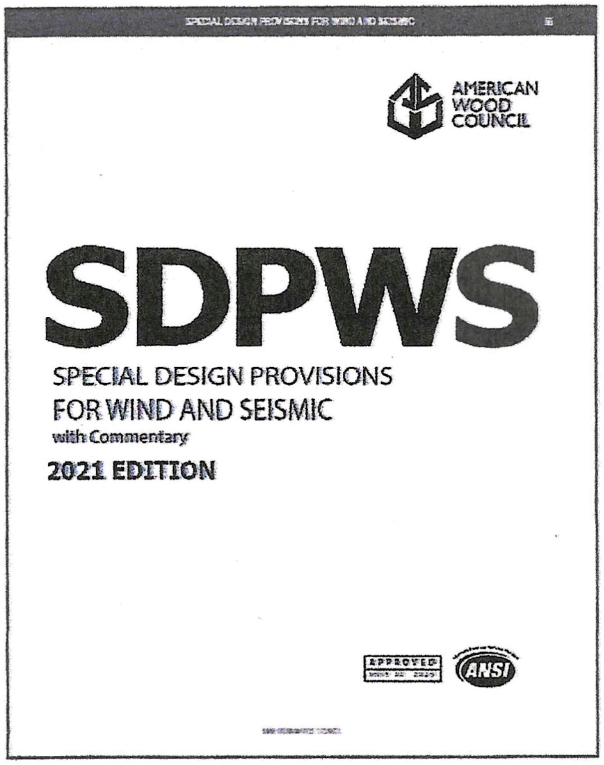
Quantification of Building Seismic Performance Factors Following FEMA P695: New Proposed System of Light-Frame Shear Walls Using Climate Adhesive

Adhesive attachment of shear wall sheathing in Current Provision



SPECIAL DESIGN PROVISIONS FOR WIND AND SEISMIC

AMERICAN WOOD COUNCIL

SDPWS

SPECIAL DESIGN PROVISIONS FOR WIND AND SEISMIC

with Commentary

2021 EDITION

APPROVED

ANSI

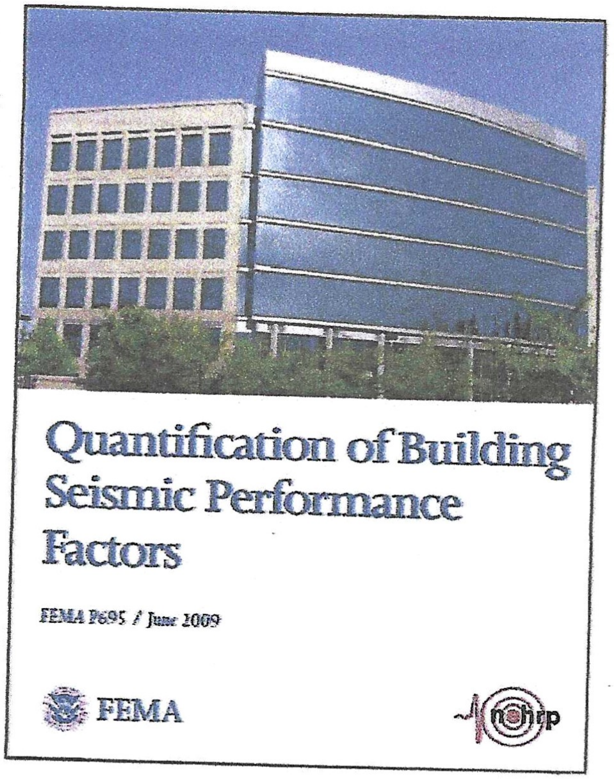
Special Design Provisions for Wind and Seismic (SDPWS) is a set of provisions developed by the American Wood Council (AWC) that cover material, design, and construction of wood members, fasteners, and assemblies to resist wind and seismic forces. The SDPWS provisions state that adhesive attachment of shear wall sheathing shall not be used alone or in combination with mechanical fasteners. The exception is that an approved adhesive attachment system shall be permitted for wind and seismic design in Seismic Design Categories A, B, and C, where $R = 1.5$ and $\Omega_0 = 2.5$, unless other values are approved.

Adhesive attachment of shear wall sheathing is generally prohibited unless approved by the authority having jurisdiction because of limited ductility and brittle failure modes of rigid adhesive shear wall systems that were reported by Filiatrault, A. and R. O. Foschi, Static and Dynamic Tests of Timber Shear Walls Fastened with Nails and Wood Adhesive, 1991. Therefore, if adhesives are used to attach shear wall sheathing, increased strength and potential for brittle failure modes corresponding to adhesive or wood failure should be addressed.

Current research has found that the current SDPWS provisions are highly restrictive and result in over-conservative designs for a newly developed adhesive (**CLIMATE™**). Therefore, this work presents an experimental and numerical investigation to propose new, less restrictive seismic performance factors for wood frame buildings following the FEMA P-695 guidelines.

Seismic performance factors (SPFs) are relevant when designing modern earthquake-resistant structures. They provide a first approach to estimating strength and displacement demands on structural systems designed with linear elastic methods, which is expected to behave nonlinearly during moderate to severe earthquakes. SPFs represent a simple tool for researchers and practitioners of structural engineering and are included in most seismic standards worldwide. SPFs represent the response modification factor R, the system overstrength factor Ω_0, the deflection amplification factor C_d, or the maximum allowable story drift Δ_{max}.

FEMA P-695



Quantification of Building Seismic Performance Factors

FEMA P695 / June 2009

FEMA

nehrp

The purpose of FEMA P-695 methodology is to provide a rational basis for determining building seismic performance factors that, when implemented correctly in the seismic design process, will result in equivalent safety against collapse in an earthquake, comparable to the inherent safety against collapse intended by current seismic codes, for buildings with different seismic-force-resisting systems. As developed, the following fundamental principles outline the scope and basis of the Methodology:

- It is applicable to new building structural systems (i.e., Shear wall systems of sheathing attached with climate adhesive).
- It is compatible with the National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (FEMA, 2004a) and ASCE/SEI 7, Minimum Design Loads for Buildings and Other Structures (ASCE, 2006a).
- It is consistent with a basic life safety performance objective inherent in current seismic codes and standards.
- Earthquake hazard is based on Maximum Considered Earthquake ground motions.
- Concepts are consistent with seismic performance factor definitions in current seismic codes and standards.
- Safety is expressed in terms of a collapse margin ratio.
- Performance is quantified through nonlinear collapse simulation on a set of archetype models.

FEMA P695 Methodology Steps

The steps comprising the Methodology are shown in Figure 1. These steps outline a process for developing system design information with enough detail and specificity to identify the permissible range of application for the proposed system, adequately simulate nonlinear response, and reliably assess the collapse risk over the proposed range of applications. Each step is linked to a corresponding chapter in the FEMA P695 report and described in the following sections. The following is a summary of the main line of the Methodology:

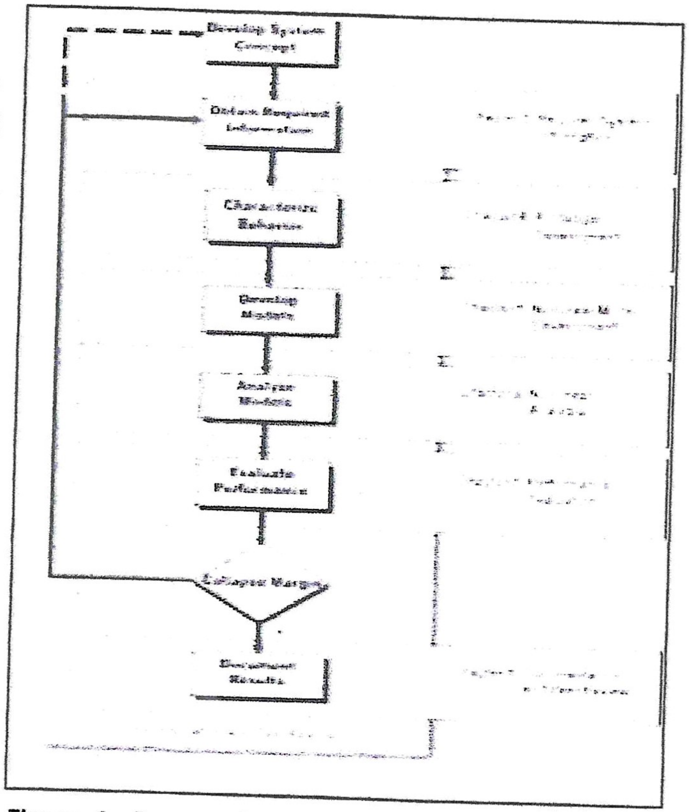


Figure 1: Process for quantitatively establishing and documenting seismic performance factors

Archetype Definition

Define the building archetypes and create representative models, incorporating the new adhesive light-frame shear system.

Ground Motion Selection

Identify and select ground motion records representing the seismic hazard at various intensity levels.

Nonlinear Structural Analysis

- Conduct nonlinear response history analyses for each archetype and ground motion set.
- Evaluate the performance of the adhesive light-frame shear system during seismic events.

Collapse Assessment

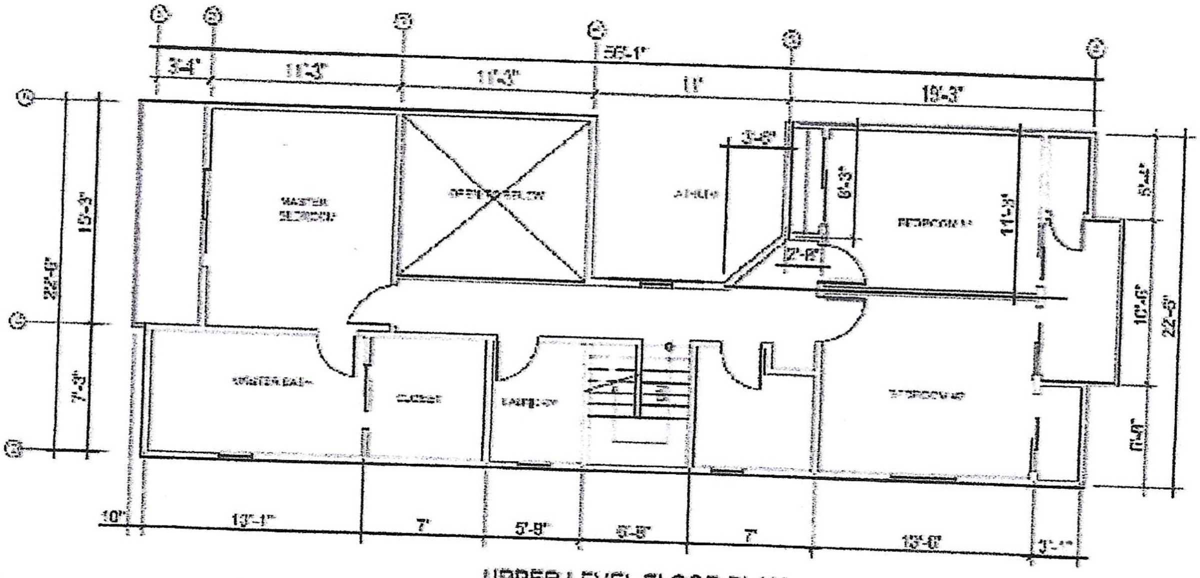
- Estimate the collapse fragility function by analyzing the results of the nonlinear structural analyses.
- Determine the probability of collapse as a function of seismic intensity.

System Performance Evaluation

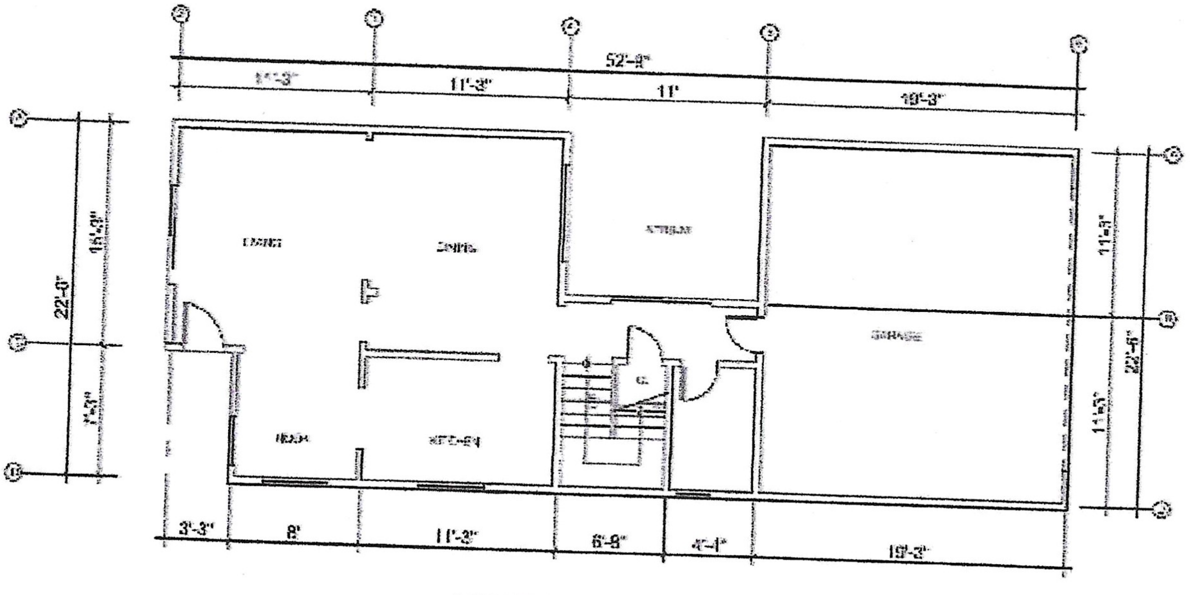
- Calculate the structural performance factors (response modification, deflection amplification, and system overstrength factor) for the new adhesive light-frame shear system.

Implemented procedure of FEMA P-695

Archetype



UPPER LEVEL FLOOR PLAN



LOWER LEVEL FLOOR PLAN

Figure 2: Floor plans for the Archetype structure

Ground Motions

Twenty ground motion records were used to perform the incremental dynamic analysis for the structure archetype.

Design Parameters

The structure is assumed to be analyzed with Max. Seismic design Category (SDC_{max})

Incremental Dynamic Analysis (IDA)

Fragility analysis curve

The seismic weight of the structure was found to be 438 kips to meet the requirement of the response modification factor (R) =5.

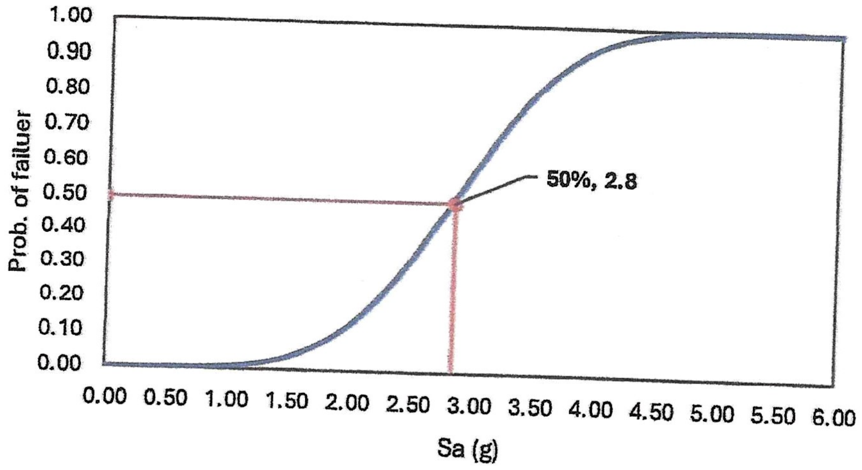


Figure 5: Collapse fragility curve for nails Adhesive archetype.

Adjusted Collapse Margin Ratio

The ductility for the Adhesive archetype was 3, so SSF is determined to be 1.18.

$$CMR = \frac{S_{CT}}{S_{MT}} = \frac{2.8}{1.5} = 1.89$$

$$ACMR = 1.89 \times 1.18 = 2.23$$

Total System Collapse Uncertainty

Considering the following conditions, the total system collapse uncertainty (β_{TOT}) can be determined from tables 7-2a to 7-2d.

1. The model quality (B) Good.
2. The quality of test data (B) Good.
3. Quality of design requirement (B) Good.

So, from Table 7-2b, $\beta_{TOT} = 0.525$.

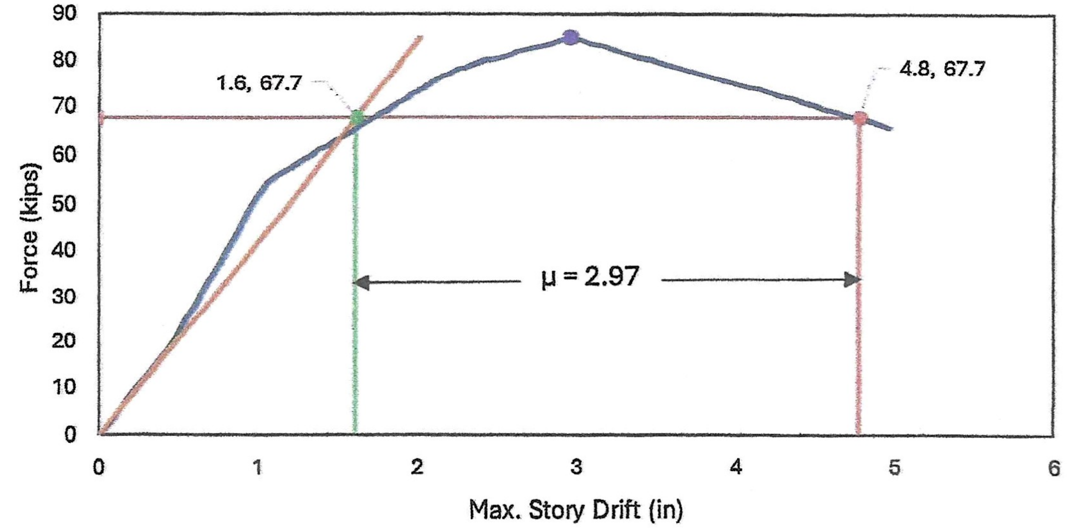
Table 7-3 provides the acceptable values of the Adjusted Collapse Margin Ratio. For $\beta_{TOT} = 0.525$, the acceptable $ACMR_{20\%}$ is 1.56.

$$ACMR \geq ACMR_{20\%}$$

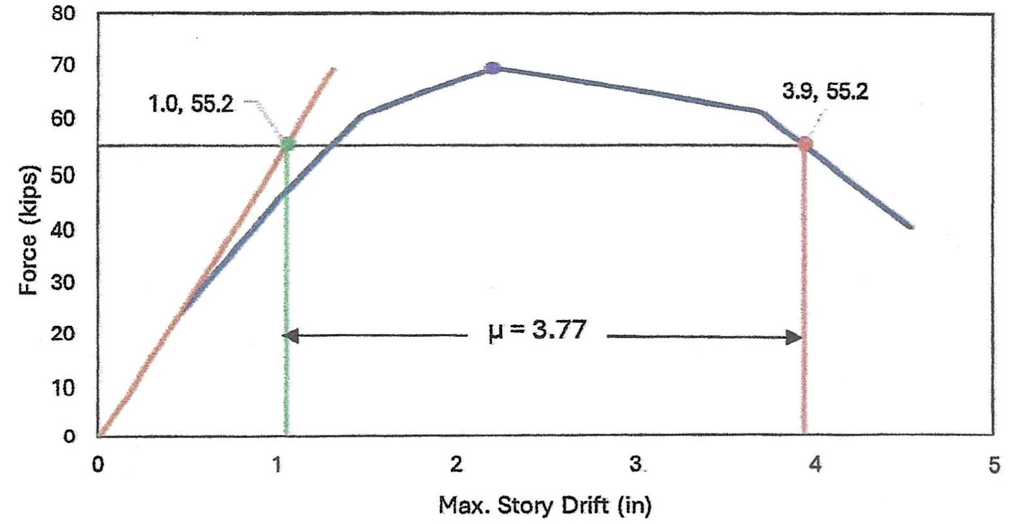
So, the archetype is passed.

Adhesive Archetype

The pushover analysis for the adhesive structure archetype (shear wall properties) shows structure ductility of 3 in the X-direction and 3.7 in the Y-direction. The overstrength factor was determined to equal 4.8~5.



(a)



(b)

Figure 4: Pushover analysis curve (adhesive archetype); (a) x-direction, (b) y-direction

The design spectral response for the short period (SD_s) = 1.0 g. (Table 5-1A).

The design spectral response for 1 second period (SD_1) = 0.6 g. (Table 5-1B)

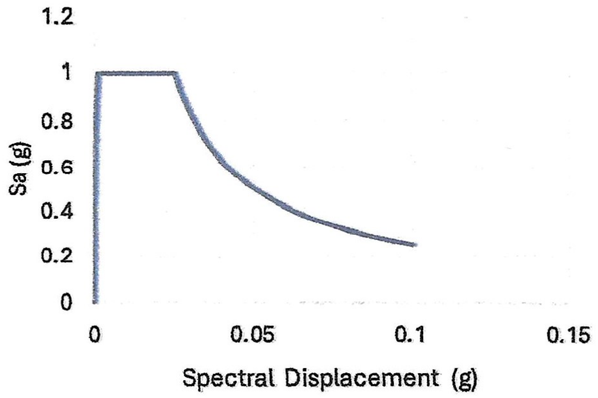
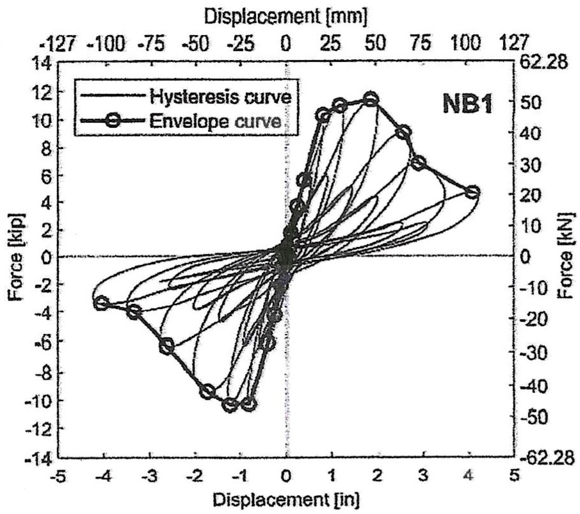
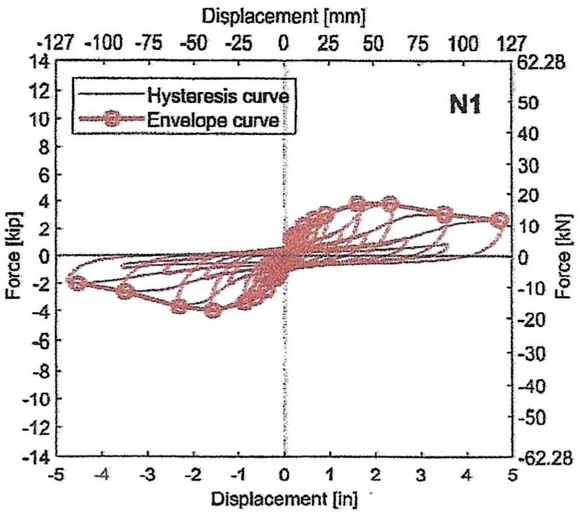


Figure 3: Plots of design earthquake (DE) response spectral acceleration of Seismic Design Category D structure archetype.

Test data of climate adhesive shear walls



Adhesive &Nails shear wall



Nails only shear wall

Nonlinear Static Analysis (Pushover)

The pushover analysis was performed for the archetypes to determine the ductility and overstrength factors. SAP2000 software was used to simulate the structure model and perform the results.

Conclusion:

Using FEMA P695 to demonstrate that a new adhesive (Climate) can achieve altered response modification coefficients $R = 5$ rather than 1.5 and overstrength factors $\Omega_0 = 5$ rather than 2.5 could significantly impact the design of wood structures positively in several ways:

1. **Increased Safety and Reliability**: By proving that the new adhesive allows for higher values of R and Ω_0, it is demonstrated that structures using this adhesive can withstand larger seismic forces than previously estimated. This results in improved safety and reliability of structures in seismic zones, potentially reducing the risk of structural failures during earthquakes.
2. **Design Flexibility**: Higher R values indicate better energy dissipation during seismic events, which could allow for more flexible design options. Structures might be designed with less conservative approaches while meeting or exceeding safety requirements. This could lead to more efficient use of materials and potentially more innovative architectural designs.
3. **Cost Efficiency**: Increasing the $\Omega 0$ factor means that the structure can reliably withstand greater forces than initially designed for, possibly reducing the amount of over-design typically required. This could lead to cost savings in materials and construction by optimizing the use of the adhesive in structural connections.
4. **Enhanced Performance During Seismic Events**: Higher R and Ω_0 values generally correlate with better performance during seismic events, meaning that buildings can sustain less damage and require fewer repairs post-earthquake. This enhances the building's overall resilience and reduces maintenance and repair costs.
5. **Code Compliance and Innovation Adoption**: By following FEMA P695, which is a methodology for quantifying seismic performance and demonstrating improved performance characteristics, there is a stronger case for code bodies to accept and integrate new materials or methods into building codes. This could lead to broader adoption of innovative materials like the new adhesive being researched, setting a new standard for seismic design in wood construction.

Overall, proving that a new adhesive can achieve higher $R$and Ω_0 values showcases its potential for improving seismic resilience and paves the way for its inclusion in future editions of design codes like SDPWS, enhancing the structural design landscape.