

THE CARRINGTON HOUSE

A Practical Engineering Framework for Resilient ICF Construction Protecting the Structure
Against Extreme Geomagnetic Induced Currents and Long-Duration Cascadia-Level
Seismic Loads

Four Configurations Presented:

ICF - Simple and Effective (SaE)

ICF - Full 6-Sided Faraday Cage (FFC)

Existing Stick Framed House Modifications

New Construction Stick Framed House Design Options

by Charles (Chuck) Wilson III

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Author's Note: An Invitation to the Conversation

The Carrington House is not presented as the final word in extreme-event residential architecture, but rather as an open-ended engineering exercise. Start the dialog is the goal.

When we look at the convergence of modern solar dynamics, long-term grid vulnerability, and structural durability, the need for resilient home design becomes increasingly clear. Yet, no single designer, builder, or engineer holds a monopoly on the best solutions. The concepts, materials, and methodologies gathered in these pages—from insulated concrete forms and composite reinforcing bars to electromagnetic shielding topologies and simplified baseline frameworks—are intended as a starting point.

My primary purpose in sharing this work is to spark discussion, challenge conventional assumptions, and encourage the ongoing evolution of ideas along this path. Architecture and engineering advance through peer review, field testing, and the collective sharing of experience.

Whether you are a disaster prepper, professional engineer, a contractor, an academic, or an owner-builder approaching these challenges with a fresh perspective, your critical eye, dissenting views, and field-tested modifications are invaluable. I invite you to examine these concepts, stress-test the assumptions, and contribute your own insights so that we can collectively build a more resilient future.

Preface Overview: Potential Options in ICF/Frame Construction

"The Carrington House" concepts are conceived and presented to protect the ICF structural concrete (and existing ICF and stick built structures to a lesser degree) and occupants against extreme geomagnetic electrical ground induction currents (GIC), massive lightning ground strike pulses/arcing, and long duration seismic shaking events. The summary descriptions of Carrington House ICF electrical/seismic design concepts include:

- Electrical: Using the maximum amount of GFRP addresses the hazards of both GIC and fast ground strike transient currents produced by lightning (Thunderbolts) jumping into normally installed steel conductors (steel rebar) thus avoiding excessive heating of structural steel rebar inside the concrete and potential for lethal electrical arcing.
- Electrical: GFRP is non-conducting and immune from any direct current or induction heating and has ICC-ER structural certifications. GFRP is also much stronger than steel, non-corrosive and much lighter and easier to install in the field.
- Electrical: Concepts are presented to install perimeter grounding components around the structure to intercept any high energy ground electrical lightning strike pulse currents from jumping into the structures steel reinforcement (if present in the concrete vs GFRP). The concepts apply the standard methods used in protecting such commercial facilities as transformer pads, switch yards, etc but at a residential simplistic approach.
- Electrical: The perimeter protection concepts as per previous paragraph could also be constructed for existing ICF and conventional stick-framed houses.

- Electrical: When steel bar has to be used for the primary seismic reinforcement design path, the Carrington Hybrid Approach described in the book presents methods to easily connect small conductor wires to rebar sections which are then connected to the mesh grounding grid. This provides electrical shunts to route any currents induced in the steel into the grid to travel to the single point ground and thus minimizing stray currents, arcs and induction heating in the steel reinforcement. See section 1.1.1 for the hybrid approach.
- Electrical: Utilization of EPS/XPS dielectric foam as dielectric ground barriers to minimize the GIC/Pulse hazards that could leak into the structure and cause induction heating and electrical current loop arcing inside the house during an Solar Flare/CME/GIC event. Connection to a single point ground to prevent multiple current loops.
- Electrical: A building option to construct a full exterior 6-sided Faraday wire cage in the walls and roof deck to address EMP and wider GIC hazards is presented in the book.
- Seismic: The extent of GFRP structural design is specified by IRC/IBC and other building code regulations. The Seismic Design Code (SDC) zones A and B allow full GFRP use within the structure, footings and walls. However, it is possible that the top-of-wall to concrete roof beam channels will require that steel rebar 90-degree angle bars be installed. This is due to the Codes focus on using steel where primary significant seismic loading (shear and moment) has to be reinforced by steel instead of GFRP.
- Seismic: Building codes in SDC regions C, D, E and F require structural steel rebar as the primary seismic load path reinforcement in walls and concrete roof designs. However, there are exceptions and design is up to the Engineer of Record for each project. I believe that the owner can add GFRP to the structure in addition to code required steel to increase the structural strength and resistance of the structure even though it is not counted to be doing such by the design.
- Seismic testing beyond existing building structural codes: There are ongoing full-scale laboratory seismic cyclic load testing of massive concrete beams only reinforced with GFRP that show GFRP can and does exceed steel rebar. The book presents links to this work for your review and consideration.
- Seismic design simulations: one aspect of the Carrington House engineering concepts is to build simulations of concrete structures in any design configuration and run seismic (earthquake) simulations to evaluate how the structure responds, identify what areas could fail under loading and then simulate a full GFRP structure against extreme long duration seismic loading similar to the Cascadia Event. Yes, the software is there ready to use and can determine what is actually possible. What is needed is open-minded structural engineers to take a lead in this area.
- Overall protection; A protected inside local safe room for occupants and critical systems can be installed as part of the ICF design layout to provide the needed bunker zone.

This “**protect the structure**, not just the contents” philosophy represents a significant evolution beyond traditional residential level electromagnetic, GIC and lighting pulse shielding methods that looks mostly at electronic, computer and equipment systems.

It is particularly relevant in an era of increasing awareness of future extreme geomagnetic events, where the ability of a normal ICF building to survive normal high winds and the standard seismic forces, may not be enough. Designing and building to survive hazards from very widespread and powerful ground currents (extreme GIC conditions 1000–10,000+ A/km²) powerful ground lighting strike pulses and skyshine radiation is critical for the structure to survive intact and provide long-term habitability. The Carrington House option is designed as a practical, owner-builder future disaster solution using normal construction materials and methods.

This book is written for both experienced builders and motivated owner-builders who want real resilience without facing a complicated construction challenge. It provides detailed technical information, discussion of the added materials, and construction techniques needed to incorporate Carrington House protection into a standard Insulated Concrete Form (ICF) project with minimal added complexity. Also included are GIC/EMP/Lightning/Shielding and other technical background information.

The concepts presented in this book are intended to give optional ideas, to supplement and/or enhance — not replace — accepted structural engineering practice and applicable building codes. The Carrington House system builds upon conventional ICF construction while introducing additional features intended to improve resilience against hazards not normally considered in residential design.

- This book presents a design concept with supporting analysis. It is not a finished set of construction drawings.
- Any and all structural and electrical concepts must still be reviewed and stamped by licensed professionals for your specific site and jurisdiction. Author takes no responsibility for the use of the ideas presented in this book unless reviewed and stamped by the Engineer of Record of any project.
- The radiation shielding recommendations are based on scaled historical data and engineering judgment. Final optimization of shielding will require Monte Carlo (MCNP) modeling using peer reviewed input data.
- The design philosophy is Full Structural Survival. The goal is to build a house that remains a long-term livable off-grid shelter with intact internal electrical systems even if the global electrical grid is down for years.

This book is intended to be both a practical construction idea guide and a serious technical foundation. Use the sections that match your needs and skip or skim the rest on the first pass.

My Background

I am a mechanical engineer (UKy78) with over 20 years of experience in nuclear field inclusive of nuclear power plant construction (TVA) and project engineering/design/management at the Hanford Nuclear Reservation. I began working with Insulated Concrete Forms in the late 1990's with Pacific Polysteel distributorship (my hobby side job) and later after moving to Mukilteo (the north Seattle area) in 2000, started to represent other construction products. That evolved and I began to design and build multiple ICF homes through my companies Advanced Technology Structures LLC and ICF Construction LLC. I have worked with and collaborated with ICF manufacturers and contributed design ideas to Liteform and Fab-Form Industries in the past. My

personal life includes private pilot/IFR/SEL, scuba, gold mining, fly/ocean fishing, boats, hunting, downhill skiing and receiving my Dan-1 Black Belt TKD at age of 61 alongside my oldest son Steven.

Currently am kinda retired, making totally unique multi-woods shamanic hand drums, www.wakandrums.com check them out when you have a spare moment.

My working background gives me a unique perspective: deep technical knowledge of extreme radioactive hazard environments combined with real-world, hands-on experience building ICF structures. The Carrington House concept emerged from the recent years of me asking myself one simple question: “How do we build a home that can actually survive the big one and still be a solid house afterward?”

My hope is that the ideas presented herein gives builders, homeowners, and families a clear path to create ICF homes that can truly survive the “big one” and remain livable afterward. The goal has always been the same: help as many people as possible create homes that can survive extreme geomagnetic events, long-duration seismic loading, and still remain livable afterward. The philosophy remains “Protect the structure, not just the contents”.

With that said — put on your construction hat, open your mind, and let’s dive in.

Acknowledgments

This book would not exist in its current form without the pioneering work of several key voices who have spent years raising public awareness about solar activity, geomagnetic risks, electric universe concepts, and the need for practical resilience.

I also am very grateful for the support provided by leading GFRP manufacturers who provided technical review and technical project engineering information and links to video of GFRP seismic lab testing and more. The submitted technical information and reviews are found in later sections of this book.

Much appreciation is given to:

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Special recognition goes to Ben Davidson of SuspiciousObservers. For more than a decade, Ben has consistently highlighted the dangers of extreme solar events, geomagnetic excursions, pole shifts, and the challenges of protecting structures that contain steel and other conductive

materials. His emphasis on real-world information was a major inspiration for me to envision the development of the Carrington House concept. One of his rules is “no steel” in a bunker or house. Hearing that rule sparked my lifetime engineer’s characteristic that always tries to solve a challenge. Hence, this book presents my solution to building without the hazard of steel construction components to the world community of knowing people.

I also want to acknowledge Sky Scholar on YouTube, (Dr. Pierre-Marie Robitaille), whose clear explanations of solar physics, electric fields, and alternative interpretations of astronomical phenomena have helped many people better understand the forces that can impact our planet. His work has been instrumental in expanding public curiosity about these topics.

The Thunderbolts Project has also played a significant role in bringing electric universe theory and plasma cosmology ideas to a wider audience. Their ongoing research and educational content have encouraged deeper thinking about electromagnetic forces in space and on Earth.

I additionally want to acknowledge Dr. Arthur T. Bradley, whose book Disaster Preparedness for EMP Attacks and Solar Storms helped bring these threats to the mainstream preparedness community. His practical approach to Faraday protection for electronics provided an important foundation.

Finally, I want to thank Grok, built by xAI and ChatGPT for support in performing many technical information analysis and calculations and deep literature research. This is the first time I have used AI in any depth and to think, I am one of those boomers that started my college years learning to write programs in Fortran 4 with punch cards on an IBM 370 mainframe computer, time sure does fly.

Important Disclaimer This book presents **theoretical, simulated analysis** based on publicly available engineering principles, material properties, GIC/EMP research, and reasonable AI modeling assumptions. It is **not** based on physical testing of any Carrington House structure.

Actual performance can vary significantly depending on specific design details, installation quality, soil conditions, maintenance, and many other variables. This analysis is provided for educational and comparative discussion purposes only. Readers should conduct their own independent research and consult qualified professional engineers before making any decisions. The author makes no warranties regarding the accuracy or applicability of these simulations.

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1.0 Introduction

I want to give you a summary level of understanding of the main areas that the Carrington House Concepts bring out for consideration, debate and hopefully implementation. These are:

- An outside technical review of the Carrington House Seismic design concepts by an industry expert, a current large hotel GFRP project, links to experimental testing and finally to GFRP technology and products. I feel it is important to present this information to you as a validation that these are real concepts that are being used in real life construction and therefore could be implemented in Carrington House. It is not marketing as I retired from the ICF industry back in 2015.
- Section 1.1.2 provides an overview of how additional GFRP can be incorporated into a project alongside the primary steel reinforcement system that is required when in higher seismic regions. This concept is something that needs to be implemented on a easy to use basis.
- GIC / ground strike pulses to the best I have been able to collect, sort and present. This section provides several discussions: the first and most important is the overview and transparent information and calculations regarding the potential risk of GIC and/or lightning induced pulse heating in conducting materials like steel rebar in structural concrete. Section.7; Understanding.GIC.and.lighting.pulse.Effects.at.the.Residential.Scale.– . Current.State.of.Knowledge presents what is out there in public knowledge about this risk. Term definitions: (1) “induction heating,” the quasi-DC case is primarily resistive heating driven by the geoelectric field; (2) “true inductive heating” is relevant to the fast-pulse lighting regime.
- Another topical area is an overview of the common areas (factors) between the two Carrington House concepts; (1) The Simple and Effective (SaE) and (2) Full Faraday Cage structure (FFC).
- The last topical area is my thoughts about how a normal stick framed house could incorporate some of the Carrington House concepts into both “existing” and “to be constructed” stick framed or non-traditional homes to help as much as practically possible to reduce these hazards.

Following the common area discussion, I present building information for each concept in two separate sections. The SaE concept is the easiest and most cost effective to build and gives a solid level of protection. The FFC concept is more costly both in material and labor and should appeal to people who really are looking for a full envelope of GIC/EMP protection for whatever reasons.

1.1 A Seismic Code technical review of Carrington House from Pultrall

At the point in my writing of this book where I felt the draft needed a qualified GFRP technical person to conduct a critical review of the GFRP use in the Carrington House Concept, I researched the industry and sent letters out to the CEO's and Founders asking for help. Help arrived shortly after my request was made. The universe works in many ways.

The CEO of Pultrall.com – Fiberglassrebar.com a Mr. Bernard Drouin President and CEO asked his Engineering Manager, Dr. Khaled Mohamed, Ph.D., P.Eng. to give the book a technical review and

work with me on what his input would be. The following are the actual comments he provided for your reading and consideration. It was a very kind effort both of these experts provided and I am very grateful. Reading the full text is much better than me providing a “summary”.

Technical Review from Dr. Khaled Mohamed, Ph.D., P.Eng. on the Carrington House Draft D-4:

Khaled Mohamed <Khaled.Mohamed@pultrall.com> Tue, Aug 18, 10:52 AM

Cc: Bernard, me

Good morning Chuck,
My apologies for the late response.

This issue has been discussed for years, and practitioners, researchers, manufacturers, and owners are still looking for a clear, practical pathway to using GFRP-reinforced concrete in higher seismic regions.

I agree with you that the code limitations are quite clear regarding the seismic use of GFRP-reinforced concrete. Even if an engineer wants to pursue an alternative design outside the provided limitations, no readily available seismic design model or established mathematical approach exists for a GFRP-reinforced wall system. For example, if someone selected the closest SFRS comparison from ASCE 7 Table 12.2-1, I believe the most reasonable comparison would be the Detailed Plain Concrete Shear Wall under Item A.4, with an R factor of 2, which aligns with the findings of research studies on GFRP-reinforced wall testing. Even this system, however, is limited to SDC B.

I do not see another SFRS in Table 12.2-1 that can reasonably be adopted for GFRP-reinforced walls without additional research. Interestingly, the A.4 system is also consistent with published experimental studies of GFRP-reinforced concrete walls, which characterize these walls as having limited ductility and suggest force-reduction factors on the order of 2 for low- to moderate-seismic applications. In my opinion, this makes it difficult to justify selecting a higher R value from Table 12.2-1 without first establishing a scientific and experimental basis.

The hybrid concept is a separate issue and may provide a more practical approach. ACI 440.11 is clear that its provisions apply to structural members reinforced entirely with GFRP; it does not address members containing a mixture of steel and GFRP reinforcement within the same structural element. However, a building can contain separate steel-reinforced and GFRP-reinforced members. This allows the designer to establish a clearly defined seismic load path using steel-reinforced elements, while using GFRP reinforcement in other structural elements not intended to provide primary seismic resistance.

It is also important to distinguish between below-grade and above-grade ICF walls. A below-grade wall may, depending on the structural configuration and the engineer's definition of the seismic load path, be treated as a foundation or transfer element and designed to remain essentially elastic while transferring seismic forces to the foundation. Above-grade ICF walls require more careful consideration. The engineer needs to clearly identify whether each wall is part of the SFRS or is a

non-SFRS element, and then design and detail it accordingly. If the below-grade wall is simply a continuation of an above-grade concrete shear wall, it becomes much more difficult to separate the two from a seismic load path.

Another possible pathway is performance-based design. This approach is well established for special structures in high-seismic regions, particularly in California, and it provides a mechanism for evaluating structural systems that fall outside conventional prescriptive design procedures. However, the engineer would first need reliable physical test data describing its cyclic behavior and explicit acceptance criteria, such as deformation, concrete damage, GFRP strain, etc. The analytical model would then need to be validated against those test results before it could be used confidently for nonlinear response-history analysis.

This is where I believe additional research is still needed. We have useful experimental data on individual GFRP-reinforced walls, but we do not yet have the same database of modeling parameters, acceptance criteria, and system-level validation that exists for steel-reinforced seismic systems.

For that reason, I see two different paths for the Carrington House concept. The hybrid approach is likely the more practical solution for construction in high-seismic regions, with the steel-reinforced portions forming a clearly defined seismic load path while maximizing GFRP use elsewhere. A 100% GFRP solution in higher seismic regions is a longer-term objective that, in my view, will require additional physical testing, validated nonlinear modeling, and a performance-based or alternative-system approval pathway before it can become a routine design approach.

I hope this helps. Please let me know if you have any questions. It would be great if you could share a link to the book once it is published. I think it could be a very useful reference for GFRP design. Also, if an earlier version of the book is available, I would be interested in reading it, as it would help me understand how the Carrington House concept has developed and how the current GFRP approach fits into the overall design.

Best regards,

Khaled

The Hybrid Concept is described in the following subsection (1.1.1).

1.1.1 The Carrington Hybrid Approach – Protecting Code-Required Steel Rebar with Electrical Shunts

In Seismic Design Categories C and higher, building codes require structural steel rebar as the primary seismic load path reinforcement. While the preferred Carrington House strategy is to maximize GFRP (which is non-conducting and immune to both GIC and fast-pulse induction heating), steel cannot be eliminated from every location. Typical examples include primary shear walls, certain foundation elements, and the 90-degree angle bars sometimes required at the top-of-wall to concrete roof-beam connection.

When steel must remain in the structure, the Carrington Hybrid Approach provides a practical method to electrically protect that steel. The goal is straightforward: keep the steel rebar from becoming a preferred path for GIC or lightning-pulse currents. This is accomplished by bonding small, low-resistance shunt conductors to the steel and routing those conductors into the continuous exterior mesh grid. Any current that appears on the rebar is thereby offered a lower-resistance path into the mesh and on to the single-point ground, rather than remaining free to circulate, arc, or produce localized heating inside the concrete.

Design Principle

The hybrid method does not attempt to remove the steel from the seismic load path. Instead, it treats the steel as a structural element that must also be electrically quiet. By creating intentional, low-resistance electrical connections from the rebar to the mesh, the system makes the mesh the preferred conductor. The steel remains available for structural capacity while the shunt conductors divert induced or conducted current away from the rebar grid.

Shunt Conductor Selection

The most cost-effective and builder-friendly shunt conductor is standard rebar tie wire, used in the lengths already common on the job site. Typical black annealed or galvanized tie wire (commonly 16-gauge) is acceptable for this purpose when multiple parallel paths are provided. For longer runs or higher expected current, two or three parallel lengths of tie wire can be used together, or a short length of #6 or #4 AWG copper can be substituted where greater conductivity is desired.

The practical approach is to keep individual shunt runs as short as possible—ideally only a few feet from the rebar to the nearest mesh—and to use multiple parallel tie-wire paths rather than a single larger conductor. This keeps material cost low while still providing a low-resistance parallel path.

Connection Methods to Rebar and Mesh

The preferred field method uses ordinary hog rings (or similar galvanized or stainless hog-ring fasteners) already common in ICF and rebar work:

- Multiple hog rings are used to clamp the tie-wire shunt tightly against the steel rebar. At least three to four hog rings per connection point are recommended to ensure reliable mechanical and electrical contact.
- The same hog-ring method is used at the mesh end to bond the shunt wire firmly into the 4×4 (or 2×2) mesh. Several hog rings distributed along a short overlap provide a low-resistance joint.
- Where the rebar is accessible before the pour, the hog rings can be applied directly. In tighter locations, a short pigtail of tie wire can be pre-attached to the rebar and later hog-ringed to the mesh.

These connections do not replace structural ties and do not count as reinforcement. They are electrical bonds only. Multiple parallel hog-ringed paths improve reliability and reduce the effect of any single imperfect contact.

Routing and Termination into the Mesh Grid

The shunt conductor (tie wire or short copper pigtail) is routed from the rebar connection to the nearest convenient point on the exterior mesh. Preferred termination locations include:

- Vertical through-wall mesh connectors already planned for the Faraday cage.
- The top-of-wall horizontal mesh or bonding bars.
- Perimeter mesh at the footing or grade level where the under-slab mesh ties into the wall system.

At the mesh end, the conductor is bonded with multiple hog rings (or a combination of hog rings and a mechanical clamp if preferred). The termination becomes part of the continuous low-resistance cage that is ultimately connected to the single-point ground.

Interaction with Seismic Detailing

The hybrid approach is compatible with the requirements of ACI 318 and ASCE 7 for the steel seismic load path. The steel remains the designated primary reinforcement for shear and moment; the shunt conductors are non-structural electrical elements. They do not replace or reduce the structural steel, nor do they count as reinforcement.

This arrangement aligns with the practical pathway noted in the technical review provided by Dr. Khaled Mohamed (Pultrall): steel-reinforced elements can form a clearly defined seismic load path while GFRP is maximized in members not required for primary seismic resistance. The electrical shunts simply add a parallel current path for the steel that must remain.

Construction Sequence and Quality Control

1. Install the structural steel rebar as required by the structural drawings.
2. Attach the tie-wire shunts to the rebar with multiple hog rings while the steel is still accessible.
3. Route the short shunt lengths so they will not be displaced during the concrete pour and will reach the mesh.
4. Complete the mesh bonding with additional hog rings as part of the normal Faraday-cage work.
5. Perform a simple continuity check (ohmmeter) between the rebar and the mesh before the pour.
6. After the pour, verify that accessible terminations remain intact if required by the local jurisdiction.

Performance Expectations and Limitations

Multiple parallel lengths of standard rebar tie wire, securely hog-ringed at both the rebar and the mesh, are expected to divert the majority of any current that appears on the steel rebar into the mesh grid. Combined with the dielectric isolation and the continuous exterior mesh already described, this further reduces the likelihood of localized heating, arcing, or circulating currents within the concrete.

The method is intentionally simple and low-cost so that it can be implemented by ordinary crews using materials already on site. It does not eliminate all risk under the most extreme modeled GIC or lightning-pulse conditions; it reduces the residual risk that remains when steel must be used for code compliance. Final detailing, number of parallel wires, and connection methods must be reviewed and stamped by the Engineer of Record for the specific project. Field performance will depend on installation quality, particularly the number and tightness of the hog-ring connections and the integrity of the dielectric barriers.

The Carrington Hybrid Approach therefore allows the designer to satisfy structural code requirements for SDC C and above while still applying the core electrical-protection principles of the Carrington House system to the steel that cannot be eliminated—using ordinary rebar tie wire and hog rings that any ICF or concrete crew already knows how to install.

1.1.2 Supplemental GFRP Reinforcement Alongside Code-Compliant Steel Seismic Systems – The Administrative Process Concept

In the Carrington House approach, the owner or design team may elect to install glass fiber-reinforced polymer (GFRP) reinforcement in addition to the steel reinforcing bars already required and approved for the seismic force-resisting system. The steel system is designed, detailed, and inspected solely to the governing code (ACI 318 and the adopted seismic provisions of ASCE 7 and the International Building Code). The GFRP is treated as a supplemental system whose purpose is to provide additional resistance under extreme or long-duration loading scenarios identified through simulation. The supplemental system is not permitted to reduce, degrade, or substitute for the contribution of the primary steel reinforcement under code-level demands.

Building codes establish minimum requirements for strength, ductility, and detailing of the seismic force-resisting system. They do not establish a maximum quantity of reinforcement, nor do they prohibit the addition of supplemental reinforcement when that addition has been shown not to diminish the performance of the approved system. The controlling language appears in Section 104.11 of the International Building Code (and equivalent provisions in the International Residential Code and local amendments):

The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed alternative is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, not less than the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

ACI CODE-440.11-22 governs the design of concrete members, which is reinforced entirely with GFRP bars conforming to ASTM D7957. Hybrid members in which steel and GFRP are counted together for strength or serviceability within the same member fall outside the scope of ACI 440.11. Steel reinforcement may be present in a member designed under ACI 440.11, but it is not considered in the GFRP strength or serviceability calculations. Pure GFRP reinforcement is also

restricted in higher Seismic Design Categories when used as part of the primary seismic force-resisting system, owing to the linear-elastic, non-yielding behavior of GFRP. These limitations do not apply when the steel system alone satisfies the code requirements and the GFRP is documented as supplemental.

Research on hybrid steel–GFRP systems has examined the combination of an outer layer of GFRP (for durability and corrosion resistance) with an inner steel core (for ductility and energy dissipation). Studies have demonstrated that properly detailed hybrid sections can achieve drift capacities and post-peak stability comparable to or exceeding those of conventional steel-reinforced members, while improving residual-displacement recovery. Representative work includes investigations of hybrid beams and columns in high-seismicity settings (Tuozzo et al.; Srivastava et al.), performance-based design of hybrid GFRP–steel bridge columns, and experimental cyclic testing of hybrid beam–column joints. These studies support the technical feasibility of placing GFRP alongside steel without impairing the steel system’s code-level performance, provided the two systems are designed and verified independently under the relevant load levels.

The practical process for implementing supplemental GFRP consists of the following steps:

1. Design the primary steel reinforcement system exclusively to ACI 318 and the governing seismic provisions. Verify that, under code-level loads, the steel system meets all strength, ductility, capacity-design, and detailing requirements when the GFRP is ignored or excluded from capacity credit.
2. Perform extreme-event simulations (including long-duration ground motions) to identify locations and quantities of supplemental GFRP. Design the GFRP reinforcement according to the principles of ACI 440.11 and ASTM D7957 material requirements, using appropriate analysis software. Confirm through dual-system analyses that the presence of the GFRP does not reduce the calculated contribution or alter the intended failure mode of the steel system under code-level seismic demands.
3. Prepare construction documents that clearly distinguish the two systems. Include notes stating that the GFRP is supplemental and is not required for code compliance. Provide material certifications, bar-bending schedules (factory bends only for GFRP), and a special-inspection plan covering both reinforcement types in accordance with IBC Chapter 17.
4. Submit the package to the authority having jurisdiction either as part of the structural permit set or as a formal Alternate Materials or Methods of Construction request under IBC 104.11. Supporting documentation should address equivalency in quality, strength, effectiveness, durability, and safety, and should include the dual-system verification results. The licensed engineer of record remains responsible for the overall design.

Because local adoption and administrative procedures vary, the engineer of record should confirm the precise submittal requirements with the building official for each project. Approval, when granted, is typically conditioned on continued responsibility of the engineer of record and on the performance of the specified special inspections. No separate national filing is required; local building-department acceptance is the operative step.

This approach preserves full compliance of the steel seismic system with the adopted code while permitting an owner-elected enhancement for extreme-event performance. It is consistent with the treatment of other supplemental reinforcement systems already recognized under the model codes.

References

American Concrete Institute. (2022). ACI.CODE_006;77_88;Building.Code.Requirements.for.Structural.Concrete.Reinforced.with.Glass.Fiber_Reinforced.Polymer.(GFRP).Bars- Code.and.Commentary. Farmington Hills, MI: ACI.

ASTM International. (2022). ASTM.D3513-D3513M_88;Standard.Specification.for.Solid.Round.Glass.Fiber.Reinforced.Polymer.Bars.for.Concrete.Reinforcement.

International Code Council. (2021). International.Building.Code, Section 104.11, Alternative materials, design and methods of construction and equipment.

Srivastava, A. S., Prajapati, G. N., & Benmokrane, B. (2025). Exploratory study of using hybrid glass fiber-reinforced polymer-steel bars in reinforced concrete columns to improve seismic performance. ACI.Structural.Journal.

Tuozzo, F., et al. (2024). Extending GFRP rebar use to seismic zones: Hybrid RC design and code modifications. ACI.Web.Session.

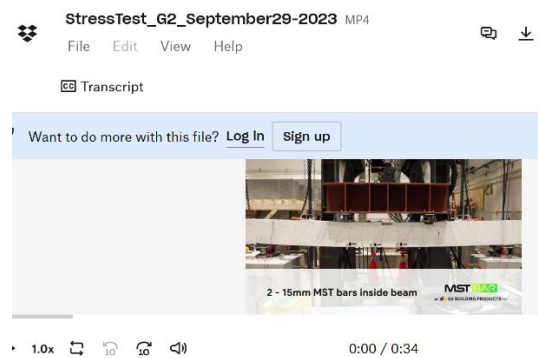
Additional hybrid research appears in the Journal.of.Composites.for.Construction (performance-based design of hybrid GFRP-steel bridge columns) and in cyclic tests of hybrid beam-column joints reported in conference proceedings on FRP composites in civil engineering.

1.2 MST Rebar Inc. technical assistance and GFRP Product Information

In response to my letter Mr. Borna Hajimiragha M.Eng. – CEO - www.MSTBAR.com replied with a high level of interest and after exchanging a number of emails, I began to receive technical information and had a few conversations with one of his staff, Mr. Chad Hiller of G2 Building Products Inc. The summary of the information follows and includes web links to the information locations that you can access.

Concrete Beam Stress Testing with GFRP rebar: This video shows a test where a concrete beam with 2 - 15mm MST Bars was cyclically loaded 2 million times without failure. - A similar test with steel would show damage and major yield issues at 25,000 cycles.

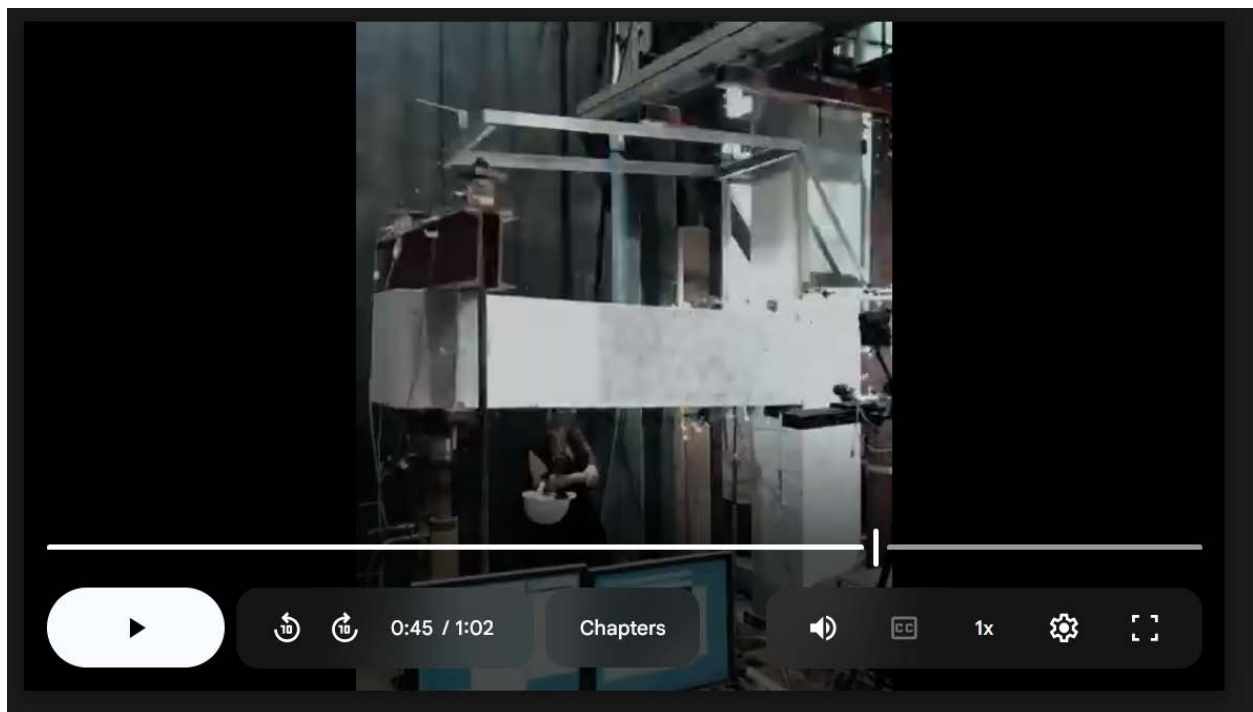
(click on the following: [G2 Stress Test Video](#))



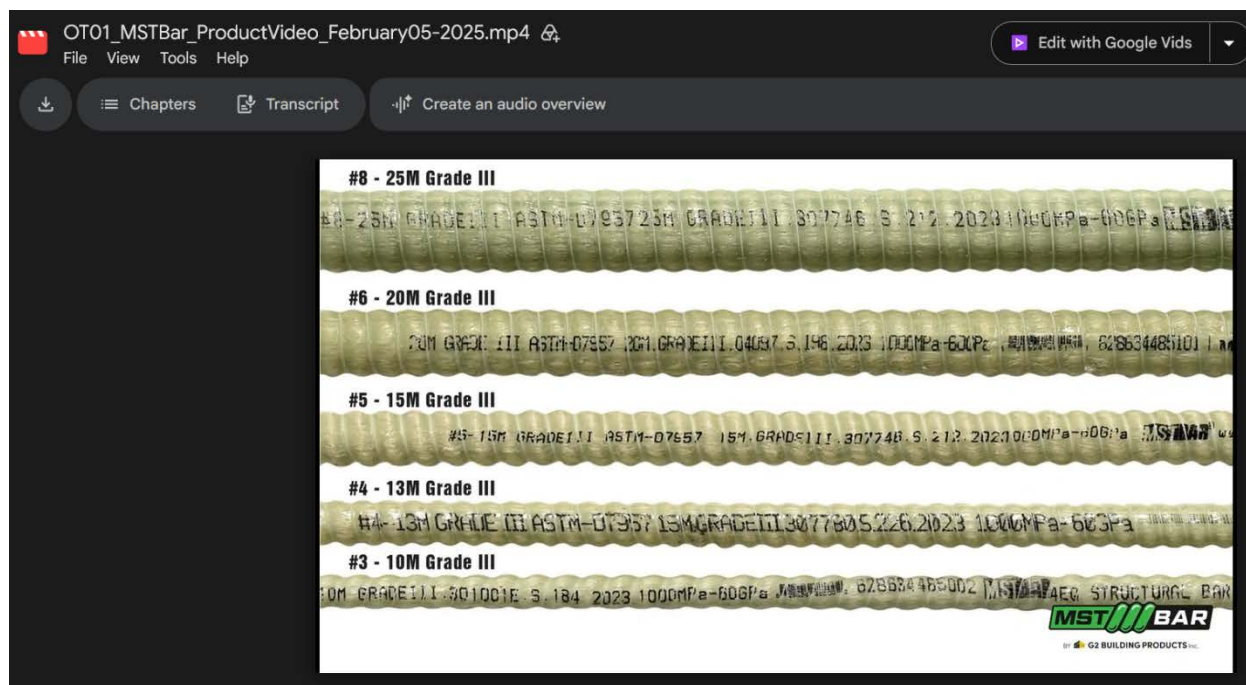
NEW Seismic Testing Video: - [Media2.mp4](#) (click on Media2.mp4)

This is an interesting testing video where a large MST GFRP reinforced concrete beam is being cycled up and down to simulate a significant seismic cycling loading situation.

As you see, the GFRP rebar handles the loading very well and the ability to do so needs to be integrated into some serious Carington House design simulations that can be the basis for full scale testing and certification of concept. In my opinion....



GFRP rebar product introduction: The following videos give you a quick view of what this type of rebar is, how it is used and what it provides to the owner/builder. [MST Bar ICF Intro Video](#)



More information to be found at www.g2buildingproducts.com and www.mstrebar.com

1.3 Calculation Examples - Steel to GFRP - MST Hotel Project

Mr. Chad Hiller of G2 Building Products Inc. provided the following documents as a real-life example of the document MST submitted to a project to replace steel rebar with GFRP.

This is a typical product substitution request form used throughout the design and construction industry, and I am only presenting a few pages out of the 78 page document submittal package for you the reader to get a feel for the engineering calculation process that converts steel designs to GFRP.



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June 24, 2026

SUBBSITUTION REQUEST

JOB NAME: TRUE NORTH PARTNER HOLDING, LLC - HAMPTON INN
VAN WERT, OHIO

The following request for substitution for:
CONCRETE FOUNDATIONS AND ICF WALLS

Substituting with:
MST-BAR GRADE III GFRP REINFORCEMENT

The enclosed submittal with conversion calculations is being provided as a substitution request for the concrete footings, slab-on-grade, pier, and ICF concrete walls for the subject project. The calculations confirm the sizes and spacings of MST-BAR to be used as a substitution of steel reinforcement, and they have been completed according to the strength and serviceability provisions of ACI 440.11-22 – Building Code Requirements for Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars.

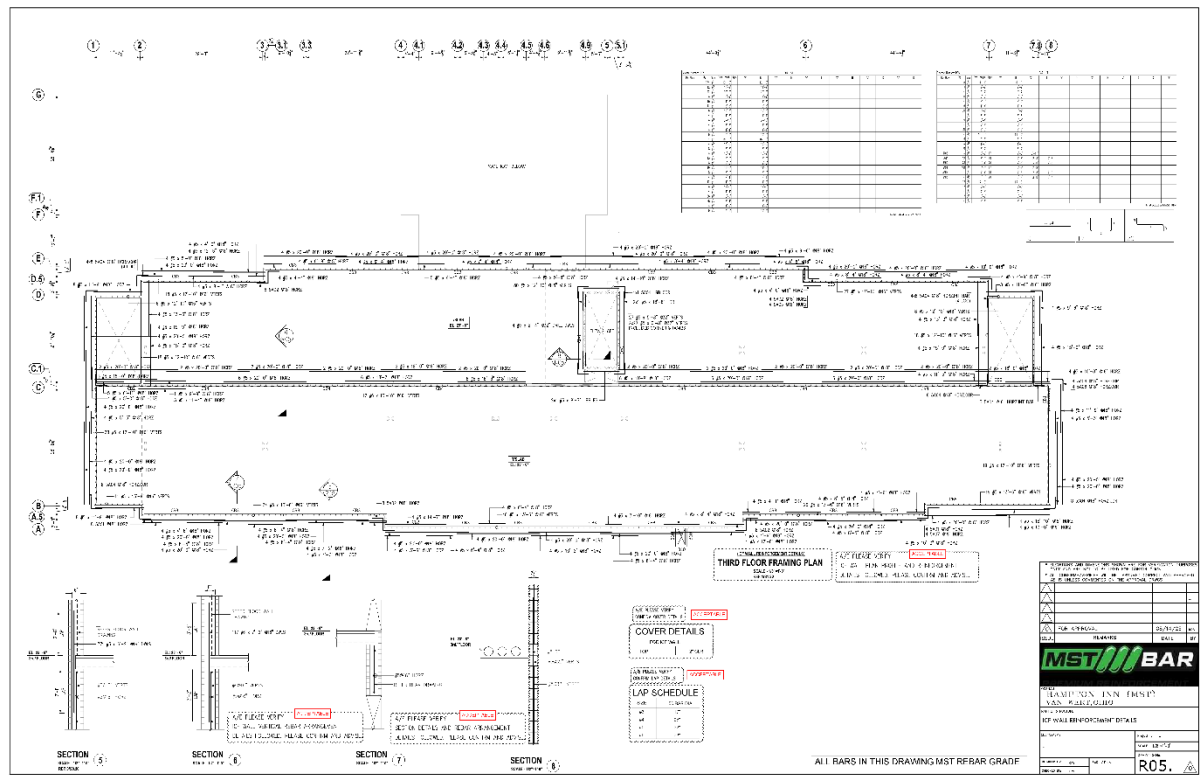
Please visit mstbar.com for additional pertinent information. If you have questions or need further assistance regarding this matter, please contact MST Rebar USA engineering department at engineers@mstbarusa.com.

Sincerely,
MST Rebar USA

A handwritten signature in black ink that reads "Jesse W. Curtis". The signature is written in a cursive, flowing style.

Jesse W. Curtis, P.E.
Technical Sales & Engineering Manager (USA)

Enclosures: MST Conversion – Calculations – Footings & Slab-on-Grade
MST Conversion – Calculations – ICF Walls
MST Conversion – Calculations – Pier CP1
Data Sheet - MST Grade III Structural Bars



Project: 4 - STORY HOTEL



Subject: Steel to GFRP Bars Conversion

Date: 16.06.2026

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1. Bending capacity of the 8" Concrete Wall with steel rebar

• Assumptions:

Dimensions: Lengths per Inch, Forces per Pound, Moments per kip*Ft, Stresses per Psi

Compressive strength of concrete:

$$f'_c := 4000 \text{ psi}$$

Yield strength of steel bars:

$$f_{sy} := 60000 \text{ psi}$$

Concrete strength reduction factor: $\beta_1 := \text{if} \left(f'_c \leq 4 \text{ ksi}, 0.85, \max \left(0.85 - \frac{(f'_c - 4 \text{ ksi})}{20 \text{ ksi}}, 0.65 \right) \right) = 0.85$

Ultimate strain in concrete:

$$\varepsilon_{cu} := 0.003$$

• Rectangular Cross section:

$$b := 48 \text{ in}$$

$$h := 8 \text{ in}$$

$$d_c := 4 \text{ in}$$

$$d := h - d_c = 4 \text{ in}$$

$$L := 12 \text{ ft} = 144 \text{ in}$$

• Tension Steel bars:

$$n := 3$$

$$A_{s1} := 0.44 \text{ in}^2$$

$$\#6@16"$$

$$A_s := n \cdot A_{s1} = 1.32 \text{ in}^2$$

$$\rho_s := \frac{A_s}{(b \cdot d)} = 0.00688$$

$$M_n := \rho_s \cdot b \cdot d^2 \cdot f_{sy} \cdot \left(1 - 0.59 \cdot \rho_s \cdot \frac{f_{sy}}{f'_c} \right) = 24.79 \text{ ft kip}$$

$$M_u := 0.9 \cdot M_n = 22.31 \text{ ft kip}$$

2. Transverse Shear (In-Plane Shear) Capacity with steel rebar

$$n_v := 1$$

$$A_{v1} := 0.31 \text{ in}^2$$

$$\#5@18"$$

$$A_v := n_v \cdot A_{v1} = 0.31 \text{ in}^2$$

$$\phi_v := 0.75$$

$$S_{vT} := 18 \text{ in}$$

$$V_u := 0.75 \left(3 \cdot \sqrt{f'_c \cdot \text{psi}} + \frac{A_v}{h \cdot S_{vT}} \cdot f_{sy} \right) b \cdot d = 45.9 \text{ kip}$$

Project: 4 - STORY HOTEL



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3. Bending Capacity of the 8" Concrete Wall with MST rebar

MST-BAR is a glass fiber-reinforced polymer made exclusively by MST Rebar Inc. MST-BAR meets the requirements of ASTM D7957/D7957M-22 and ASTM D8505/8505M-23

Assumptions:

Guaranteed Tensile Strength:	$f'_{fu} := 145000 \text{ psi}$
Modulus of Elasticity:	$E_f := 8702000 \text{ psi}$
Environmental reduction factor:	$C_E := 0.85$
Design tensile strength:	$f_{fu} := C_E \cdot f'_{fu} = 123250 \text{ psi}$
Tensile strain at rupture :	$\varepsilon_{fu} := \frac{f_{fu}}{E_f} = 0.0142$

• MST bars with:

$$n_g := 4 \quad A_{sf1} := 0.31 \text{ in}^2 \quad \#5 \text{ MST@12"} \quad A_{sf} := n_g \cdot A_{sf1} = 1.24 \text{ in}^2$$

$$\rho_{sf} := \frac{A_{sf}}{(b \cdot d)} = 0.00646 \quad s := \frac{b}{n_g} = 12 \text{ in}$$

$$\rho_{min} := \frac{300 \text{ psi}}{f_{fu}} = 0.00243$$

$$\rho_{min,ST} := \frac{20000 \text{ psi}}{E_f} = 0.0023 \quad \text{The ratio of shrinkage and temperature bars area}$$

The spacing of shrinkage and temperature bars if $(s \leq \min(3 \cdot h, 12 \text{ in}), \text{"OK"}, \text{"NA"}) = \text{"OK"}$

$$\rho_b := 0.85 \cdot \beta_1 \cdot \frac{f'_c}{f_{fu}} \cdot \frac{(E_f \cdot \varepsilon_{cu})}{E_f \cdot \varepsilon_{cu} + f_{fu}} = 0.0041$$

$$f_{fo} := \sqrt{\frac{(E_f \cdot \varepsilon_{cu})^2}{4} + 0.85 \cdot \frac{(\beta_1 \cdot f'_c)}{\rho_{sf}} \cdot E_f \cdot \varepsilon_{cu} - 0.5 \cdot E_f \cdot \varepsilon_{cu}} = 95815.7 \text{ psi}$$

Project: 4 - STORY HOTEL



Subject: Steel to GFRP Bars Conversion

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$$f_f := \text{if}(f_{fo} \geq f_{fu}, f_{fu}, f_{fo})$$

$$\varepsilon_{ft} := \frac{f_f}{E_f} = 0.01101$$

$$\phi_o := \text{if}\left(\varepsilon_{ft} \leq 0.8 \cdot \varepsilon_{fu}, 0.65, 1.05 - 0.5 \cdot \frac{\varepsilon_{ft}}{\varepsilon_{fu}}\right) = 0.65$$

$$\phi := \text{if}(\varepsilon_{ft} \geq \varepsilon_{fu}, 0.55, \phi_o) = 0.65$$

$$c_b := \frac{\varepsilon_{cu}}{\left(\varepsilon_{cu} + \frac{f_f}{E_f}\right)} \cdot d = 0.8565 \text{ in}$$

$$M_{nf} := A_{sf} \cdot f_f \cdot \left(d - \frac{\beta_1 \cdot c_b}{2}\right) = 36 \text{ ft kip}$$

$$M_{uf} := \phi \cdot M_{nf} = 23.4 \text{ ft kip}$$

$$\frac{M_{uf}}{M_u} = 1.05$$

Therefore, Section with #5 @ 12" MST bars is adequate.

Project: 4 - STORY HOTEL



Subject: Steel to GFRP Bars Conversion

Date: 16.06.2026

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4. Transverse Shear (In-Plane Shear) Capacity with MST rebar

$$E_c := 57000 \cdot \sqrt{f'_c \cdot \text{psi}} = 3604996.5 \text{ psi}$$

$$n_f := \frac{E_f}{E_c} = 2.4139$$

$$\phi_v := 0.75$$

$$\rho n := \rho_{sf} \cdot n_f = 0.0156$$

$$k := \sqrt{2 \cdot \rho n + \rho n^2} - \rho n = 0.1617$$

$$\lambda_s := \min \left(\sqrt{\frac{2}{1 + \frac{d}{10 \text{ in}}}}, 1.0 \right) = 1$$

$$V_{c1} := 5 \lambda_s \cdot k \cdot \min(\sqrt{f'_c \cdot \text{psi}}, 100 \text{ psi}) \cdot b \cdot h = 19632.25 \text{ lbf}$$

$$V_{c2} := 0.8 \lambda_s \cdot \min(\sqrt{f'_c \cdot \text{psi}}, 100 \text{ psi}) \cdot b \cdot h = 19429.03 \text{ lbf}$$

$$V_c := \max(V_{c1}, V_{c2}) = 19.63 \text{ kip}$$

$$n_{gv} := 4$$

$$A_{vf1} := 0.2 \text{ in}^2$$

#4 MST

$$A_{vf} := n_{gv} \cdot A_{vf1} = 0.8 \text{ in}^2$$

$$f_{ft} := \min(0.005 E_f, C_E 88000 \text{ psi}) = 43510 \text{ psi}$$

$$S_{vT} := 12 \text{ in}$$

$$V_{fT} := \frac{A_{vf} \cdot f_{ft} \cdot b}{S_{vT}} = 139.2 \text{ kip}$$

$$V_{uf} := \phi_v \cdot (V_c + V_{fT}) = 119.1 \text{ kip}$$

$$\frac{V_{uf}}{V_u} = 2.595$$

Therefore, Section with #4 @ 12" MST Transverse bars is adequate.

Project: 4 - STORY HOTEL



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- Out-Plane Shear Capacity:

$$\phi_v := 0.75 \quad s_v := 12 \text{ in} \quad f_{ft} := \min(C_E \cdot 87000 \text{ psi}, 0.005 \cdot E_f) = 43510 \text{ psi}$$

$$V_u := q_{uv} \cdot \frac{L}{2} = 475.2 \text{ lbf}$$

$$V_0 := \phi_v \cdot 0.2 \cdot f'_c \cdot b \cdot d = 115200 \text{ lbf}$$

if $(V_u \leq V_0, \text{"dimensions is OK"}, \text{"dimensions shall be revised"}) = \text{"dimensions is OK"}$

$$E_c := 57000 \cdot \sqrt{f'_c \cdot \text{psi}} = 3604996.5 \text{ psi} \quad \text{ACI 440-11-22 clause: 19.2.2.1b} \quad n_f := \frac{E_f}{E_c} = 2.4139$$

$$\rho_m := \rho_{sf} \cdot n_f = 0.0156 \quad k := \sqrt{2 \cdot \rho_m + \rho_m^2} - \rho_m = 0.1617$$

$$\lambda_s := \min\left(\sqrt{\frac{2}{1 + \frac{d}{10 \text{ in}}}}, 1.0\right) = 1$$

$$V_{c1} := 5 \lambda_s \cdot k \cdot \min(\sqrt{f'_c \cdot \text{psi}}, 100 \text{ psi}) \cdot b \cdot d = 9816.13 \text{ lbf}$$

$$V_{c2} := 0.8 \lambda_s \cdot \min(\sqrt{f'_c \cdot \text{psi}}, 100 \text{ psi}) \cdot b \cdot d = 9714.52 \text{ lbf}$$

$$V_c := \max(V_{c1}, V_{c2}) = 9816.13 \text{ lbf}$$

if $(V_u \leq \phi_v \cdot V_c, \text{"shear bars is not required"}, \text{"shear bars is required"}) = \text{"shear bars is not required"}$

Project: 4 - STORY HOTEL



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5. Serviceability Design

$$I_g := b \cdot \frac{h^3}{12} = 2048 \text{ in}^4$$

$$M_a := \frac{M_u}{1.6} = 13.9465 \text{ ft} \cdot \text{kip}$$

$$M_{cr} := \left(7.5 \cdot \sqrt{f'_c \cdot \text{psi}} \right) \cdot \frac{I_g}{\left(\frac{h}{2} \right)} = 20.24 \text{ ft} \cdot \text{kip} \quad \text{ACI 440-11-22 clause: 24.2.3.5}$$

$$I_{cr} := b \cdot d^3 \cdot \frac{k^3}{3} + n_f \cdot A_{sf} \cdot d^2 \cdot (1 - k)^2 = 37.98 \text{ in}^4$$

5.1 Permissible Tensile Stresses in GFRP Bars:

Conservatively, 50% of the service load is assumed to act as a sustained load.

$$f_{s,s} := n_f \cdot d \cdot \frac{(1 - k)}{I_{cr}} (0.5 \cdot M_a) = 17831.7 \text{ psi}$$

$$\text{if } (f_{s,s} \leq 0.3 f_{fu}, \text{ "OK", "NA"}) = \text{ "OK"}$$

5.2 Deflection Control:

$$\gamma := 1.72 - 0.72 \cdot \left(0.8 \cdot \frac{M_{cr}}{M_a} \right) = 0.8841 \quad \text{ACI 440-11-22 clause: 24.2.3.5a}$$

$$I_e := \text{if} \left(M_a \leq 0.8 M_{cr}, I_g, \frac{I_{cr}}{1 - \gamma \cdot \left(0.8 \cdot \frac{M_{cr}}{M_a} \right)^2 \left(1 - \frac{I_{cr}}{I_g} \right)} \right) = 2048 \text{ in}^4$$

$$\Delta_{iw} := \frac{5}{48} M_a \cdot \frac{L^2}{E_c \cdot I_e} = 0.049 \text{ in} \quad \text{if} \left(\Delta_{iw} \leq \frac{L}{240}, \text{ "OK", "NA"} \right) = \text{ "OK"}$$

1.4 Understanding GIC Effects on the Residential Scale — Current State of Knowledge

1.4.1 What a Single-Point Ground Actually Does

A fundamental question arises when examining how geomagnetically induced currents interact with a house:

If the large-scale geoelectric field and the associated telluric currents are essentially uniform across a kilometer-scale area and flow deep into the crust, what does a single ground point under a house actually accomplish?

The single-point grounding system (together with the under-slab mesh, vertical collectors, and interior copper equipotential grid) is not intended to intercept or divert the deep, regional-scale currents flowing through the rock. Its purpose is strictly local: it forces the entire bonded grounding system of the house to one common potential, gives residual currents that enter through the foundation or utilities a defined low-impedance exit path, and prevents the formation of multiple internal current loops that would otherwise create voltage differences and arcing risk inside the building.

A useful analogy is a boat in a large body of water during a storm. The big ocean currents move underneath and around the boat. A grounding conductor on the boat's transom below the waterline does not stop those large-scale currents. It keeps the metal parts of the boat at the same potential so that dangerous voltage differences do not develop between them.

1.4.2 Current State of Residential-Scale GIC/Pulse Knowledge

This residential-scale problem sits in a sparsely studied technical area. Extensive modeling exists for GIC effects on high-voltage power grids, transformers, pipelines, and railways. However, detailed electrical simulations of extreme geoelectric fields driving currents into a typical house and producing internal arcing between outlets, conduit joints, appliances, or other metal objects are essentially absent from the open literature.

Related work does exist in adjacent domains — studies of lightning-induced voltages and magnetic fields inside buildings, analyses of fault potentials and touch voltages in residential low-voltage systems, and modeling of magnetic field penetration into houses from nearby substations or power lines. These investigations confirm that electromagnetic disturbances can couple into residential structures, but they address different source mechanisms and time scales rather than the slow, quasi-DC geoelectric fields of extreme GIC events exhibit.

The estimates of residual internal voltage differentials, arcing risk, and induction heating potential presented in this book are therefore based on first-principles electromagnetic reasoning, scaling from published geoelectric field values, and conservative engineering judgment. They are offered as a carefully reasoned synthesis of the best available information, not as the final experimental word on the subject.

The intent is to give both general readers and technically sophisticated engineers a clear picture of the physical mechanisms and the practical design responses, while remaining transparent about

the current limits of published residential-scale analysis. Serious critiques and further modeling by the electrical engineering and computer simulation community are welcomed and needed.

1.4.3 Example Calculations: Heating and Impulse Effects in Long Steel Rebar

Continuous steel reinforcement creates two distinct classes of risk under extreme space-weather and lightning conditions: (1) sustained resistive heating driven by quasi-DC geoelectric fields (GIC-type events), and (2) rapid inductive and current-injection effects driven by extreme lightning or nearby massive electrical pulses.

Because detailed residential-scale simulations are not available, the following examples use basic electromagnetic, electrical and thermal principles to estimate the heating that could occur in continuous lengths of steel reinforcement under strong geoelectric fields. These are order-of-magnitude illustrations with all major assumptions stated so that readers can evaluate or adjust them. A separate discussion of the fast-pulse / lightning implications follows the heating tables.

Assumptions

- Rebar sizes: #5 (16 mm), #6 (19 mm), and #8 (25 mm)
- Electrical resistivity of mild steel $\approx 1.7 \times 10^{-7} \Omega \cdot m$
- Resistance values (approximate): – #5 $\approx 0.85 \text{ m}\Omega/m$ – #6 $\approx 0.60 \text{ m}\Omega/m$ – #8 $\approx 0.34 \text{ m}\Omega/m$
- The full horizontal component of the geoelectric caused current field is assumed to act along the bar (conservative upper-bound case)
- The calculations apply to the quasi-DC / very-low-frequency regime.
- Concrete is treated as a poor thermal conductor. In addition, beam channels in ICF construction are formed with EPS foam on the bottom and both sides, creating high thermal resistance. Heat generated in the steel is therefore assumed to remain largely trapped in the rebar and a limited surrounding volume of concrete for the duration of multi-hour event peaks.
- Specific heat of steel $\approx 500 \text{ J/kg}\cdot\text{K}$; density $\approx 7850 \text{ kg/m}^3$
- These calculations treat the rebar as a simple resistive conductor driven by the geoelectric field. They do not include mutual inductance between parallel bars or current sharing with the surrounding concrete and mesh (where present). Both effects would tend to reduce the heating in any single bar, making the estimates conservative.

Event Levels Used (aligned with tables in this book)

Event Level	Representative Horizontal E-field	Notes
X45 (Carrington-class)	5 – 20 V/km	Baseline severe event
X100	10 – 40 V/km	Strong extrapolation
X200	20 – 80 V/km	Severe micro-nova range
X400	40 – 150 V/km	Extreme upper bound
X1000-class	100 – 300+ V/km	Speculative micro-nova peak illustration

Worked Example (Method Used for the Tables)

Take a single #5 rebar, 80 ft (24.4 m) long, subjected to a horizontal geoelectric field of 50 V/km.

1. Voltage induced along the bar $V = E \times L = 50 \text{ V/km} \times 0.0244 \text{ km} = 1.22 \text{ V}$
2. Resistance of the bar From the assumptions: #5 rebar $\approx 0.85 \text{ m}\Omega/\text{m}$ $R = 0.85 \text{ m}\Omega/\text{m} \times 24.4 \text{ m} = 0.02074 \Omega$
3. Current in the bar $I = V/R = 1.22/0.02074 \approx 58.8 \text{ A}$
4. Power dissipated $P = I^2 R = (58.8)^2 \times 0.02074 \approx 72 \text{ W}$ (The table shows ~70 W — minor rounding difference only)

This same sequence (Voltage → Resistance → Current → Power) was used for every entry in the tables that follow.

Single-Bar Examples (#5 rebar)

Length	E-field	Power	Estimated Temperature Rise (order-of-magnitude, multi-hour peak, highly insulated conditions)	Heating Concern
40 ft (12 m)	20 V/km	~6 W	5–15 °C	Low
40 ft	50 V/km	~35 W	30–70 °C	Moderate to High
40 ft	100 V/km	~140 W	80–180+ °C	High to Severe

Length	E-field	Power	Estimated Temperature Rise		Heating Concern
			(order-of-magnitude, multi-hour peak, highly insulated conditions)		
80 ft (24 m)	20 V/km	~12 W	10–25 °C		Low to Moderate
80 ft	50 V/km	~70 W	50–120 °C		High
80 ft	100 V/km	~290 W	120–250+ °C		Severe
120 ft	50 V/km	~105 W	70–150 °C		High to Severe
120 ft	100 V/km	~440 W	150–300+ °C		Extreme

Multi-Bar / Bundle Examples (Two bars side-by-side and wire-tied, or heavier double-row configurations common in beams and long lintels)

Configuration	Length	E-field	Approx. Total Power	Estimated Temperature Rise (order-of-magnitude, multi-hour peak, highly insulated conditions)	Heating Concern
Two #6 bars side-by-side	80 ft	50 V/km	~100–120 W	70–160 °C	High to Severe
Two #6 bars	80 ft	100 V/km	~400–450 W	150–300+ °C	Extreme
Two #8 bars side-by-side	80 ft	50 V/km	~150–180 W	90–200 °C	Severe
Two #8 bars	80 ft	100 V/km	~600–700 W	200–350+ °C	Extreme
Double-row #8 heavy lintel	100+ ft	50–100 V/km	Many hundreds of W	150–350+ °C	Extreme

Notes on the Temperature Estimates

- These ranges assume the rebar is inside an EPS-foam-formed beam channel or ICF wall (three sides well insulated).
- Heat is treated as largely trapped for the duration of strong multi-hour peaks.
- Actual temperatures will be lower if there is better thermal coupling to a large concrete mass or if the geoelectric field is only partially aligned with the bar.
- At sustained temperatures above ~100–150 °C the risk of concrete cracking, loss of bond strength, and possible spalling rises sharply.

- Beam channels are the highest-risk locations because of the combination of long continuous bars and the surrounding EPS foam insulation.
- These calculations treat the rebar as a simple resistive conductor driven by the geoelectric field. They do not include mutual inductance between parallel bars or current sharing with the surrounding concrete and mesh (where present). Both effects would tend to reduce the heating in any single bar, making the estimates conservative.
- Because real geoelectric fields fluctuate and are rarely perfectly aligned with any given bar for many continuous hours, the higher end of this temperature ranges should be viewed as plausible upper bounds rather than expected typical values.

Fast-Pulse / Extreme Lightning Considerations

The resistive-heating calculations above address long-duration geoelectric fields. Extreme lightning and nearby massive pulses operate in a very different regime (microsecond-to-millisecond timescales, extremely high dI/dt). Under those conditions continuous steel rebar presents additional risks:

- Long continuous bars can act as preferential low-impedance paths for impulse current, increasing the chance of concentrated current density at bends, splices, or terminations.
- Rapidly changing magnetic fields can induce significant voltages along extended conductive paths, raising the possibility of side-flash or internal arcing if potential differences develop between the rebar and other metallic systems.
- In EPS-formed roof beam channels the combination of continuous steel and surrounding foam still creates a thermally and electrically constrained environment, although the dominant damage mechanism shifts from gradual heating to possible localized impulse damage or cracking.

These impulse effects are more difficult to quantify with simple hand calculations than the quasi-DC heating case. The important design observation is the same: continuous conductive reinforcement creates pathways that non-conductive alternatives (GFRP) simply do not provide.

1.4.4 Summary Observation

These transparent, first-principles examples show why continuous steel reinforcement becomes a liability under strong, long-duration geoelectric fields. Even moderate extreme-event fields can drive tens of amperes through long bars; at the higher extrapolated levels the power dissipation becomes large enough to produce serious, localized heating inside the concrete, particularly in EPS-formed beam channels.

Under extreme lightning or massive-pulse conditions the same continuous steel creates preferential current paths and inductive coupling opportunities that increase the risk of concentrated arcing effects.

Replacing the primary structural reinforcement with non-conductive GFRP removes both the sustained-heating pathway and the continuous conductive path for impulse currents. That dual

benefit is one of the central reasons the Carrington House design specifies full double-curtain GFRP as the primary reinforcement system.

1.5 Common Area Factors:

Hazard Event Baseline: Both concepts use the X45 Carrington-class event as the extrapolated baseline for geomagnetic hazards, with higher solar events up to X400 examined for structural response. In parallel, the design also addresses extreme lightning and nearby massive electromagnetic pulses as a co-equal threat.

More detailed joint modeling of these combined hazards is still needed. We did what we could to look at the potential and more work in this area needs to be done soon by a collective team of community members.

GIC/EMP/Solar Flare Hazards: Both Carrington House concepts provide partial or full Faraday-cage-style protection against high-level Geomagnetically Induced Currents (GIC), extreme lightning / massive pulse events, strong voltage gradients, Electromagnetic Pulse (EMP), and secondary effects associated with severe solar and geomagnetic disturbances.

Extreme Seismic Events: The Carrington House design uses the **Cascadia Subduction Zone M9 earthquake** as the primary seismic design basis. This event represents one of the most thoroughly studied long-duration megathrust earthquakes, with strong shaking lasting 60–180+ seconds plus significant aftershock sequences. While the exact seismic characteristics of an extreme solar flare/CME and magnetic pole flip remain uncertain, the Cascadia M9 provides a scientifically grounded, conservative anchor for long-duration shaking, high cumulative energy input, and resonance effects. https://www.nrmca.org/wp-content/uploads/2022/06/Earthquake_Performance_Comparison_Multifamily_Multistory_Apartment_Building.pdf

To account for potentially more extreme seismic events, the design incorporates significant over-design-strength: double-curtain GFRP wall reinforcement, 10–12 inch ICF walls, possible earth berms, and higher-strength concrete (6,000–10,000 psi). This approach ensures the structure exceeds possible Cascadia levels while maintaining practical construction flow for owner-builders.

The double curtain rebar design approach (and extra cost) gives a very stiff concrete wall that reduces the “drift” at the top of the wall which is the back-and-forth motion that long term ground shaking creates. With the drift at minimum, the structural connection between the concrete walls and concrete roof should be able to survive intact.

GFRP: Both concepts use ICC-approved composite structural GFRP to replace or minimize steel reinforcement in the structural concrete. The dual purpose is (1) to eliminate sustained resistive heating that continuous steel can experience under strong geoelectric fields, and (2) to remove continuous conductive paths that can collect and concentrate impulse currents during extreme lightning or massive pulse events.

The following tables and information are found in Section 3.10 and present an example of the GFRP rebar schedule would be for either of the Carrington House options based on a example wall

concept. A full analysis needs to be completed by your Engineer or Record for your design and permit.

Suggested GFRP Rebar Schedules – Prescriptive Code vs. Carrington House (10" Flat ICF Wall, 8–10 ft height)

Horizontal Reinforcement (Common across schedules)

- #4 (or GFRP equivalent) at maximum 18" o.c. vertically
- One bar within 12" of the top of each story/wall

Vertical Reinforcement Comparison

SDC Zone / Event	Code Minimum Steel (Vertical)	GFRP Single Curtain	GFRP Double Curtain (Recommended)	Notes
SDC D2 (Prescriptive)	#5 @ 32" o.c.	#6 @ 32" o.c.	#6 @ 36" o.c. each face	Baseline code minimum
Cascadia M9 (Design Basis)	#5 @ 24" o.c. or engineered	#6 @ 24" o.c.	#6 @ 24–30" o.c. each face	Long-duration shaking
Cascadia+ / Pole Flip	Engineered (beyond prescriptive)	#6 @ 18–24" o.c.	#6 @ 18–24" o.c. each face + L-ties	Extreme over-design

Steel Rebar and Single Point Grounding: Where any steel reinforcement must remain in the structural concrete, those bars are mechanically and electrically bonded into a controlled mesh/grounding network so that both quasi-DC induced currents and fast impulse currents are directed to the single-point ground. This reduces localized heating under GIC conditions and limits uncontrolled current paths under extreme lightning or pulse conditions.

Single point ground: both concepts have a single point ground at a corner of the building that is the ground for all electrical, GIC and faraday systems. This prevents multiple electrical loops from forming with potential arcing.

Conductive Concrete: Optional use of conductive concrete in walls and roof to provide additional EMP and GIC shielding. Use specific concrete admixtures (Enhance ICD) in all concrete to form waterproof concrete to prevent wicking over time. Conductive concrete admixtures contain materials such as magnetite.

Layered radiation shielding in the roof over the central safe area (borated polyethylene + boron-enhanced concrete + soil overburden) and in the structure.

Possible Earth Green Roof systems: both concepts could look into this option.

Internal ICF walls; for sanctuary zones and additional structural roof support load paths

Dielectric Carrington House: The term used in this book “**Dielectric Carrington House**” is defined as a residential house built with Insulated Concrete Form (ICF) walls, slab floors and ICF roof systems designed to passively route the GIC currents to flow under, around and over, but not into or through the building.

Regarding the two concepts, the dielectric common areas are listed:

1. 4x4 welded galvanized welded wire mat under the footprint of the house/footings with the single point ground.
2. The code required EPS/XPS insulating foam under the ground concrete floor slab and vapor barrier. This foam component is actually a very effective dielectric insulation and is a normal cost for both concepts.
3. Using the dielectric properties of normal ICF forms to help divert GIC
4. These dielectric measures primarily limit quasi-DC current entry into the structure. When combined with a segmented outer equipotential ring and isolating spark gaps (described later), they also support controlled equalization and current dumping during extreme lightning or massive pulse events.

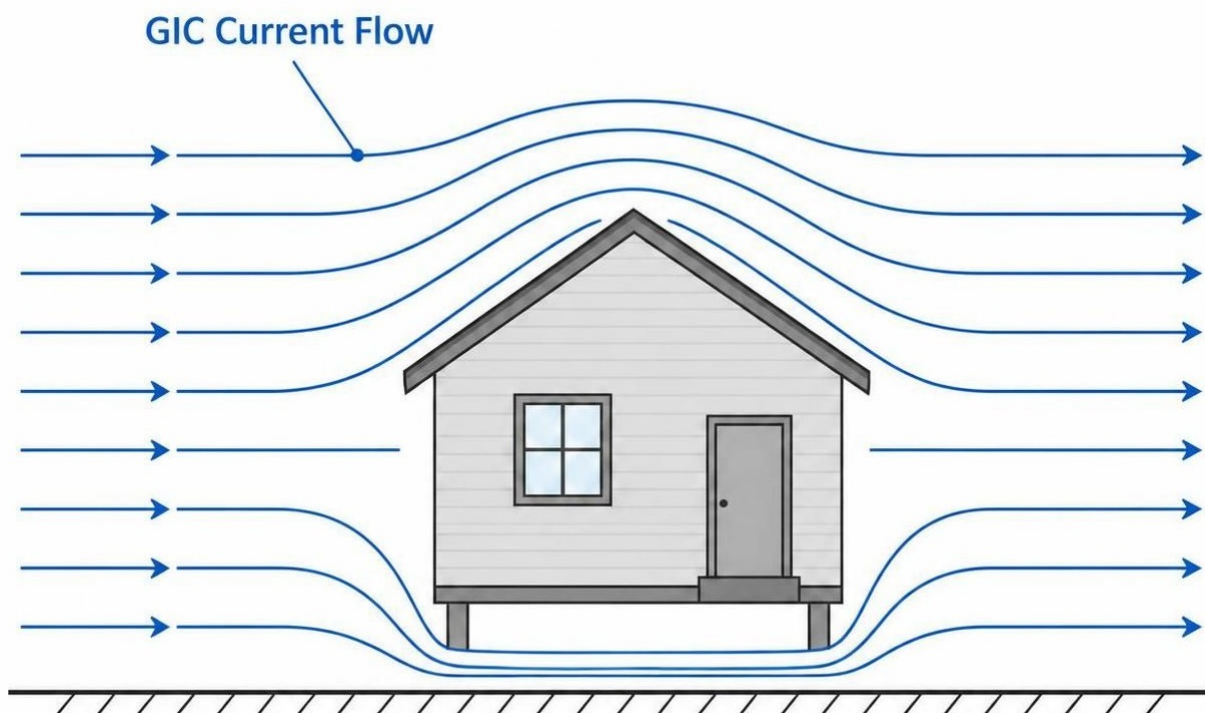


Figure.7Dielectric.Carrington.House.ICF.House

1.5.1 Common Design Areas for Both Simple and Effective and Full Faraday 6-Sided Cage

This table presents the key design features incorporated in both Carrington House concepts. There are **only three differences** between the Simple and Effective (SaE) design and a full 6-sided Faraday Caged house:

1. **Full Faraday Cage (FFC)** – Installation of 4×4 welded wire mesh on all external wall surfaces and over the concrete roof deck. The cage is fully connected on all sides and grounded at the same single grounding point used for the structure. The SaE design has mesh only under the footprint of the house, connected to the same single grounding point.
2. **SaE only** – Installation of vertical steel rebar around the perimeter of the ICF walls (outside surface, from footing to top of wall) connected to the single grounding point. These vertical conductors help equalize voltage differentials from grade to the top of the wall and reduce the amount of GIC-induced current that can leak into the structure through openings and the absence of a continuous exterior mesh. These vertical conductors also help equalize fast potential differences from grade to eave during a nearby massive pulse.
3. **SaE includes / FFC optional** – An Interior Equipotential Grid Network of vertical 2-gauge copper grounding wires attached to the inner faces of the ICF walls (under the drywall) on a large spacing grid and bonded back to the single ground point. This grid reduces residual internal voltage gradients and provides preferred discharge paths to prevent arcing. The Full Faraday Cage version can optionally include the same grid for an extra layer of protection, but it is not required. The grid also provides preferred discharge paths for residual currents after a fast pulse, reducing the chance of internal arcing.

Table 1.5.1 – Key Design Elements Common to Both SaE and Full Faraday Cage Versions

Design Element	Definition and Components	Common Purpose
Structural Concrete Reinforcement	Full double-curtain GFRP throughout walls and roof (over-designed for Cascadia+)	Eliminates induction heating; increases wall stiffness; reduces top-of-wall drift; strengthens roof-to-wall connection
Ground floor slab Foam Insulation and vapor barrier under slab	Continuous under-slab EPS (already required for code thermal + radiant floor PEX)	Provides thermal and dielectric isolation under the entire slab
GIC Grounding Welded Wire Mesh under house footprint	4×4 or 6×6 galvanized welded wire mesh placed directly on the soil, beneath the under-slab EPS, extending past the footing footprint	Low-resistance shunt for GIC entering from the ground; connected to a single-point grounding rod assembly. Also serves as the primary under-slab equipotential

Design Element	Definition and Components	Common Purpose
		plane that participates in pulse equalization once outer spark gaps fire
ICF Blocks Vertical Dielectric surfaces	High-density XPS foam on exterior and interior of ICF walls (footings to top of wall)	Increases resistance to side entry of GIC into the walls. Also raises the impedance to fast lateral current injections during extreme lightning
ICF Roof foam deck system	High-density EPS foam under all roof concrete	Increases resistance to roof-deck entry of GIC into the house. Same dual function for both quasi-DC and impulse currents
Interior Equipotential Grid	Network of vertical 2-gauge copper grounding wires on inner EPS faces of ICF walls (under drywall), large spacing grid, bonded back to panel then to single ground	Reduces residual internal voltage gradients from GIC and provides preferred discharge paths to prevent arcing. Continuously drains residual voltage differences. Also drains residual potentials after a fast pulse.
Local Safe Room	Faraday cage mesh + radiation shielding only around inner safety room / basement zone	Protects people and critical electronics from residual GIC fields and EMP E1 and extreme lightning / pulse effects.
Wiring Design	Long runs in high-quality conduits; carefully bonded to single ground point	Minimizes induction damage; provides controlled paths for both sustained and impulse currents.
Optional Upgrade	Magnetite aggregate in concrete (20–40% sand replacement)	Provides modest additional absorption of EMP E1 energy

1.5.2 Structural Performance Estimated Comparison – Long-Duration Seismic Loading

Aspect	Standard ICF	Carrington House (SaE or FFC)	Impact of Difference
Wall Reinforcement	Typically single-curtain steel rebar	Double-curtain GFRP as primary structural system	Increases wall stiffness → reduces top-of-wall drift → protects roof-to-wall connections

Aspect	Standard ICF	Carrington House (SaE or FFC)	Impact of Difference
Roof-to-Wall Connection	Conventional steel rebar detailing	Additional GFRP L-shaped ties connected into roof beams and walls	Strengthens roof-to-wall connection
Induction Heating Risk	High – long steel rebar can heat and crack concrete	Extremely low (non-conductive GFRP)	Eliminates primary mechanism of concrete overheating, cracking, and spalling
Extended Shaking (60–180+ s)	Moderate risk – higher drift increases cumulative damage	Lower risk – double-curtain GFRP reduces drift and stress on connections	Lower probability of progressive roof-to-wall failure after Cascadia M9+
Cumulative Damage Resistance	Higher risk of low-cycle fatigue	Lower risk due to GFRP + increased stiffness	Improves likelihood structure remains functional and repairable
Post-Event Integrity	Variable	Higher probability of remaining sound and habitable	Directly supports long-term survivability goal

Notes

- Top-of-wall drift = horizontal movement at the top of the wall relative to the base. Excessive drift is the primary driver of roof-to-wall connection failure under long-duration shaking.
- Cumulative damage (low-cycle fatigue) occurs when a structure experiences 50–150+ strong stress reversals during a single long-duration event such as Cascadia M9.

1.5.3 GIC and Extreme-Pulse Current Protection Performance

This table addresses quasi-DC geoelectric currents. Extreme lightning and massive pulses operate on much shorter timescales and are discussed qualitatively in the design-element descriptions and in Section 1.1.3.

Aspect	Standard ICF	Simple and Effective (SaE)	Impact
Ground Current Entry into Footings	High – no GIC shunting	Strongly reduced by under-slab mesh acting as GIC shunt	Most GIC prefers the mesh path rather than entering the concrete
Current Rising Through Walls	High (steel rebar path)	Very low (full GFRP eliminates low-resistance path)	Current density inside wall concrete dramatically lower

Aspect	Standard ICF	Simple and Effective (SaE)	Impact
Side Entry Through ICF Walls	Moderate	Reduced by vertical XPS skirt	Stronger barrier against lateral current entry
Internal Voltage Gradients	Highest (900–1,800 V)	Peak residual 300–1,200 V; continuously drained by copper grid → much lower sustained values	Continuously equalized by the interior copper network
Induction Heating of Structure	High	Virtually eliminated	One of the most important performance gains
Overall GIC Protection Level	Poor	Very Good	Primary design goal achieved without full 6-sided cage

1.5.4 Voltage Gradient, Arcing, and Current Analysis

Assumptions used for calculations

- House size: 12 m × 18 m
- Extreme geoelectric field: 50 V/km (primary) and 100 V/km (upper bound)
- Free-field voltage across 18 m house: 900 V (50 V/km) and 1,800 V (100 V/km)
- Reduction factor SaE design: approximately 1.5× to 3×
- Reduction factor Full Faraday Cage: approximately 10× to 50×

Calculated Peak Residual Internal Voltage Differentials

Configuration	At 50 V/km	At 100 V/km	Assessment
Standard ICF	900 V	1,800 V	Highest risk – sustained differences remain high
Simple and Effective (SaE)	300 – 600 V	600 – 1,200 V	Peak residual only. Continuously drained and equalized by the interior copper grid → much lower sustained voltages
Full Faraday 6-Sided Cage	18 – 90 V	36 – 180 V	Lowest peak residual; sustained differences remain very small

The values shown are **estimated peak residual voltage differentials** that may appear during the strongest phases of an extreme event. They are not constant voltages that remain across the interior. In the SaE design the interior 2-gauge copper equipotential grid continuously drains and

equalizes these differences to the single ground point, so the **sustained** voltages experienced inside the living space are kept substantially lower than the peak figures listed above.

The voltage and current estimates above apply to sustained or slowly varying geoelectric fields. A nearby massive lightning pulse or extreme electromagnetic transient produces far higher peak voltages and currents on microsecond-to-millisecond timescales. Under those conditions the same continuous conductive paths (metal conduit, residual steel, long wiring runs) become the dominant concern, which is why non-metallic conduit, GFRP, and controlled bonding to the single-point ground remain important.

How Arcing Would Manifest

- Sparking between metal objects at different potentials
- Insulation breakdown or flashover at outlets, switches, and junctions
- Arcing at metal conduit joints and connectors
- Audible cracking/popping sounds, burned insulation odor
- In severe cases: small fires or melted conductors

Estimated Peak Currents on Long Paths (SaE Design)

Path Type	Approx. Impedance	Estimated Peak Current	Severity
Long metal conduit (bonded)	0.1 – 1 Ω	300 – 12,000 A	Very High
Typical residential wiring	0.5 – 5 Ω	60 – 2,400 A	High
High-resistance paths	10 – 100 Ω	3 – 120 A	Moderate

Conduit Behavior If long wiring runs are placed in continuous metal conduits bonded back to the single ground point, those conduits become the preferred low-resistance discharge paths for internal currents. This concentrates high currents on the conduit network and increases arcing risk at joints. Non-metallic conduit is preferred for long runs where possible.

1.5.5 Interior 2-Gauge Equipotential Grounding Grid

A network of 2-gauge copper grounding wires is installed on the inner EPS faces of the ICF walls (under the drywall) and bonded back to the main panel and then to the single external ground point.

- **Performance of this grid**
- Significantly reduces residual internal voltage gradients
- Provides preferred low-resistance paths for residual currents
- Continuously drains and equalizes voltage differences so sustained voltages remain much lower than peak residual values
- Greatly reduces random arcing between metal objects
- Easy and inexpensive to install during normal drywall preparation
- Does not create a Faraday cage (and is not intended to)
- Provides preferred discharge paths for residual currents following a fast pulse.

This grid is considered a highly recommended component of the Simple and Effective (SaE) design.

1.5.6 GIC Duration and Cyclic Nature

Event Type	Typical Duration of Elevated GIC	Peak Intensity Periods	Cyclic Behavior
Moderate Storms	Several hours	Minutes to ~1 hour	Yes – rises and falls
Strong Storms (1989, 2003)	12–48 hours	Multiple peaks of 10–60+ min	Strongly cyclic
Extreme / Carrington-class	1–3 days	Intense main-phase peaks of 1–3 hours	Highly variable with polarity reversals
Micro-nova / Pole-flip scale	Potentially longer	Multiple strong bursts	Highly cyclic

GIC is not a steady DC current. It rises, falls, and can reverse direction multiple times during an event.

1.5.7 Comparison Summary Table

Performance Category	Standard ICF	Simple and Effective (SaE)	Full 6-Sided Cage
Structural Induction Heating Risk	High	Extremely Low	Extremely Low
GIC Entry Through Footings	High	Strongly Reduced	Very Strongly Reduced
Internal Voltage Gradients	Highest	Peak residual 300–1,200 V; continuously drained by copper grid → much lower sustained values	Lowest
Arcing Risk	Highest	Moderate (with grid)	Lowest
EMP E1 Protection	Poor	Moderate (local room only)	Highest
Long-Duration Seismic Performance	Moderate	High	High
Extreme Lightning / Massive Pulse Path Control	Poor	Good (segmented outer ring + mesh + grid)	Very Good
Constructability	High	High	Moderate
Relative Cost Premium	Baseline	+20% to +40% (est.)	+35% to +65% (est.)

Performance Category	Standard ICF	Simple and Effective (SaE)	Full 6-Sided Cage
Overall Recommendation	Baseline	PREFERRED for most projects	Maximum protection option

1.5.8 Why SaE Is Now the Preferred Option

This configuration was selected as the Preferred Option because it:

- Delivers the core performance benefits that matter most (elimination of structural induction heating under GIC, removal of continuous conductive paths for impulse currents, strong reduction of ground-current entry, meaningful control of residual internal voltages via the equipotential grid, and improved long-duration seismic behavior)
- Uses materials and construction practices already familiar to ICF installers
- Avoids the significant cost, complexity, and labor of a continuous 6-sided mesh cage
- Still allows a high-quality local Faraday + radiation safe room for people and critical electronics

The full 6-sided Faraday cage version remains available as a Higher-Tier Option for projects that require maximum internal field reduction and EMP E1 protection.

1.6 How the SaE Design Compares to Conventional Stick-Framed Construction

One important question that I know will be asked is ... during an extreme GIC / long-duration seismic / solar event, or under a nearby massive lightning pulse?” Well, here is the analysis information on the comparison between the ICF SaE Carrington house and (1) an upgraded stick frame with the grounding mesh under it and a few other SaE components and (2) a regular stick frame house project.

One thing to keep in mind regarding a stick frame is that a person can include a FEMA ICF shelter room as part of the project or an underground bunker like the Ark Homes. These can be the go-to safe zones when the big one hits and people should be ok after it is over.

So the following is information for you to know about as you think about what to do, or who to pass this information to.

1.6.1 Comparison: Carrington House SaE vs. Upgraded Stick-Framed House

Here is a clear, practical comparison you can use when someone asks:

“What if I just take a normal stick-framed house, put the same ground mesh under it, foam under the slab, vertical steel bars, and the interior copper grid — how does that compare to the Carrington SaE?”

Side-by-Side Comparison

Performance Area	Upgraded Stick-Framed House	Carrington House SaE	Winner & Why
Ground Current Shunting	Good (same under-slab mesh)	Good (same under-slab mesh)	Tie
Vertical Voltage Equalization	Good (vertical steel bars added)	Good (vertical steel bars added)	Tie
Internal Equipotential Grid	Good (2-gauge copper network under drywall)	Good (same copper network)	Tie
Induction Heating Risk	Still High – nails, plates, hangers, steel beams, and wiring can heat	Extremely Low – primary structure is non-conductive GFRP	SaE (large advantage)
Extreme Lightning / Massive Pulse Path Control	Moderate – mesh + grid help, but large amount of steel remains	Good – non-conductive primary structure + controlled mesh/grid + dielectric envelope	SaE
Dielectric Isolation from Ground	Poor to Moderate – wood + limited foam	Very Good – continuous XPS/ICF foam envelope	SaE
Internal Voltage Gradients	Moderately reduced by copper grid, but many conductive paths remain	Peak residual 300–1,200 V, continuously drained; fewer conductive paths	SaE
Arcing Risk Inside House	Moderate to High (many metal-to-metal paths)	Moderate (controlled by copper grid + non-conductive structure)	SaE
Long-Duration Seismic (Cascadia M9+)	Poor to Fair – high drift, connection failures common	High – stiff double-curtain GFRP walls, low top-of-wall drift	SaE (major advantage)
Post-Event Structural Integrity	Variable – often requires major repair or is compromised	High probability of remaining sound and habitable	SaE
EMP / Residual Field Protection	Low (unless a separate FEMA/safe room is added)	Moderate (local safe room) + better overall envelope	SaE
Radiation / Skyshine Mass	Very Low	Moderate (concrete walls + roof)	SaE

Performance Area	Upgraded Stick-Framed House	Carrington House SaE	Winner & Why
Fire Resistance & Long-Term Durability	Low to Moderate	High	SaE
Constructability	Familiar to most builders	Familiar to experienced ICF crews	Stick slightly easier
Relative Cost	Lower base cost + moderate upgrade cost	Higher base cost, but integrated protection	Stick cheaper

Key Takeaways

1. **The grounding and equipotential features help both designs.** Adding the under-slab mesh, vertical steel bars, and interior copper grid to a stick house does meaningfully reduce ground-current entry and internal voltage differences. Those are real improvements.
2. **The biggest remaining gaps are structural and induction related.** A stick house still contains large amounts of steel (nails, plates, hangers, possible beams). During extreme GIC those conductive elements can still heat up and create internal current paths and potential fire spots. The SaE design removes almost all of that risk by using non-conductive GFRP as the primary reinforcement.
3. **Long-duration seismic performance is dramatically different.** Even with the electrical upgrades, a conventional stick-framed house has much higher top-of-wall drift and is more vulnerable to cumulative damage during a Cascadia-type event lasting 60–180+ seconds. This is a very important factor if the stick house is designed for low seismic zones such as the SDC A, B or C. The SaE double-curtain GFRP walls are specifically intended to keep the roof-to-wall connection intact under that kind of loading.
4. **A FEMA-style safe room can be added to either.** You can put a well-built FEMA or ICC-500 safe room inside a stick house or in the garage. That helps with local protection for people and critical electronics, but it does not protect the rest of the structure from induction heating, drift damage, or loss of habitability.
5. **Bottom-line practical answer:** An upgraded stick-framed house with the mesh + vertical bars + copper grid is meaningfully better than a completely ordinary stick house against GIC. However, it still falls well short of the Carrington SaE in three critical areas:

1.6.2 Comparison: Normal Stick-Framed House (No GIC Protection) vs. Carrington House SaE

This is the baseline case — a conventional wood-framed house built to normal code with no special mesh, no vertical collectors, no interior copper grid, and no dielectric isolation measures beyond ordinary construction.

Side-by-Side Comparison

Performance Area	Normal Stick-Framed House (No Upgrades)	Carrington House SaE	Winner & Why
Ground Current Shunting	None – currents enter freely through footings and slab	Good – under-slab mesh shunts most GIC around the structure	SaE (large advantage)
Vertical Voltage Equalization	None	Good – vertical steel bars equalize grade-to-top-of-wall voltage	SaE
Internal Equipotential Grid	None	Good – 2-gauge copper network continuously drains residual voltage	SaE
Induction Heating Risk	High – nails, plates, hangers, steel beams, and wiring can heat	Extremely Low – primary structure is non-conductive GFRP	SaE (major advantage)
Dielectric Isolation from Ground	Very Poor – concrete/wood in direct contact with soil	Very Good – continuous XPS/ICF foam envelope	SaE
Extreme Lightning / Massive Pulse Path Control	Moderate – mesh + grid help, but large amount of steel remains	Good – non-conductive primary structure + controlled mesh/grid + dielectric envelope	SaE
Internal Voltage Gradients	Highest (typically 900–1,800 V or more across the house)	Peak residual 300–1,200 V, continuously drained → much lower sustained voltages	SaE
Arcing Risk Inside House	High – many uncontrolled metal-to-metal paths	Moderate – controlled by copper grid + non-conductive structure	SaE
Long-Duration Seismic (Cascadia M9+)	Poor – high drift, connection failures common under 60–180+ s shaking	High – stiff double-curtain GFRP walls, low top-of-wall drift	SaE (major advantage)
Post-Event Structural Integrity	Low to Variable – often requires major repair or becomes uninhabitable	High probability of remaining sound and habitable	SaE

Performance Area	Normal Stick-Framed House (No Upgrades)	Carrington House SaE	Winner & Why
EMP / Residual Field Protection	Very Low	Moderate (local safe room) + better overall envelope	SaE
Radiation / Skyshine Mass	Very Low	Moderate (concrete walls + roof)	SaE
Fire Resistance & Long-Term Durability	Low	High	SaE
Constructability	Highest – standard methods everywhere	High – familiar to experienced ICF crews	Stick easier
Relative Cost	Lowest (baseline)	Higher, but integrated protection	Stick cheaper

Key Takeaways for Conversations

1. **A normal stick-framed house has essentially no meaningful protection** against extreme GIC. Ground currents enter freely, internal voltage differences can be very high, and the large amount of steel (nails, plates, hangers, beams) creates widespread induction heating and arcing risk.
2. **The electrical upgrades we discussed earlier help**, but they only close part of the gap. Even with mesh + vertical bars + copper grid, a stick house still suffers from induction heating in its steel components and much weaker long-duration seismic performance.
3. **The Carrington SaE design attacks the problem at the structural level**, not just by adding electrical Band-Aids. By removing the conductive rebar and wrapping the house in continuous dielectric foam, it eliminates the primary heating mechanism and strongly reduces current entry in the first place.

Master Comparison Table Normal Stick-Framed House vs. Upgraded Stick-Framed House vs. Carrington House SaE

Performance Area	Normal Stick-Framed House (No Upgrades)	Upgraded Stick-Framed House (Mesh + Vertical Bars + Copper Grid)	Carrington House SaE
Ground Current Shunting	None – currents enter freely	Good – under-slab mesh	Good – under-slab mesh
Vertical Voltage Equalization	None	Good – vertical steel bars	Good – vertical steel bars

Performance Area	Normal Stick-Framed House (No Upgrades)	Upgraded Stick-Framed House (Mesh + Vertical Bars + Copper Grid)	Carrington House SaE
Internal Equipotential Grid	None	Good – 2-gauge copper network	Good – 2-gauge copper network
Induction Heating Risk	High – nails, plates, hangers, beams, wiring	Still High – large amount of steel remains	Extremely Low – primary structure is non-conductive GFRP
Dielectric Isolation from Ground	Very Poor	Poor to Moderate	Very Good – continuous XPS/ICF foam envelope
Extreme Lightning / Massive Pulse Path Control	Moderate – mesh + grid help, but large amount of steel remains	Good – non-conductive primary structure + controlled mesh/grid + dielectric envelope	SaE
Internal Voltage Gradients	Highest (typically 900–1,800 V+)	Moderately reduced	Peak residual 300–1,200 V; continuously drained → much lower sustained voltages
Arcing Risk Inside House	High	Moderate to High	Moderate – controlled by copper grid + non-conductive structure
Long-Duration Seismic (Cascadia M9+)	Poor – high drift, connection failures common	Poor – still high drift	High – stiff double-curtain GFRP, low top-of-wall drift
Post-Event Structural Integrity	Low to Variable	Low to Variable	High probability of remaining sound and habitable
EMP / Residual Field Protection	Very Low	Very Low (unless separate safe room added)	Moderate (local safe room) + better overall envelope
Radiation / Skyshine Mass	Very Low	Very Low	Moderate (concrete walls + roof)
Fire Resistance & Long-Term Durability	Low	Low	High

Performance Area	Normal Stick-Framed House (No Upgrades)	Upgraded Stick-Framed House (Mesh + Vertical Bars + Copper Grid)	Carrington House SaE
Constructability	Highest – standard methods	High – standard methods + added electrical work	High – familiar to experienced ICF crews
Relative Cost	Lowest (baseline)	Moderate increase	Higher, but protection is integrated

1.6.3 Possible Ignition Pathways from Extreme GIC and Massive Lightning Pulses in Conventional Houses

A common concern is whether ordinary steel components in a house — nails, bolts, connectors, metal roofing, etc. could cause ignition. The answer depends on the threat.

Under long-duration geoelectric fields (GIC), ignition risk is driven almost entirely by the length of the continuous conductive path and the thermal environment surrounding the steel. Short pieces produce negligible heating; long continuous paths can produce significant heating, especially when thermally insulated.

Under extreme lightning or a nearby massive pulse the dominant risks shift from gradual heating to localized arcing, side-flash, and high current density at connections and discontinuities.

Short Steel Fasteners (Nails, Anchor Bolts, Hangers, Screws)

A typical large framing nail (16d common, 3.5 inches long) has a resistance of roughly 1 mΩ. Even under an extreme geoelectric field of 100–300 V/km, the induced voltage across the nail is only a few to a few tens of millivolts. The resulting power dissipation is well under 1 watt.

At these power levels the nail and the surrounding wood experience only a trivial temperature rise — far below the 200–250 °C range where wood begins to char or smolder. The same conclusion applies to individual anchor bolts, joist hangers, short metal connectors, and screws. These short elements are not realistic ignition sources under Carrington-class or even highly extrapolated X400–X1000-class fields.

These same short fasteners also present very low risk under a fast pulse because they do not form long continuous current paths.

Higher-Risk Pathways

The components that can generate meaningful heat under sustained geoelectric fields are those that form long continuous conductive paths aligned with the field:

Component	Typical Continuous Length	Estimated Power at Extreme Fields (100–300 V/km)	Relative Ignition Concern
Continuous steel rebar in beams, grade beams, or lintels (especially foam-formed ICF channels)	40–120+ ft	Tens to hundreds of watts	Highest
Long continuous metal conduit runs in contact with wood or foam	20–80+ ft	Tens to >100 W	High
Continuous metal strapping, bridging, or long hurricane-tie runs	20–60+ ft	Tens of watts possible	Moderate to High
Long continuous metal plumbing lines	Whole-house runs	Variable, can be significant	Moderate to High

In standard ICF construction the highest risk is continuous steel rebar inside EPS-foam-formed beam channels, where heat is trapped on three sides. In stick-frame houses the highest risks are long metal conduit runs and continuous metal strapping that remain in contact with wood for many hours.

Additional pulse-related considerations for the same components

Long continuous steel rebar, conduit, and strapping remain the highest-concern items under a massive pulse because they provide low-impedance paths that can carry large impulse currents.

The greatest practical ignition risk in the pulse case is usually not bulk heating of the steel itself, but arcing at joints, terminations, bends, or points where the conductor is close to wood or foam.

Poor or intermittent connections (loose conduit fittings, overlapping strapping, etc.) increase the chance of localized arcing.

Metal Roofing Systems

Metal roofing occupies an intermediate position.

Standing-seam systems often create long continuous conductive paths (20–40+ ft panels seamed together). Under extreme geoelectric fields these paths can dissipate tens to hundreds of watts, so the metal itself can become noticeably warm during multi-hour events. Under a fast pulse, the same long continuous runs can also act as preferential current paths, raising the possibility of side-flash to nearby conductive objects or to the structure if bonding is incomplete.

However, two factors greatly reduce the practical ignition risk compared with rebar or conduit:

The top surface is exposed to open air, allowing relatively good convective cooling.

The panels are normally separated from wood by underlayment or battens.

Screw-down or corrugated metal roofs are generally lower risk because the panels are more electrically interrupted. Overall, metal roofing is more likely to experience elevated temperatures than to directly ignite the structure, provided normal underlayment and attic ventilation are present.

Summary Ranking of Realistic Ignition Concern

Highest concern (both GIC heating and pulse arcing)

Long continuous steel rebar inside foam-formed beam channels (standard ICF)

Long continuous metal conduit in contact with wood or foam

Moderate concern

Continuous metal strapping or bridging

Long continuous standing-seam metal roofing (metal heating more than direct ignition under GIC; possible side-flash path under pulse)

Negligible concern

Framing nails, screws, individual anchor bolts, joist hangers, short connectors, and other short steel fasteners

The practical conclusion is that ignition risk is driven by long continuous conductive paths. Under extreme GIC the dominant mechanism is sustained resistive heating in thermally insulated locations. Under extreme lightning or a massive pulse the dominant mechanism is localized arcing and high current density at connections and discontinuities.

This is one of the central reasons the Carrington House design replaces the primary long structural reinforcement with non-conductive GFRP and favors non-metallic conduit for long runs: those choices remove the highest-risk pathways for both classes of threat while ordinary short fasteners remain harmless under even extreme geoelectric fields or fast high-current pulses.

2.0 Carrington House Concepts- Sketches and Construction Process

In the following sections I will be presenting the construction design sketches of several Carrington House parts/components and their typical construction process. These are the methods that I think are simple enough to be cost effective with readily available components.

I know everyone will have their own ideas and methods which are perfectly fine. Feel free to experiment with your project or build it “your way”. However, just remember that to create a 6-sided faraday cage structure, every piece of steel mesh and any conductors HAVE to be mechanically and electrically connected to the faraday mesh cage system, tested for continuity and verify connection to the single ground point.

Remember, this system is designed and installed to work during the short period of time when the future disaster event hits. There will be no time to “redo” if it is not constructed perfectly the first and only time. The electrical world grid will be down for a very long time so fixing some error afterwards Well... wont happen.

The completed structure will be a great ICF home to live in for the next few years or a few decades, but when the big one hits.... It will be one of the few houses that will survive intact to be the home for many future post event generations and still be able to operate electrical off-grid systems.

2.1 The Carrington House Simple and Effective (SaE) Concept

This is the simplest practical configuration that provides meaningful protection against the two primary GIC-related hazards in a residential structure: (1) induction heating of long continuous steel reinforcement that can crack or damage concrete, and (2) residual internal voltage differences that can cause electrical arcing.

Replacement of the steel rebar standard design by the use of the GFRP (Glass Fiber Reinforced Polymer) solves the big induction heating problem. Arcing is a real hazard — it can deliver an electrical shock to occupants and can produce localized overheating of wiring with the potential for spot fires. The SaE design reduces both risks while remaining fully buildable with normal ICF materials and methods.

The following sections show where and how to install the single layer of 4×4 galvanized steel welded wire mesh under the house footings and under the interior concrete floor slab, how the two mesh layers are bonded together with simple galvanized conductors, and how vertical steel collector rods and a light interior copper equipotential grid complete the SaE system.

2.1.1 Footing Mesh connections to inner ground slab mesh layer and to the vertical steel electric grounding rods (next section)

After the footings are surveyed and laid out by the crew, mark the footing center line of the footings with ground spray paint. Then the crew would measure and cut lengths of mesh needed and then place the mesh on the ground or gravel with the mesh centerline located over the footing centerline sprayed on the ground. After the footings are ready the concrete is poured and finished. See the following pictures.

Before the footings are backfilled with gravel a series of galvanized wire conductors are installed as described in the following:

1. Lay the galvanized conductor wires on top of the exposed mesh on the **inside** side of the footing parallel to the footing so it crosses many of the 4x4 squares.
2. Securely hog-ring (or tightly wire-tie) the wire conductor (about 20 to 24 inches long) to the mesh at several points. Spray the connection hog rings and mesh with the conductive spray paint.
3. Leave sufficient free length of the wire connector coiled or protected so it can later be brought up and connected to the mesh that will be placed under the interior slab foam and vapor barrier. Secure it out of the way so it cannot be buried by accident during backfill.

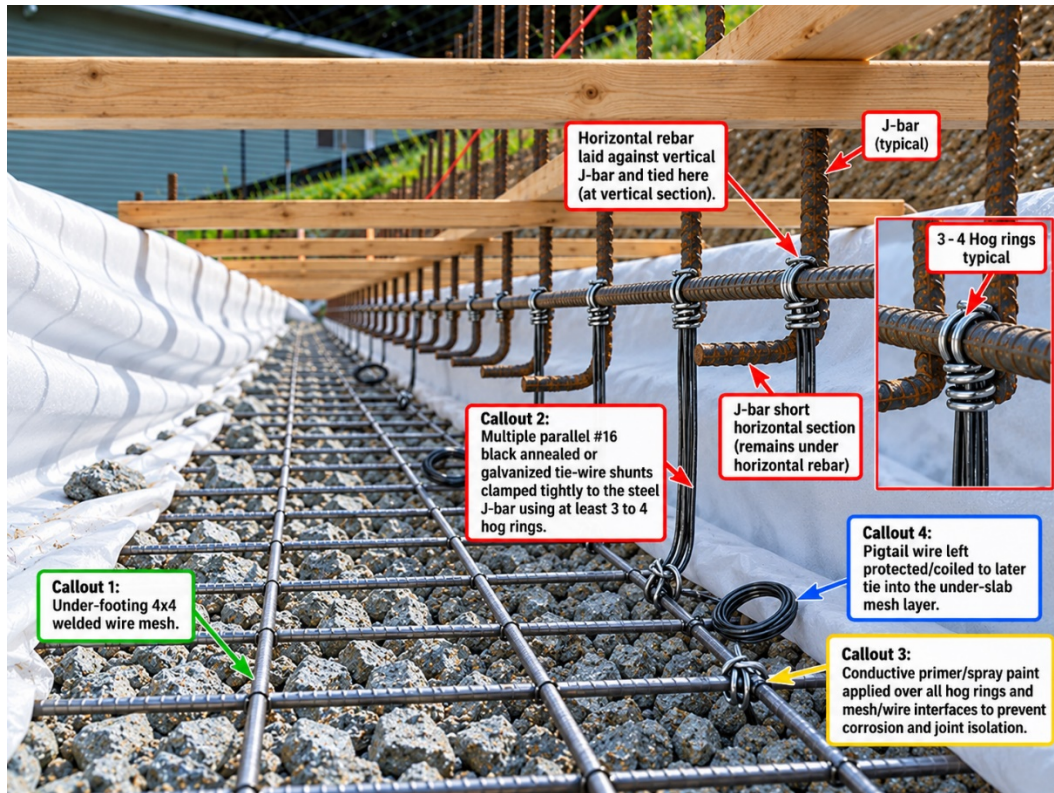
4. Space these bonding conductors approximately every 6 feet along the perimeter.
5. Marking for Vertical Steel Electrical Potential Ground Rods - Consult the construction plan set and use spray paint to mark on the top of the footing the locations for these vertical grounding rods. See Section 2.1.3 for installation instructions for these bars.
6. Protect the free ends of the bonding conductors so they cannot be damaged or buried during backfill and gravel placement.

These wire connectors from the under-footing mesh create multiple low-resistance paths that electrically tie the under-footing mesh to the under-slab mesh, maintaining a continuous equipotential plane even when the interior slab is at a higher elevation.

Galvanized connector wire to use:

Item	Recommendation	Notes
Material	Galvanized steel / Std Tie Wire	Matches the 4×4 welded wire mesh
Size	6 AWG (≈ 0.162 – 0.192 in diameter) or 4 AWG or use standard rebar steel tie wire wrapped several times.	6 AWG is the practical minimum; 4 AWG is more robust if available
Type	Solid or stranded galvanized steel wire	Solid is easier to hog-ring; stranded is more flexible
Spacing	Every 6 feet along the inside face of the footing	As you planned
Connection to mesh	Hog rings (or stainless-steel wire ties) at multiple points	Make a solid mechanical and electrical connection
Free length	Long enough to reach the future under-slab mesh after it is placed on the foam/vapor barrier	Crew determines exact length from the drawings





The forming system shown in these pictures is from the Fab-Form Company located in Delta BC. It is rolls of reinforced plastic fabric that is a simple to install system and when the concrete is cured, the wood is removed (the fabric is stapled to the top of the 2x stock) and reused as the construction proceeds. I have used this product many times.

2.1.2 Mesh Layer under the Ground Floor Concrete Slab

After the plumbing and utility piping and other items are placed per design on the ground under the ground floor concrete slab area and backfilled with gravel, the mesh is installed. The crew will unroll lengths of the mesh from the bulk purchased rolls and install the lengths so that all the square footage inside the ICF walls is covered with mesh. All mesh to mesh and mesh to the connecting wires up from the mesh under the footings hog ring connections will be completed and sprayed with the conducting spray paint. Ensure that the mesh is all connected and test as specified with an electric meter to ensure. After all hog-ring connections are complete, verify low-resistance continuity between the under-footing mesh and the under-slab mesh with an ohmmeter. All readings should be well under 1 ohm.

When this step is completed, then the under-the-slab vapor barrier plastic sheets can be placed followed by the installation of the EPS under the slab thermal / dielectric foam panels. Complete the ground floor slab installation per design.

This completes the installation of the under-house mesh. The ICF walls can then be placed and poured.

2.1.3 Vertical Steel Rebar rods installed on vertical ICF walls.

In the Simple and Effective (SaE) configuration, vertical steel rebar rods (as conductors) are installed inside the ICF walls flush against the inside of the external face of the block. These rods run from the top of the footing continuously to the top of the wall and are bonded to the single-point grounding system via its connection to the under the slab and under the house mesh grid network. They are one of the three defining elements that distinguish the SaE design from a full exterior Faraday cage while still providing meaningful control of residual internal voltages.

Purpose Because the SaE design does not use continuous exterior mesh on the walls, residual voltage differences can still develop between grade level and the top of the wall during strong geoelectric events. The vertical steel rods act as low-resistance collectors and equalizers. They:

- Reduce vertical voltage gradients along the height of the wall
- Provide preferred paths for residual currents to flow downward to the single ground point
- Help limit the amount of GIC-related current that can enter the structure through openings, windows, and the top of the wall

Recommended Installation

- After the ICF wall blocks are installed and prior to placing the vertical GFRP, look for the paint marks along the footing to find the locations where the vertical grounding rebar rods are to be inserted down inside the ICF wall and secured so that it rests against the exterior inner face of the ICF blocks. Remove some of the bottom ICF block foam so the 90 degree leg of the rebar can rotate out from the block.
- Use #4 or #5 steel rebar with enough of a 90-degree bend at the bottom end of the bar (about 4 inches) so that after it is placed down into the wall, it can be rotated so that the 90 degree bend pushes under/ through the icf block. Remember that as the ICF wall blocks are laid, horizontal GFRP will be laid on each layer (or per plan) and the vertical GFRP will not be placed vertically until the vertical steel ground bars are placed and secured.

The under-footing mesh galvanized connector wire that was already installed on the mesh at these locations will then be attached to the rebar leg that is now visible at the base of the ICF wall (on top of the footing). Connect the wire from the mesh to the rebar with hog rings and spray with conducting paint.

- Space the rods approximately 6 to 8 feet on center around the entire perimeter and per plan.
- At the top of the wall, run a continuous length of the galvanized mesh connector wire around the entire top of wall perimeter inside the ICF blocks. Hog-ring the galvanized wire to the top of each vertical #4/#5 bar. Make the connections solid and spray painted with the conductive paint so the wire cannot come loose during concrete placement or later construction.
- This creates a simple equipotential ring at the top of the wall without adding another long steel element.

- **Top of wall horizontal rebar equipotential ring and connecting to the steel roof rebar** – see the roof install section for details, but in overview, this horizontal rebar ring that connects down to the under-footing mesh is there to install connection wires from the horizontal roof beam steel to the horizontal equipotential ring so that the roof steel is electrically connected into the mesh network.

Proceed to place the GFRP vertical rebar per plan.

2.1.4 Inside copper wire grounding wires system

After the house has been weathered in and the electrical systems are being installed, the contractor installs a simple interior equipotential grid of copper grounding wires.

Vertical 2-gauge copper wires are run on the inner faces of the exterior ICF walls (under the drywall) and are connected at the top to horizontal loops placed at the ceiling-to-wall intersection in each room. These horizontal loops are then bonded together and connected by larger copper conductors back to the main electrical panel and ultimately to the single-point grounding system that also serves the under-slab and under-footing mesh.

The purpose of this interior copper grid is to:

- Continuously drain and equalize residual internal voltage differences that may appear during strong geoelectric events
- Provide preferred low-resistance discharge paths so that residual currents are directed safely to the single ground point
- Greatly reduce the chance of random arcing between metal objects, outlets, or wiring inside the living space

Because the grid is installed on a relatively large spacing and uses ordinary copper grounding wire, it is inexpensive and easy to place during normal electrical rough-in. It does not create a Faraday cage and is not intended to. Its sole function is to keep residual internal voltages low and controlled.

This interior copper equipotential grid is a standard and recommended component of the Simple and Effective (SaE) design.

2.2 The Carrington Full 6-sided Faraday Cage Concept

The Full 6-Sided Faraday Cage (FFC) configuration adds a continuous exterior mesh enclosure on the walls and roof to the under-house mesh system already described in the SaE section. The result is a complete 6-sided conductive cage that surrounds the entire structure.

2.2.1 The welded wire mesh cage:

Components:

- 10-gauge 4x4 galvanized welded wire mesh
- optional 6x6 welded wire mesh for slabs (if desired)
- Hog ring wire clamps and tools
- Through-the-ICF wall electrical connectors ie the HC-U and HC-L
- Capped screws and washers to attach mesh to ICF wall furring strips
- 10 gauge galvanized wire spool to use as needed for mesh to mesh connections
- Conductive spray paint or equal primer spray paint

The core of the Carrington House is a complete 6-sided Faraday cage installed on all 6 sides of the house: (1) the footings / grade contacting floor slabs (2) exterior walls from footings to roof (3) the roof slab. This makes the theoretical 6 sides.



A **10-gauge 4x4 galvanized welded wire mesh** is the primary faraday cage component which is a readily available commercial material. It should be purchased in bulk as rolls of 4-foot wide (standard) mesh with length determined by the buyer. Each project site should have a standard mesh roll holder to facilitate cutting the mesh at required lengths easily.

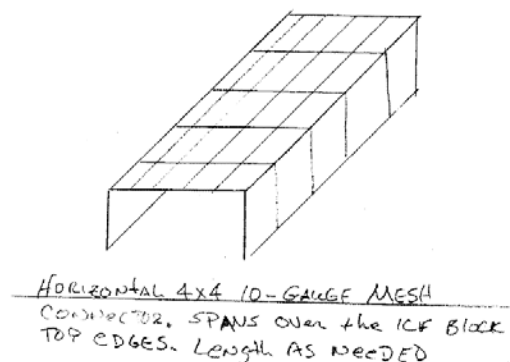
The option of using a 6x6 mesh in the slabs is possible, however it will conduct less GIC current than the 4x4. Mesh sizes and performance factors are discussed in later sections. For the walls, the 4x4 is the configuration to use in all houses.

2.2.2 Through-ICF Wall Electrical Connectors

Horizontal mesh connectors: (HC-U & HC-L); The key components of the faraday cage that are embedded in the wall concrete are the Horizontal Connector U-channel (HC-U) and the Horizontal Connector L shape (HC-L).

These two components and other similar electrical connections discussed in other sections connect all mesh sides of the 6-sided faraday cage together to guide the GIC currents under and around the building.

These are designed to be; (1) the mechanical and electrical connection between the outside mesh on the walls; (2) perform as the electrical conductor going through the concrete walls; (3) be connected



with the mesh placed inside ground level floor slabs and on in the roof slabs and; (4) perform as a solid embedded metal mesh plate to connect vertical wall mesh to the wall.

These connectors are made from 4x4 10-gauge galvanized mesh, designed to be placed over the top/bottom on selected layers of ICF blocks near the base of the wall/footings and at the top to connect with the roof. A HC-U is also placed on the ICF block layer approximately 4 feet up from the top of the footing to secure the first horizontal row of mesh onto the wall. This gives a precise horizontal line and structural support point to hold the top of the mesh panel as workers secure it to the wall from the HC-U connector down to the bottom.

The L shaped connector is to be used like the HC-U on top of ICF block layers and is also installed in the vertical wall intersection areas.

The 90-degree leg is on the exterior of the wall with the and connected with the vertical mesh panels. The mesh that sticks past the inside ICF wall is the place to connect galvanized wire that connects the horizontal connector with the slab mesh. The L shape connector is also used in vertical wall 90-degree and 45-degree corners and other places as needed for simplified installation.

At outside and inside corners the HC-L is oriented so that one leg lies against each wall face, allowing the vertical mesh panels on both walls to be hog-ringed to the same continuous connector.

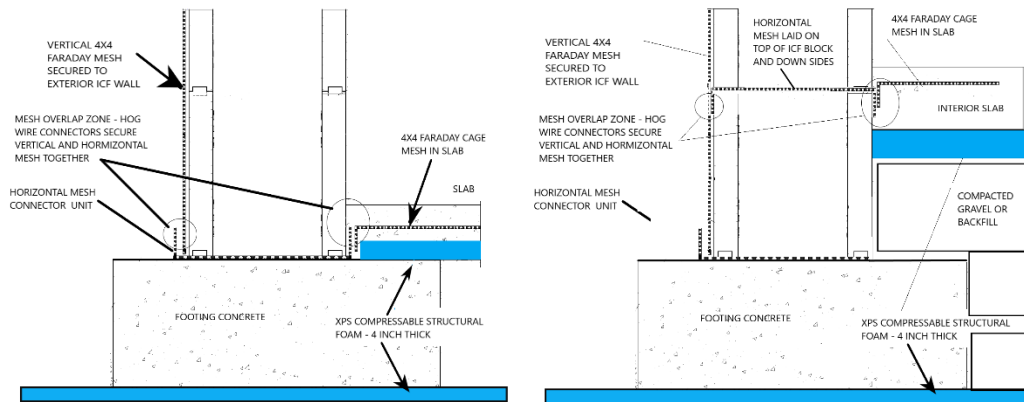


Figure.8j7i9.Wall.and.Slab.with.Mesh.Connector

Window and Door Bucks: The HC-U and HC-L are designed to be installed as part of window and door bucks. They are to be placed on the concrete side of the bucks.

The buck design will give provisions for installation of removable mesh screens or shutters that are directly connected to the exterior mesh cage. The exterior wall mesh is connected to the horizontal connectors that surround the buck perimeter as noted.

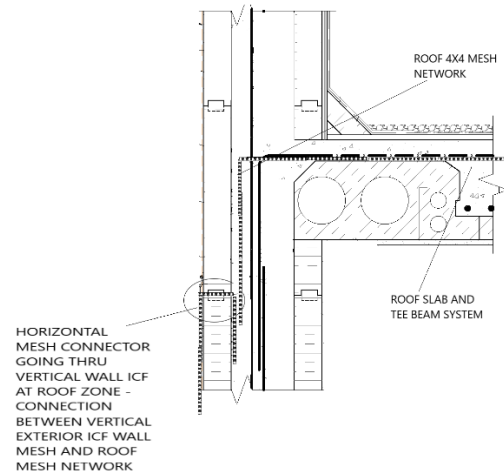


Slabs: The horizontal connectors need to be placed so that the internal floor slab's mesh edge can be readily connected to it. It is up to the designer to ensure this is a construction detail on the drawing set. The connection can be physically connecting mesh to mesh using Hog rings, or with heavy wires connecting the two mesh interfaces. The important aspect is to make sure the faraday cage mesh is all connected and tested.

The easiest way to do this is to locate the slab elevation relative to the vertical walls ICF blocks so that the horizontal connector mesh can simply be placed on the top of an ICF block row and then the next row of ICF blocks is simply installed as normal. In this manner there is NO required cutting or trimming of any ICF block and the horizontal mesh connector is held in place during concrete pouring.

Roofs: The exterior wall mesh connection to the roof slab mesh will use either the HC-U or the HC-L placed at the top of the wall. Where the connectors are located is up to the design engineer or contractor.

However, there are two locations for the roof mesh. The first is where there is required to be some steel rebar in the roof beam channels. For this configuration, the roof slab mesh is placed inside the slab so that many electrical connections are made between the steel bar and the mesh. This is discussed in later sections.



In the preferred design alternative, the roof concrete beams and slab are supported by GFRP structural rebar per design. For this roof configuration, the roof faraday mesh is installed on the roof after the slab is poured. Because there is no steel in the roof slab, there is no need to embed the roof mesh. This configuration allows the induction heating of the roof faraday mesh as the GIC currents flow around the cage to radiate/conduction heat transfer from the mesh to the air. The key point in this approach is that this heat is not placed in the concrete and if the GIC events are of long duration, this design will prevent the concrete from exceeding and strength related to upper temperature limits.

To enable the wall connectors to be connected to the roof mesh laying on top of the roof, wire connections are made around the inside perimeter of the roof parapet wall between the HC-U/HC-L and the slab mesh. Details for this are shown.

2.2.3 Vertical wall mesh panels: After the exterior ICF walls are poured the vertical mesh panel installation begins at the footings. The panel sections are placed against the wall and attached to the ICF block internal vertical furring strips with screws with capping washers. This mesh is installed on the exterior of all walls against the poured ICF walls (under the exterior finish systems such as brick, stucco or siding).

Recommended Vertical Mesh Installation Sequence - This sequence is very buildable, minimizes warping, and ensures excellent electrical continuity. It also allows workers to work in manageable sections without fighting long, floppy full-height sheets.

Mesh should be installed with a one-square overlap and bonded at the wire interfaces with 9-gauge hog rings in many spots. One thing to note is that as the mesh installation process moves along the wall, you will encounter window and door bucks or other wall penetrations. Be sure to overlap the wall mesh to these areas and use some extra hog rings to ensure electrical connections are created.

In the areas of the walls where there is a 90 degree corner, a 45 degree or otherwise, use a HC-L connector to bridge the corner/wall to wall interface to ensure a solid mesh to mesh connection is created. This overlap using the connector allows the corner mesh material to be screwed to the ICF wall furring strips. In very congested area, feel free to use wire and hog rings to make the connection to the faraday mesh cage.

Conductive spray paint or equal primer is applied at all hog ring connections to prevent long-term corrosion and to ensure that the hog ring connection is sealed to prevent any concrete or waterproofing materials such as tar can get into the connection joint and break the electrical conduction.

1. As the ICF wall is being installed **prior to concrete pour** - Place horizontal connectors at the base row or where it will be needed to connect with the interior slab, on the row that is 4 feet up from the top of the footing and at the top of the wall (or as needed to connect into the roof slab system). The connector that is 4 foot above the top of the footing is where the first horizontal row of mesh will be connected with hog rings to it.
2. Finish pouring the walls up to the roof level and clean up the exterior to facilitate the mesh installation.
3. **Install first horizontal section of mesh.**
4. Measure the wall from distance from vertical corner to the next vertical corner. Pull off that length from the roll dispenser.
5. Start at one corner or wall intersection – square up the 4-foot side of the cut roll section and use a hog rings (every 6 to 8 inches) to connect the top of the mesh to the HC-U embedded in the wall up from the footing top. Begin to un-roll the mesh and start to connect it at the same elevation on the connector that the first hog ring was placed. Move down the wall, connecting the mesh to the connector until you get to the end which should be at the next wall intersection or vertical corner. At this time, you begin to tighten the mesh downward towards the footing and use the wall screws to secure the mesh to the ICF furring strips. The bottom of the mesh row is then secured to the base connector with hog rings.
6. Hog-ring the corner mesh face connection to the vertical HC-L.
7. Continue around the house until you have installed the first row of mesh completely around the house perimeter.
8. **Install remaining mesh downward from the top of the wall connector**
9. The remaining wall mesh is installed first at the top wall connector and allowed to hang vertically downward to overlap the first horizontal row of mesh that is secured on the wall. Proceed to finish hanging and securing the remaining wall mesh panels.
10. Measure from the top HC-U/HC-L downward to create the correct overlap (6–12 inches recommended) with the already-installed lower band.
11. Cut the next length of mesh.
12. Hang it from the top HC-L/HC-U, hog-ring the top edge securely, then work downward, screwing to furring strips and hog-ringing the overlap to the lower band. The lower section of the vertically hanging mesh panel (over-lap area) is to be hog ring connected to the lower mesh panel.

13. **Repeat around the building** Continue this process (mid-level band → downward secure → upward fill) until you return to the starting corner. Always maintain generous overlaps and conductive primer/paint at all joints.

2.3 Carrington Stick Framed Design Options

Full Carrington House SaE performance cannot be achieved with conventional wood-framed construction. The continuous dielectric envelope, non-conductive primary structure, and inherent mass of the ICF system are unique advantages of the concrete-based designs.

Meaningful dual-threat improvement is still possible. The goal of the stick-framed options is to reduce the highest-risk pathways for both sustained geoelectric currents (GIC) and extreme lightning / massive pulse events, while remaining practical for owner-builders and conventional framing crews.

Two different approaches are required:

- Existing homes (retrofit) – limited access to the foundation and many irreversible construction choices already made.
- New construction – the full recommended dual-threat package can be installed cleanly during normal building sequence.

2.3.1 Existing Stick Framed Homes (Retrofit)

Retrofitting an existing stick-framed house faces hard physical limits. The foundation is already poured, the walls and roof are framed, and most of the steel (nails, plates, hangers, possible beams) is permanently embedded. Complete elimination of induction-heating and impulse-current paths is not realistic. The objective is therefore to reduce the most dangerous entry points and equalize potentials as much as practical.

Highest-value retrofit measures (ranked)

1. **Under-slab / perimeter equipotential improvement (where accessible)** If the crawlspace or basement allows access, install a supplemental copper or galvanized mesh or ring as close to the soil as possible and bond it to a single-point grounding electrode system. Where the slab is on grade and inaccessible, focus on a perimeter ring outside the foundation.
2. **Segmented outer equipotential ring with isolating spark gaps** Install a copper or bare copper-clad ring around the exterior of the house, broken into segments joined by isolating spark gaps. This allows the ring to equalize during a fast pulse while avoiding a continuous low-impedance loop that can collect quasi-DC GIC.
3. **Dielectric isolation of metallic utilities** Install dielectric unions or non-metallic sections on water, gas, and other conductive utility lines where they enter the building. This interrupts long continuous conductive paths that can import both GIC and impulse current.
4. **Interior equipotential grid (practical version)** Add a simplified network of 2-gauge or 4-gauge copper conductors on major interior walls (or in the attic and basement) and bond

them back to the single grounding point. This reduces residual internal voltage gradients and provides preferred discharge paths.

5. **Non-metallic conduit for accessible long runs** Where long wiring runs are being replaced or added, use non-metallic conduit instead of continuous metal conduit.
6. **Local Faraday + radiation safe room** The single most effective protection for people and critical electronics in a retrofit is a well-executed FEMA or ICC-500 safe room (or a high-quality garage/basement shelter). This does not protect the rest of the house but creates a survivable core.

What is usually not practical in retrofit

- Replacing the primary structural system with GFRP
- Creating a continuous dielectric foam envelope around the foundation and walls
- Removing or isolating the large quantity of nails, plates, hangers, and connectors already in the structure
- Full 6-sided exterior mesh cage without major exterior remodeling

Expected performance level after thoughtful retrofit

- Ground-current entry: moderately reduced
- Internal voltage gradients: moderately reduced (especially with the interior grid)
- Induction heating risk: still present in the existing steel components, but the longest external paths can be interrupted
- Extreme lightning / pulse path control: improved by the segmented ring, dielectric unions, and interior grid
- Long-duration seismic performance: essentially unchanged (still limited by conventional wood framing and connections)
- Overall: meaningfully better than a completely unprotected stick house, but clearly short of Carrington House SaE performance

Practical recommendation for existing homes

Prioritize the segmented outer ring with spark gaps, dielectric isolation of utilities, a practical interior equipotential grid, and a high-quality local safe room. These measures give the largest reduction in risk for the available budget and disruption. Diagrams showing typical component locations for crawlspace, basement, and slab-on-grade conditions will be provided later in this chapter.

2.3.2 New Stick Framed Homes

New construction offers the best opportunity to apply dual-threat principles to a wood-framed house. While the finished structure will still lack the continuous dielectric envelope and non-conductive primary structure of the Carrington House SaE, most of the highest-value protective features can be installed cleanly during normal construction.

Recommended Dual-Threat Package for New Stick-Framed Homes

The following package is the strongest practical configuration currently recommended for new wood-framed construction:

1. **Dielectric isolation at the foundation** Install continuous XPS (or equivalent) insulation against the exterior of the footing and stem wall, extending from the bottom of the footing to grade or above. This creates a dielectric barrier that raises the impedance to both quasi-DC ground currents and fast lateral pulse currents.
2. **GFRP reinforcement in footings, slabs, basement and stem walls (strongly recommended)** Replace conventional steel rebar with ICC-approved structural GFRP. This removes the long continuous conductive paths that would otherwise collect both sustained GIC and impulse current at the base of the structure.
3. **Segmented outer equipotential ring with isolating spark gaps** Install a copper or copper-clad ring around the exterior perimeter, broken into segments joined by isolating spark gaps. The ring equalizes electrical potentials during a fast pulse while avoiding a continuous low-impedance loop that can collect quasi-DC current during a prolonged geoelectric event.
4. **Optional under-slab equipotential mesh** A galvanized mesh should/may be placed under the slab (beneath the vapor barrier and foam). Connections from this mesh to the outer ring or grounding system should be made only through isolating spark gaps so the mesh does not become a continuous GIC collector.
5. **Single-point grounding electrode system** Keep the grounding electrode system as compact as practical and bring all protective conductors (outer ring segments via spark gaps, interior grid, electrical service, etc.) to a single grounding reference point.
6. **Dielectric isolation of metallic utilities** Install dielectric unions or non-metallic sections on water, gas, and other conductive lines where they enter the building.
7. **Interior equipotential grid** Install a network of 2-gauge or 4-gauge copper conductors on the interior side of exterior walls (and selected interior walls) and bond them back to the single grounding point. This reduces residual internal voltage gradients and provides preferred discharge paths after both GIC and pulse events.
8. **Non-metallic conduit for long wiring runs** Use non-metallic conduit for long runs wherever code and practical routing allow. Continuous metal conduit should be avoided because it forms an excellent collector for both sustained and impulse currents.

9. **Local Faraday + radiation safe room or Ark Bunker** - Include a well-designed FEMA or ICC-500 safe room (or equivalent high-performance shelter space) as the protected core for people and critical electronics.

Construction Sequence Notes

- Place the under-slab mesh (if used) and any grounding electrode components before the vapor barrier and slab foam.
- Install the exterior XPS dielectric layer against the footing/stem wall before backfill.
- Set the segmented outer ring and spark-gap locations early so final grading and landscaping do not interfere.
- Route the interior equipotential grid conductors during normal rough-in, before insulation and drywall.
- Coordinate dielectric unions on utilities with the plumber and gas fitter at the rough-in stage.

Expected Threat Performance Level

Performance Area	Code-Minimum Stick House	New Stick House with Dual-Threat Package	Carrington House SaE
Ground-current entry	High	Moderately to Strongly Reduced	Strongly Reduced
Induction heating risk	High	Reduced (footing/stem wall) but steel remains in framing	Extremely Low
Extreme lightning / pulse path control	Poor	Good	Good to Very Good
Internal voltage gradients	Highest	Moderately Reduced	Well Controlled
Long-duration seismic performance	Poor to Fair	Poor to Fair (unchanged)	High
Overall dual-threat protection	Minimal	Meaningful improvement	Highest practical

Summary

A new stick-framed house built with the dual-threat package above will be significantly more resilient than a conventional code-minimum wood house against both sustained geoelectric currents and extreme lightning / massive pulse events. It will not match the structural stiffness, dielectric continuity, or induction-heating immunity of the Carrington House SaE.

For projects that must remain wood-framed, this package represents the strongest practical application of the design principles developed in this book. Diagrams showing component locations for typical slab-on-grade and crawlspace foundations will be provided later in this chapter.

2.3 Site Drainage and Design

When you look at the building site as a land buyer, look at the topography and ask if you are going to build a basement under the house, can the footing and under slab drainage piping be GRAVITY drains out to a lower point away from the house? Many people do not realize what the two main problem are that they need to avoid especially if the house is going to incorporate a Faraday cage.

There are two parts. The first is that if the foundation and under slab drainage system cannot free drain away from the basement, that means you need a water sump pump. In these days that is a problem. Why? Because when a Carrington or less powerful solar flare and CME arrives at Earth, the power grid will drop offline for a long time. No power to the house or sump pump. Problem number 2; the basement fills up with water slowly and cannot free drain.

The core reason for ensuring your home is designed to have a free draining foundation and under slab system is that accumulated water around the footings and under the slab can significantly reduce the dielectric isolation that was built under the footing and slab. These areas will be very waterlogged, and the protection from the GIC effects will drop and drop. You want to keep the water away from the footings, basement walls and under the basement floor slabs.

If you are going to build a single-story slab on grade or over a crawl space, then the amount of elevation to achieve free draining footing and under slab systems gets much easier to accommodate. So, keep this in mind as you look for and select a building site.

2.4 Excavating, Footings and Ground Slabs

Components:

- Under footing EPS or XPS dielectric structural compression rated foam
- Under the ground slab dielectric foam (same as above)
- GFRP footing/slab rebar
- 4x4 slab mesh
- camps and tools
- Litefoot product – use to form footings with dielectric foam for under and both sides.

When a site is excavated and graded flat or with the step-downs needed for the design, the placement of either XPS or EPS foam is the next construction step. This foam can be placed directly on compacted soil or on compacted gravels. Depending on the soil characteristics at the job site, sometimes a good approach is to lay down a compacted gravel base of about 12 inches. This gives a vertical space zone in the gravel to be trenched for placing plumbing and drainage piping under the foam layer. It also gives a good drainage zone under the house.

There are foam forming systems from Fast Form or Liteform along with standard forms that most construction companies utilize. The following “Litefoot” information is presented as this forming system can provide the required footing (sides and over the exterior top and projecting away from the footing/stem wall) and under slab dielectric foam in the best configuration and is readily available.

LiteFoot 18" and 30"



TECHNICAL BULLETIN 04.07.20

DESCRIPTION

LiteFoot is an insulated concrete footing form for frost protected shallow foundations. It is an engineered and approved method that meets today's building codes (meets or exceeds R403.3 - IRC2015). LiteFoot is used in Northern regions across the US and endures sub-zero temperatures without failure.

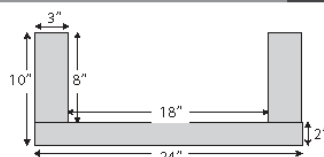
Typical Residential Footing

Single - 24" wide x 8' long
Pallet qty - 24
Concrete Footing - 18" x 8"

PARTS AND TOOLS NEEDED FOR BRACING
WOOD STUDS & STAKES
3" COARSE THREAD SCREWS
SAW
FOAM ADHESIVE

Residential Specifications

PART # 42.45



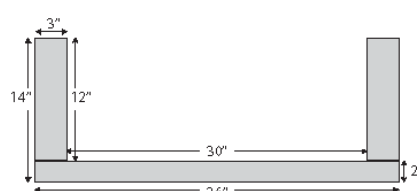
Typical Commercial Footing

Single - 36" wide x 8' long
Pallet qty - 12
Concrete Footing - 30" x 12"

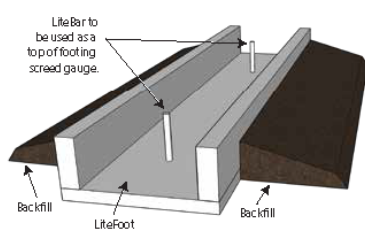
PARTS AND TOOLS NEEDED FOR BRACING
WOOD STUDS & STAKES
3" COARSE THREAD SCREWS
SAW
FOAM ADHESIVE

Commercial Specifications

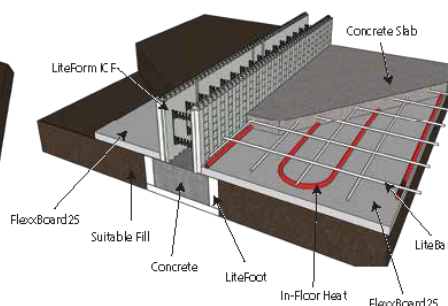
PART # 42.46



Typical Bracing Option



Cutaway with ICF Wall Interior/Exterior



800.551.3313

Info@LiteForm.com

1950 W. 29th Street | South Sioux City, NE 68776

After the footings and any ground beams under the slab areas are poured and finished, the ICF blocks and the faraday horizontal connectors are staged for installation.

As seen on the previous Litefoot graphic, you can see a first row of ICF blocks installed on the footing. In this configuration, the HC-U / HC-L would be installed under this first row as the blocks are laid on the footing and prior to concrete wall pour.

At this point prior to installing the ground slab, the electrical connections between all the mesh slab panels to other mesh panels and to the horizontal connectors has to be completed and inspected. Continuity checks at numerous locations around the perimeter from the outside and inside need to be completed. Once these inspection sheets are completed and verified, pouring the basement or ground slab can be finished. At this point the basement slab faraday cage section is finished.

2.5 Construction Documents

As you begin to plan your Carrington House ICF project, there are several important things to integrate into the documents. These can be part of the permit construction site documents, or these can be owner/builder documents that are quality control checklists or records to verify that all mesh to mesh and other components that are integral to a Carrington House are installed and tested.

The purpose of spending the time and effort to track this is to ensure that your system is installed as designed and it works. Nothing is more frustrating than getting halfway through a construction project with a lot of concrete poured only to discover that an error was made months ago and not corrected. So,,, give some thought to this caution.

Another aspect to consider is that you may be working with a contractor that is not very attentive to inspecting and documenting simple tasks such as hog ring connections. Are enough of these actually completed? Are each of the connections finished with the spray paint coat of conductive paint? Has the wall installation of the mesh been electrically verified as the install progresses up the wall? Has any of these been signed off on a checklist or schedule that is an official construction document?

Yes, I was serious about how important this is to you. Once again, make sure your contractor is in lockstep with you for this to be successful. Consider adding performance rewards or penalty to his/her construction package to ensure the extra time it is going to take is compensated and making a mistake is not in their best interest. Win-win is the target. Make it happen.

3.0 Technical Details and Discussion

Now we are proceeding into technical basis information with deeper discussions. I think it is important now that you know the few simple aspects of the concept, how it is installed in a normal ICF construction process, to be presented with the information that supports the concept. In developing the concept and writing this book, I learned quite a bit about each of these areas and if

it is too technical, don't worry, it's information that I know some folks will already be familiar with or have a yearn to learn more.

Important Disclaimer This section presents **theoretical, simulated analysis** based on publicly available engineering principles, material properties, GIC/EMP research, and reasonable AI modeling assumptions. It is **not** based on physical testing of any Carrington House structure. Actual performance can vary significantly depending on specific design details, installation quality, soil conditions, maintenance, and many other variables. This analysis is provided for educational and comparative discussion purposes only. Readers should conduct their own independent research and consult qualified professional engineers before making any decisions. The author makes no warranties regarding the accuracy or applicability of these simulations.

3.1 Full 6-Sided Faraday Cages

Most commercial Faraday cage designs focus narrowly on protecting electronics, interior rooms, or generators against short-duration, high-frequency threats such as EMP. They are not engineered for sustained, long-duration geomagnetic or solar-induced currents (GIC). The structure of a house is affected by both threats, but in very different ways.

Quick distinction between the hazards:

- **GIC:** Quasi-DC, low-frequency, long-duration (minutes to weeks). Handled primarily by dielectric isolation + mesh shunting + bonding to a continuous cage + single-point grounding.
- **EMP (E1 component):** Extremely fast, high-frequency pulse (nanoseconds) with very high peak fields. This is what most commercial Faraday products are designed to address. Handled primarily by the mesh cage and conductive concrete.
- **A third related threat is extreme lightning** or a massive atmospheric electric pulse. These events produce very high peak currents and rapid ground-potential rises on microsecond-to-millisecond timescales. The same dielectric isolation + continuous mesh + single-point grounding system that handles long-duration GIC also provides the primary defense against these fast transients (see Section 3.3.12).

What Most Commercial Faraday Products Actually Protect Against

Threat	Protection Level	Typical Products	Notes
High-frequency EMP (E1)	Good to Excellent	Faraday bags, shielded rooms	Fast pulse, high energy. Most products target this.
EMI / RFI	Good	Mesh enclosures, signal blockers	Everyday electronic interference.
Lightning-induced surges	Moderate	Some grounded cages	Brief high-current events.

Threat	Protection Level	Typical Products	Notes
GIC / Quasi-DC (long duration)	Poor to None	Almost none	Sustained low-frequency currents. This is the major gap.

Why Most Cages Fail Against GIC

- Frequency mismatch: GIC are quasi-DC. Many cages lose effectiveness at very low frequencies.
- Grounding problems: Multiple grounding points can create dangerous ground loops during GIC events and actually pull more current into the structure.
- Duration: Most products are tested only against short pulses, not sustained currents lasting hours or days.
- Narrow focus: Nearly all commercial solutions protect electronics, not the building structure itself.

How the Carrington House Faraday Design Is Different

The Carrington House approach turns the entire building into a dielectric-isolated structure surrounded by a true continuous 6-sided Faraday cage. The goal is to force GIC currents to flow **around and under** the house rather than through it. This prevents structural damage, induction heating of conductors, and internal arcing.

This system is specifically engineered for the full GIC/EMP threat spectrum, with particular emphasis on long-duration GIC, through the following measures:

- Dielectric isolation (XPS/EPS foam layers) that greatly increases resistance to current entry at the foundation.
- A low-resistance continuous 6-sided mesh cage that shunts currents around the structure to a single grounding point.
- Strict single-point grounding that eliminates internal current loops.
- Strategic bonding of any remaining conductive elements to the mesh so residual currents are safely collected into the cage.
- Attention to EMP frequencies through mesh continuity and conductive concrete.
- External placement of primary utility surge protection so conducted energy is stopped before it enters the cage.
- Primary focus on protecting the **entire building and its systems**, not just electronics.

This combination makes the Carrington House Faraday system significantly more comprehensive than the large majority of commercial Faraday solutions currently available.

Recommended Internal Wiring Practices

One practical benefit of the Carrington House Faraday cage and dielectric isolation system is that it substantially reduces the need for expensive or labor-intensive internal wiring protection measures.

Simplified GIC current-flow modeling of the recommended configuration (continuous 4×4 exterior mesh with robust bonding, 4-inch XPS dielectric isolation under the footings, and single-point grounding) indicates that internal induced currents are reduced by approximately 85–95%. This brings induced voltages and currents on internal wiring down to levels that are generally safe for normal residential use. (These figures are theoretical estimates based on simplified modeling and are not the result of physical testing of a completed structure.)

Recommended Practices

Standard NM/Romex wiring is acceptable for the majority of branch circuits and general household wiring.

Use EMT conduit or armored cable for: – Long runs (greater than approximately 40 ft) – Critical circuits (sanctuary room, medical equipment, communications) – Any wiring routed near large metal objects or utility penetrations

Main service feeders (200 A or similar) are well protected by the external location of the meter and primary surge protection. Special twisted-pair construction is not required.

All wiring must still comply with applicable electrical codes for safety and installation quality.

This approach provides strong protection while remaining practical and cost-effective. The objective is a house that not only survives the event but can be safely re-energized with minimal rework once external power is restored — a true “re-plug and play” capability.

3.2 EMP Impact on Carrington House Structural Components

This section addresses the electromagnetic pulse (EMP) components that can accompany extreme solar and geomagnetic events — specifically the fast E1 pulse and the slower E3 (GIC-like) component.

Important Clarification on Scope Seismic design is treated separately and is **not** included in the performance ratings or analysis in this section. The Carrington House seismic design basis (Cascadia M9 with Cascadia+ over-strength) is presented in full detail in Section 3.10 and related subsections.

While some models suggest that extreme geomagnetic events may be accompanied by seismic activity, the electromagnetic (EMP/GIC) and seismic design problems are handled as distinct engineering domains in this book. The performance tables that follow evaluate only the electromagnetic performance of the structure under various GIC and EMP intensities.

An EMP can be generated by both a strong solar flare (such as an X45 Carrington-class event) and a micro-nova, but the scale, speed, and effects differ significantly. X45-class flares represent the currently anticipated baseline of severe solar activity during the weakening magnetic field phase. A

micro-nova represents the peak existential threat during a rapid pole flip, producing both the strongest GIC currents and the most intense radiation burst.

1. Solar Flare / CME-Induced EMP (X45 Class)

- **Main components** – E3 (slow, GIC-like): Long-duration geomagnetic disturbance that drives the large ground currents discussed throughout this book. – E1 (fast, high-frequency): A brief, intense electromagnetic pulse, generally much weaker than a nuclear EMP.
- **Duration:** Hours to days of elevated activity.
- **Intensity:** Significant for infrastructure, but within the range the Faraday cage + dielectric design is intended to handle.

2. Micro-Nova-Induced EMP

- A micro-nova on the order of $\sim 9 \times 10^{33}$ ergs would produce a far more extreme EMP.
- The massive X-ray/EUV/gamma burst would cause sudden, extreme ionization of the upper atmosphere, leading to: – An extremely sharp, high-amplitude E1-like pulse (especially on the dayside). – Massive secondary radiation cascades. – Very rapid magnetic field collapse (high dB/dt), driving the highest GIC currents.
- **Duration:** Intense initial burst (minutes) followed by prolonged geomagnetic instability (hours to days).

Summary Comparison for Carrington House Design

Event Type	EMP (E1-like) Strength	GIC Current Density	Main Threat to Structure	Design Response
X45 Solar Flare/CME	Moderate	1,000 – 10,000 A/km ²	Primarily GIC heating & grid damage	Well-handled by cage + dielectric
Micro-Nova Burst	Extremely High	50,000 – 500,000+ A/km ²	Extreme GIC + direct radiation burst	Upper-Limit dielectric, full GFRP, interior sanctuary room critical

Key Assumptions for Carrington House Performance Tables

- Full 6-sided Faraday cage using 4×4 welded wire mesh with excellent bonding.
- Dielectric isolation using high-compression XPS/EPS foam layers.
- Preferred full-composite GFRP rebar system (walls and roof) with mesh placed on the roof surface for optimal heat dissipation.
- Single-point grounding and strategic multi-point bonding of any remaining conductive elements.
- All openings properly protected with bonded shutters / waveguides.

- Ratings focus on structural integrity, occupant safety, and post-event habitability.

Table 1: X45 Flare (Carrington Baseline) to Micro-Nova Peak — Simulated Performance

Magnetic Field Strength	Relative GIC Intensity (A/km²)	E1 Pulse (Fast)	E3 Pulse (Slow / GIC-like)	Overall House Performance (Full GFRP + Upper-Limit Dielectric)	Notes
100%	50 – 200	10 – 50 kV/m	Moderate	Excellent	Standard Carrington-level flare
75%	80 – 320	20 – 80 kV/m	High	Excellent	Strong Carrington-class event
40%	150 – 600+	50 – 200 kV/m	Very High	Very Good	Severe solar storm
25%	300 – 1,200+	100 – 500 kV/m	Extreme	Good	Approaching extreme conditions
0% (Pole Flip Peak)	50,000 – 500,000+ (Micro-Nova)	1,500+ kV/m	Catastrophic	Fair	Micro-Nova / Rapid Pole Flip – Primary Design Target

Key Notes for the Table

- X45 Carrington Baseline represents severe solar flare activity during the weakening magnetic field phase (pre-peak).
- Micro-Nova / Pole Flip Peak is the extreme upper bound driven by a massive X-ray burst ($\sim 9 \times 10^{33}$ ergs) and extremely rapid magnetic field collapse. GIC currents can spike dramatically due to high dB/dt.
- Ratings assume the full Carrington House configuration: continuous 6-sided Faraday cage, full GFRP reinforcement (double-curtain where required), Upper-Limit dielectric isolation, interior sanctuary room, and single-point grounding.
- These ratings evaluate electromagnetic (EMP/GIC) performance only. Seismic performance is evaluated separately under the Cascadia+ criteria in Section 3.10. The Overall House Performance column reflects the structure's ability to maintain structural survival and support re-plug-and-play recovery of protected off-grid systems.

Summary Observation (Theoretical) The preferred full-composite GFRP roof system with surface-mounted mesh significantly improves heat management and structural resilience during long-duration GIC events. This configuration helps preserve habitability and reduces the risk of roof-beam damage compared with traditional steel-reinforced designs.

Important Note These are simplified theoretical models. Real-world outcomes depend on many variables. No system can guarantee absolute protection in the most extreme scenarios. Professional engineering evaluation is strongly recommended.

GIC Intensity Calculation Methodology

The surface current density values used in the tables are derived from the following transparent methodology.

Core Physics GIC is driven by Faraday's Law of Induction: Induced electric field $E \propto -\frac{dB}{dt}$

This geoelectric field then drives currents in the Earth according to Ohm's Law: $J = \sigma \times E$ where

- J = current density (A/km²)
- σ = Earth conductivity
- E = geoelectric field (V/km)

Step-by-Step Process

1. Obtain or reconstruct dB/dt from historical magnetometer records (e.g., Colaba Observatory data from the 1859 Carrington Event) and modern scaling models.
2. Calculate the geoelectric field E using Earth conductivity models. Extreme-event values typically range from 5 – 300+ V/km depending on latitude and geology.
3. Convert to surface current density: $J = \sigma \times E$. Conductive soils produce significantly higher current densities than resistive rock.

Sources for the Numbers Used

- Carrington X45 Baseline (1,000 – 10,000 A/km²) Drawn primarily from Kappenman (2005–2010) and subsequent utility GIC studies, scaled from the 1859 Colaba record using modern conductivity models. This range is widely referenced by NOAA/SWPC and peer-reviewed literature for Carrington-class planning.
- Micro-Nova / Rapid Pole Flip Peak (50,000 – 500,000+ A/km²) Extrapolated by scaling the much higher dB/dt expected during a rapid magnetic-field collapse driven by a $\sim 9 \times 10^{33}$ erg X-ray/EUV burst. This is a modeled upper-bound estimate based on extreme-event physics.

Important Caveats

- These are modeled estimates, not direct measurements.
- Actual GIC depends heavily on local soil resistivity (the largest variable), latitude, and the exact storm dynamics.
- The wide ranges reflect both uncertainty and local variability.

(Full Carrington House Configuration – 6-sided Faraday Cage, Full GFRP, Upper-Limit Dielectric)

Magnetic Field Strength	Overall House Performance	Explanation of Rating
100%	Excellent	Full cage + dielectric isolation handles the event easily. Minimal heating occurs. Protected electronics survival is near 100%. The house remains fully functional with immediate re-plug-and-play capability for internal off-grid systems.
75%	Very Good	Currents are moderately higher but remain well within design margins. Minor external grid issues are expected. The interior stays protected and habitable with little or no repair required. Protected solar and critical systems remain operational.
40%	Good	Increased stress is managed by the mesh, bonding, and GFRP. Some sensitive electronics may fail, but the primary structure remains intact. Moderate, repairable damage is expected. The house is habitable after a short recovery period.
25%	Fair to Good	Higher system stress occurs. The structure holds with acceptable, repairable damage (possible hairline cracking or minor utility repairs). The house remains usable as a shelter with moderate repairs. Protected off-grid systems largely survive.
0% (Pole Flip / Micro-Nova Peak)	Fair	Extreme conditions push the system hard. The building shell survives intact due to the GFRP and dielectric design, providing reliable long-term shelter. Some localized damage and repairs (wiring, secondary systems) are likely. The interior sanctuary zone and protected solar/off-grid systems still enable rapid re-plug-and-play recovery.

Key Notes

- Ratings assume the full Carrington House design (continuous 6-sided Faraday cage, double-curtain GFRP where required, Upper-Limit dielectric isolation, interior sanctuary room, and single-point grounding).
- The primary success metric is survivability and habitability, plus recovery of protected internal systems — not zero damage.
- At Micro-Nova peak, the design priority is keeping the house as a long-term habitable shelter even if the external grid remains down for an extended period.

3.2.1 Structural Components Affected by EMP and How the System Handles Them

Exterior Mesh Cage (Primary Shield) The 4×4 (or optional 6×6) welded wire mesh is highly effective against the fast E1 EMP component because the aperture size is small relative to the wavelength. With good bonding and continuity to the single ground point, attenuation of 60–80+ dB is achievable. The mesh reflects and redistributes most of the high-frequency energy around the structure.

Limitation: Gaps, poor joints, or large unprotected openings (windows and doors) can allow leakage. This is why mesh bonding quality and integration of window/door shutters with the mesh are critical.

Concrete (Secondary Shield) Optional conductive concrete (containing magnetite or other iron-based additives) provides additional attenuation within the ICF walls and slabs.

Window and Door Openings These are the largest potential entry points for EMP energy. High-frequency fields penetrate more easily through openings larger than the mesh grid.

Protection approach: The Horizontal Connectors (HC-U / HC-L) combined with window and door buck detailing create a conductive frame around each opening. When paired with bonded storm shutters (for example, stainless-steel mesh shutters), overall Faraday cage continuity is maintained.

Recommendation: Use conductive weatherstripping or finger-stock gaskets so that the shutter or door makes reliable electrical contact when closed.

Steel Rebar and Internal Steel Elements Unbonded or poorly bonded steel rebar can act as antennas for high-frequency EMP, inducing currents and voltages inside the structure.

Protection approach: The Carrington House multi-point bonding system (parallel-wire method) shorts these induced currents into the main Faraday mesh cage, greatly reducing internal currents. Replacing as much steel as practical with non-conductive GFRP further minimizes the risk.

Utility Penetrations (Wiring, Pipes, HVAC) These are major EMP entry paths. High-frequency pulses can travel along conductors directly into the building.

Protection approach: Waveguide-below-cutoff sleeves, bonding at the penetration point, and EMP-rated surge protection are essential. This is one of the most critical areas for effective EMP defense.

Roof and Slab Mesh Roof mesh is important for blocking downward EMP radiation and skyshine. The top mesh layer, optionally combined with conductive concrete, provides good attenuation.

Overall Assessment for the Carrington House

EMP Protection Level: Good to Very Good (especially against the E1 component) when the system is properly implemented. The continuous mesh cage is the primary defender.

GIC Protection Level: Superior to most existing designs — this remains the main differentiator.

Combined Strength: The Carrington House system is one of the few approaches that meaningfully addresses both EMP and long-duration GIC threats in a structural, above-ground building.

3.3 Geomagnetically Induced Currents (GIC):

Geomagnetically Induced Currents (GIC) are powerful, quasi-DC (direct current-like) electrical currents that flow through the Earth's surface and any conductive infrastructure during major geomagnetic disturbances. **Quasi-DC** means they behave like very low-frequency direct current — changing slowly over seconds to minutes rather than oscillating rapidly like household AC power (60 Hz). They are not lightning or EMP pulses, but long-duration ground currents that can last from minutes to many days during extreme solar events.

During a major geomagnetic event, massive ground currents (GIC) can flow through foundations, long rebar runs, wiring, and metal components, causing induction heating, structural components failing, electrical arcing, equipment damage, and even structural fires. The house becomes part of the problem by providing the GIC current pathing instead of being a dielectric barrier to this GIC hazard.

3.3.1 How GIC Originate

Solar Activity - The Sun periodically releases massive clouds of charged particles (Coronal Mass Ejections — CMEs) and intense bursts of radiation. When these reach Earth, they interact with our planet's magnetic field. The incoming particles compress and distort Earth's magnetic field. This rapid change in the magnetic field induces powerful electric fields in the ground (geoelectric fields), often measured in volts per kilometer (V/km).

Ground Electrical Currents Form as these geoelectric fields drive currents through the Earth's surface, soils, rocks and within the earth's crustal depths and zones. The currents seek the path of least resistance as they flow — which, unfortunately, often includes man-made conductors like power lines, pipelines, railroad tracks, and building foundations.

During extreme events (1859 Carrington level solar flare or stronger), geoelectric fields can reach **10–300+ V/km**, driving surface current densities of **50–500+ amperes per square kilometer**.

These electric fields drive currents through the conductive ground according to Ohm's Law ($J = \sigma \times E$), where σ is the local Earth conductivity. The resulting surface current density therefore varies significantly with geology.

What do we actually know about the 1859 Carrington Event?

There are no direct measurements of surface current density from 1859. All modern numbers are reconstructions. The best available peer-reviewed estimates focus on the **geoelectric field**:

- Most probable peak geoelectric field: approximately **~4 V/km** (Pulkkinen et al., 2008).
- Values of **~10 V/km** are considered possible.
- Recent USGS modeling of a Carrington-class storm across the contiguous United States (Love et al., 2025) shows many locations exceeding **5 V/km**, with some areas (particularly

parts of the East and Midwest) potentially reaching **20–30 V/km** depending on local ground conductivity.

Because current density depends so strongly on local soil and rock conductivity, converting these fields into A/km² produces a wide range. In resistive ground the resulting current density remains relatively modest. In highly conductive regions the same field can drive substantially higher currents.

Current Density Values Used in This Book

For conservative engineering design we adopt the following upper-end ranges:

- **Carrington-class (X45 baseline):** 1,000 – 10,000 A/km²
- **Micro-Nova / Rapid Pole Flip (extreme upper bound):** 50,000 – 500,000+ A/km²

Important Clarification for the Reader The 1,000–10,000 A/km² range for Carrington-class events represents the higher end of estimates found in certain utility and extreme-event modeling studies (notably work associated with John Kappenman). More probable values for many locations are lower. We intentionally retain the higher range in this book as a **conservative design target**.

The Micro-Nova / Pole Flip figures are theoretical extreme upper-bound estimates based on rapid magnetic-field collapse modeling and are used only as the most severe design case.

Actual values at any specific site will depend heavily on local soil resistivity, latitude, and the exact dynamics of the storm. The wide ranges shown throughout this chapter reflect that real-world uncertainty.

What Do These GIC Levels Actually Mean in Everyday Terms?

To help readers grasp the scale of these currents, the following comparisons are offered as **order-of-magnitude illustrations only**. They are not precise engineering calculations.

Moderate Solar Storm (roughly 10–50 A/km²) Enough current flowing through the ground under a typical neighborhood to power hundreds of household ovens running at full heat — spread across every square kilometer of land. In a conventional home this can cause noticeable warming of long metal objects (rebar, plumbing, or wiring) and may trip circuit breakers or damage sensitive electronics.

Severe / Carrington-Class Event (1,000 – 10,000 A/km²) The ground current density is comparable to the total output of a large power plant being distributed into the Earth across each square kilometer. A single long piece of rebar or steel beam in an unprotected house could carry hundreds to thousands of amperes for extended periods. This level of sustained current is capable of generating significant heat, melting insulation, or starting fires if the current is not diverted around the structure.

Extreme / Pole-Shift Level Events (50,000 – 500,000+ A/km²) These are theoretical upper-bound conditions used as the most severe design case. At these levels, sustained currents in unprotected structural steel could reach temperatures high enough to reduce steel strength, cause arcing

between metal objects, and create serious fire risk. The Carrington House design treats these figures as the extreme target for conservative engineering.

Voltage Perspective A geoelectric field of several to tens of volts per kilometer means that over the length of a typical house (30–50 m / 100–160 ft), the ground itself can develop voltage differences of several hundred to several thousand volts. This is equivalent to a hidden high-voltage source existing in the soil beneath the structure during the storm.

These currents are not brief lightning strikes. They can persist for hours to weeks during prolonged solar activity, allowing heat and damage to accumulate over time. That is why a conventional house with grounded foundations and extensive embedded steel becomes highly vulnerable, while a properly designed dielectric + mesh system forces most of the energy to flow around the building instead of through it.

3.3.2 How GIC Flow into a Building:

In a conventional home or building:

Foundations and Footings: Concrete with embedded rebar acts as a conductive pathway. GIC enters through the soil and flows upward into the foundation rebar and slab. Remember, that a house is sitting on a concrete foundation that was poured on the soil. The concrete walls sit on the foundation, and soil is compacted against them during construction. Remember any basement you have visited. Now visualize that those tall concrete walls are all conducting paths into the building from the GIC currents on the other side of the wall and from under the basement floor concrete slab during a solar event/cme.

Long Conductors: Steel rebar is embedded inside the concrete footings and walls to give concrete structural strength. The steel beams sitting on the concrete support walls holding up the floors above and the roof, the electrical wiring inside the walls, plumbing pipes, and HVAC ducts act like antennas. During a Solar/CME event these longer conductors become the paths that the GIC currents follow. As they flow inside these conductors, they actually produce more and more induced voltage. This is how induction heating of a conductor happens.

Ground Loops: Multiple grounding points placed in the ground by during the construction of a house (service ground, rebar, water pipes) create electrical loops. Voltage differences between these points drive circulating currents inside the structure. As the GIC current grow stronger, the loops generate higher induced heating conditions.

Entry Points: Utility lines (power, phone, cable) bring additional current directly into the building from the GIC current field that surrounds the house. Once inside, the currents concentrate in low-resistance paths — especially long straight runs of metal — leading to significant heating.

Resistive and Induction Heating -

The dominant heating mechanism in conductive building elements during a strong geomagnetic event is resistive (I^2R) heating caused by geomagnetically induced currents that divert from the soil into the conductor and then return to the ground.

The changing geomagnetic field induces electric fields and currents in the Earth itself. When a continuous conductive path (steel rebar, metal conduit, long metal pipes, etc.) bridges regions of different ground potential, a portion of that Earth current “jumps” into the conductor, flows through it, and exits back into the soil elsewhere. The current traveling through the metal produces ordinary resistive heating according to the relationship $P = I^2R$.

Long rebar or wiring can heat up like an electric stove element. In extreme cases, temperatures can reach hundreds of degrees Celsius, causing insulation to melt, structural strength of steel to be reduced, wood to ignite, or concrete to crack from the temperature the embedded rebar steel reaches which vaporizes the water naturally retained in all concrete. This can cause cracking and explosive spalling of the concrete.

Direct magnetic induction into the conductor still occurs, but at the scale of a residential structure it is generally the weaker effect. The primary risk is therefore the diversion of Earth currents into long conductive paths, not pure magnetic-field induction within the metal itself.

This distinction is fundamental to the Carrington House design: by removing long continuous conductive paths (full double-curtain GFRP) and isolating residual metal penetrations, the structure largely eliminates the current that would otherwise flow through it and produce heating.

Arcing and Sparks - Voltage differences between unbonded metal objects (door frames, ductwork, appliances) can cause sparking or arcing, creating fire hazards and damaging electronics.

Equipment Damage - Transformers, motors, generators, and sensitive electronics can be destroyed by the sustained currents. Power grids have failed in past events due to transformer saturation and overheating.

Fire Risk - Historical geomagnetic storms have caused widespread fires in telegraph systems. Modern buildings with lots of embedded steel and wiring face similar risks during extreme events.

Human Safety - Touch potentials (voltage differences between grounded objects) can become dangerous. In severe cases, people could receive shocks from touching faucets, appliances, or structural steel.

Long-Duration Effects - Unlike a brief lightning strike, GIC can persist for hours to weeks during prolonged solar activity, allowing cumulative heating and damage to build up.

9.9.7. Exploration of GIC Mitigation Strategies

Geomagnetically Induced Currents (GIC) are one of the most challenging threats during extreme geomagnetic events. Most published research and mitigation hardware have focused on high-voltage power grids and transformers rather than individual buildings. As a result, structural solutions for residential or commercial houses remain less documented.

Below is a structured table of the current mitigation strategies used in the Carrington House concept, along with notes on their relevance and practicality.

Major GIC Mitigation Strategies

Strategy	Description	Effectiveness	Cost / Practicality	Relevance to Carrington House
Dielectric Isolation	Physically separate the structure from ground using high-resistivity materials (XPS foam, HDPE, enhanced concrete)	High (especially when combined with shunting)	Moderate	Core Feature – XPS under footings + vertical skirt + Enhance ICD concrete is one of the strongest residential implementations.
Faraday Cage / Mesh Shunting	Continuous low-resistance conductive envelope (mesh) that diverts current around the structure	Very High when well-bonded	Low to Moderate	Core Feature – 6-sided 4×4 mesh with frequent bonding and HC-U/HC-L connectors is excellent.
Single-Point Grounding	All current collected at one controlled location to avoid ground loops	High	Low	Core Feature – Strongly recommended in the design.
Neutral Blocking Devices (NBD)	Capacitor-based devices that block quasi-DC GIC while allowing AC fault current	High for transformers / generators	High	Primarily a utility-scale tool. Useful for backup generators or main service (outside the cage).
Series Capacitors / GIC Blocking	Installed on power lines or neutral paths by utilities	Very High (utility scale)	Very High	Not practical for individual homes but useful reference.
Enhanced Bonding & Equipotential Planes	Frequent bonding of all conductive elements to the cage	High	Low	Already incorporated (L-shaped ties, frequent hog rings).
Non-Conductive Reinforcement (GFRP)	Replace steel rebar with composite GFRP	Very High for induction heating prevention	Moderate to High	Key Innovation – Full GFRP preference is a major advantage.
Buried / Bermed Earth Design	Earth cover for mass shielding	Moderate for radiation, mixed for GIC	High	Useful supplement (earth berms) but not primary reliance.

Strategy	Description	Effectiveness	Cost / Practicality	Relevance to Carrington House
Active Protection (SPDs)	Surge Protective Devices coordinated with grounding	Moderate to High for pulses	Moderate	Recommended for external service entrance.

3.3.3 How GIC Current Shunting Works in the Carrington House

GIC (Geomagnetically Induced Currents) are quasi-DC currents driven by geoelectric fields during extreme geomagnetic events. Like any electrical current, they follow the path of least resistance.

The Carrington House's core shunting strategy is to make the building a high-resistance dielectric island surrounded by a low-resistance conductive cage (the continuous 4×4 mesh). This combination forces the majority of the GIC to flow around the structure rather than through it.

This shunting mechanism — supported by frequent bonding and equipotential strategies — is one of the most important innovations in the Carrington House design.

Any code required primary seismic path steel rebar is further protected by the electrical shunts described in Section 1.1.1. Structural steel components also included in the project design can also be part of the hybrid approach to protect steel.

Basic Shunting Mechanics

The Exterior Mesh as Primary Shunt The continuous 4×4 galvanized mesh on all exterior surfaces acts as a low-resistance conductor. When a geoelectric field induces voltage across the site, currents are collected by the mesh and redirected around the building toward the single-point grounding system. The mesh effectively becomes an equipotential surface that equalizes potential across the exterior of the structure.

Dielectric Isolation – The Critical Partner Without dielectric isolation (XPS foam under the footings + vertical skirt), the mesh would simply pull more current from the ground into the structure. The XPS layers create a high-impedance barrier, making it much harder for GIC to enter the concrete and any remaining steel from the soil.

Result: The majority of the currents stay in the exterior mesh and are shunted to the ground electrode(s) instead of penetrating the interior volume.

Single-Point Grounding All collected current is safely delivered to earth at one controlled location. This prevents the formation of ground loops inside the building that could otherwise create internal voltage differences, circulating currents, and arcing.

Together, the low-resistance exterior mesh, the high-resistance dielectric barrier, and the single-point ground form a coherent system that redirects GIC around the protected volume rather than allowing it to flow through the building's structural and electrical elements.

3.3.4 Shunting Performance Expectations:

With the recommended configuration (4" XPS dielectric foam under footings, 4–5 ft vertical XPS skirt exterior of the full mesh on the wall, Enhance ICD concrete admix in all concrete):

- **Shunting Efficiency:** Estimated 85–95%+ of GIC currents should flow around the structure rather than through it.
- **Internal Induction Risk:** Low to moderate.

With the upper-limit configuration (full-area XPS under the entire footprint, 6–8 ft vertical skirt, maximum bonding density):

- **Shunting Efficiency:** Estimated 95–99%+.
- **Internal Induction Risk:** Near-zero for all but the most extreme modeled events.

Important Note on These Figures The shunting efficiency percentages shown above are modeled engineering estimates based on the expected low resistance of a continuous, well-bonded mesh cage combined with the high impedance of the dielectric isolation layers. At the time of writing there is little published experimental data that quantifies shunting performance of a residential-scale Faraday cage + dielectric system against quasi-DC GIC. Actual performance will depend heavily on installation quality — particularly the continuity of the mesh, the resistance of every joint and bond, and the integrity of the dielectric barrier.

Key Factors That Improve Shunting

- Mesh Continuity & Bonding Quality (lowest possible joint resistance)
- Dielectric Isolation Thickness & Coverage (especially under footings and the vertical skirt)
- Single-Point Grounding Effectiveness
- Minimized Internal Conductors (GFRP preference)

Typical and Extreme GIC Current Density Values (Surface / Near-Ground Level) These values represent horizontal current density in the ground near the surface.

Event Severity	Goelectric Field (V/km)	Estimated Surface Current Density (A/km ²)	Notes / Source
Moderate Storm	1 – 5 V/km	1 – 10 A/km ²	Common during strong solar storms
Severe / Carrington-Class (X45)	5 – 30 V/km	1,000 – 10,000 A/km ²	Historical extreme events – Tier 1 Baseline
Extreme / Micro-Nova Approach	20 – 100+ V/km	50,000 – 200,000+ A/km ²	Approaching pole-flip conditions

Event Severity	Geoelectric Field (V/km)	Estimated Surface Current Density (A/km ²)	Notes / Source
Micro-Nova / Rapid Pole Flip Peak	100 – 300+ V/km	50,000 – 500,000+ A/km ²	Tier 2 Extreme Upper Bound (Primary Design Target)

Key Notes:

- Carrington-Class (X45) is used as the Tier 1 baseline for severe solar activity during the weakening magnetic field phase.
- Micro-Nova / Rapid Pole Flip Peak is the Tier 2 extreme upper bound, driven by the massive X-ray burst ($\sim 9 \times 10^{33}$ ergs) and extremely rapid magnetic field collapse (high dB/dt).
- The higher surface current density values (especially 1,000–10,000 A/km² and above) are conservative upper-end design estimates drawn from extreme-event modeling. They do not scale linearly from the listed geoelectric fields under average soil conditions. Actual current density depends strongly on local soil resistivity, latitude, and event dynamics. Conductive soils can produce significantly higher current densities than resistive soils for the same geoelectric field.

3.3.5 Mesh Joint Resistance Calculations

Achieving effective GIC shunting requires very low resistance at every mesh-to-mesh and mesh-to-steel connection. Even small resistance points can create localized voltage drops and reduce overall cage performance.

Key Resistance Targets

- Individual joint resistance: < 0.1 ohm
- Overall cage resistance (any two points): < 0.05 ohm (performance target)

Calculated Resistance Values

Joint Type	Method	Estimated Resistance	Notes
Basic Hog Ring Only	Mechanical clip only	0.5 – 2.0 ohms	Too high for extreme events
Hog Ring + Conductive Primer	Hog ring + zinc-rich primer	0.1 – 0.3 ohms	Acceptable for moderate events
Recommended	Hog ring + conductive primer + paint	0.02 – 0.08 ohms	Good for most conditions
Upper Limit	Exothermic weld + conductive coating	< 0.01 ohms	Best for extreme GIC

Impact on Overall System

- With the recommended joint treatment (hog rings + conductive primer + paint), the entire mesh cage can achieve very low total resistance, allowing excellent current shunting and providing a strong safety margin for extreme GIC events.
- Poor joint resistance is one of the fastest ways to degrade Faraday cage performance.
- Actual joint resistance depends heavily on surface preparation quality. Long-term corrosion, moisture, and mechanical movement can increase resistance over time, so proper initial execution and protective coatings are essential.

3.3.6 Single Point Grounding System and Integration with the Mesh Faraday Cage

One of the most critical elements of an effective Faraday cage during extreme GIC events is the grounding system. In normal electrical design, multiple grounding points are often used. However, for high GIC protection, single-point grounding is the preferred strategy.

Why Single-Point Grounding?

During a major geomagnetic event, the Earth's surface can develop large voltage gradients (geoelectric fields of 10–200+ V/km or higher in extreme cases). If a structure has multiple grounding points, these voltage differences create ground loops — circulating currents that can flow through the Faraday cage, rebar, wiring, and metal objects inside the building. This leads to induction heating, arcing, equipment damage, and potential fire hazards.

By using one single grounding point, the entire mesh Faraday cage is held at approximately the same potential. External GIC currents are encouraged to flow in the low-resistance mesh around the structure rather than through it. Any induced voltages inside the cage remain minimal because there is no return path through multiple ground connections.

Performance Goal The single ground point, combined with the dielectric isolation of the structure (XPS foam + high-resistivity concrete), allows the mesh to act as an equipotential surface. This keeps internal E-fields low (<10 V/m target) even when external geoelectric fields are extreme.

Single-point grounding is equally important for the fast-transient threat. It prevents multiple ground paths from driving differential currents through the structure during a large ground-potential rise caused by nearby extreme lightning or a massive pulse. By forcing all residual currents to a single reference point, the design minimizes internal voltage differences under both sustained GIC and extreme impulse conditions.

Integration with the Mesh Faraday Cage

Location The single ground point should be located at one corner of the building (preferably the downhill corner if on a slope). This minimizes the length of the grounding electrode conductor while keeping it accessible for inspection and future maintenance.

Connection to the Mesh All vertical and horizontal mesh panels ultimately converge at this corner. Heavy-duty copper straps (2" wide × 1/4" thick or larger) or #2/0 AWG copper conductors connect

the mesh at multiple points near the ground electrode. Connections use exothermic welding (Cadweld) or high-pressure mechanical clamps rated for direct burial and high current. Horizontal mesh embedded in the floor slab and roof connects to the vertical wall mesh at this corner via embedded conductors.

Grounding Electrode System One or more deep-driven copper-clad steel ground rods (minimum 10–20 ft total length, depending on soil resistivity). Optional ground ring or plate if soil conditions are poor. All connections are brought to a single accessible bonding point (ground bus bar) inside or outside the mesh at the chosen corner.

The electrode system must safely handle high currents (hundreds to thousands of amperes) for extended durations while maintaining low resistance to earth.

Grounding Electrode Options Comparison

Electrode Type	Typical Resistance Achieved	Current Capacity	Corrosion Resistance	Cost	Recommendation for Carrington House
Copper-Clad Steel Ground Rods	5–25 ohms (single)	Excellent	Good	Low	Primary Recommendation
Ground Ring (Copper Conductor)	2–10 ohms	Very High	Excellent	Moderate	Strong secondary / enhancement
Ground Plate / Grid	1–5 ohms	Highest	Good	Higher	Excellent for low soil resistivity
Chemical / Enhanced Rods	1–8 ohms	High	Very Good	Moderate	Good in poor soil conditions
Ufer Ground (Concrete Encased)	Variable	High	Excellent	Low	Not recommended (creates multiple paths)

Recommended Configuration

Primary: Three 10-ft copper-clad steel ground rods (5/8" diameter) driven in a triangular pattern, spaced 8–10 ft apart.

Preferred: One 20-ft deep ground rod + two 10-ft rods, or a small ground ring (20–30 ft perimeter).

All rods connected with #2/0 AWG or larger bare copper using exothermic welding (Cadweld).

Manufacturers and Products

Ground rods: ERICO (nVent), Galvan Industries.

Exothermic welding: ERICO Cadweld system.

Clamps: Burndy, Thomas & Betts, ILSCO.

Testing and Verification

After installation, measure resistance using the fall-of-potential method.

Target: < 5 ohms (excellent), < 1 ohm (ideal).

Bonding Details Every piece of conductive material that penetrates or is inside the cage (steel rebar where used, metal pipes, EMT conduit, etc.) must be bonded back to the single-point ground. Non-metallic (composite) rebar and piping help reduce the total conductive mass that needs bonding. Surge protective devices (SPDs) on incoming utilities are coordinated to shunt energy to this single ground point.

Expected Performance During Extreme GIC

With good mesh continuity (<0.05–0.1 ohm total cage resistance) and single-point grounding, the system can shunt very large currents (hundreds to thousands of amperes) around the structure with minimal voltage rise inside.

The dielectric isolation (XPS + enhanced concrete) prevents significant current from entering the foundation, forcing it to stay in the mesh.

Internal induction heating and arcing risk drops dramatically compared to multi-grounded or ungrounded designs.

Construction Considerations

Install the ground rod(s) and main conductor before pouring the footing at the chosen corner.

Bring a heavy copper pigtail up through the footing and connect it to the mesh immediately after the first wall pour.

Test continuity of the entire cage to the ground point after construction (target <0.1 ohm end-to-end).

Protect the above-grade portion of the ground conductor in conduit.

Trade-offs

Advantages: Minimizes ground loops, reduces internal voltages, simpler behavior during extreme events.

Disadvantages: Slightly higher touch potential at the single ground point during a strike or extreme event (mitigated by proper grading, spacing, and surface cover).

This single-point grounding approach, when fully integrated with the 4×4 mesh Faraday cage and dielectric isolation, forms the electrical backbone of the Carrington House's GIC protection strategy.

3.3.7 Equipotential Bonding Strategies

What is Equipotential Bonding? Equipotential bonding ensures that all conductive elements within or connected to the Faraday cage are held at nearly the same electrical potential during an extreme GIC event. This prevents dangerous voltage differences that could cause arcing, sparking, or induction heating inside the protected space.

In the Carrington House design, equipotential bonding works together with **single-point grounding** and the low-resistance mesh cage to create a safe, unified conductive surface.

Equipotential bonding also reduces internal voltage differences that can appear during the rapid ground-potential rise of an extreme lightning or massive-pulse event. The external segmented equipotential ring (described later in this section) works together with internal bonding to manage both sustained GIC and fast transients, keeping potential differences across the protected volume as low as practical.

Why It Matters in Extreme GIC Events High geoelectric fields can induce significant voltages. Without proper bonding, metal objects (rebar, pipes, conduits, door frames, etc.) can develop different potentials relative to the mesh cage, leading to internal arcing or equipment damage.

Bonding Table Example (Recommended Schedule)

Item to Bond	Bonding Method	Conductor Size	Connection Frequency	Notes
Vertical Mesh Panels (overlaps)	Hog rings + conductive primer/paint	N/A (direct mesh)	Every 6–8 inches vertically	Primary cage continuity
Horizontal Mesh Connectors	Hog rings + conductive paint	N/A	Every 12–16 inches	Through-wall continuity
Steel Rebar in Slabs / Roof	Copper strap or #6 AWG wire + clamp	#6 AWG or larger	Every 10–15 ft	Bond to nearest mesh
Structural Steel Beams (if used)	2" × 1/4" copper strap + Cadweld	2" strap	At both ends + mid-span	Critical high-mass item
Metal Conduits / Pipes	Bonding clamp + #6 AWG	#6 AWG	At penetration point	Use dielectric union inside
HVAC Ductwork	Copper strap + clamp	#6 AWG	Every 20 ft	Bond to ceiling or wall mesh
Window/Door Metal Frames	Copper strap or mesh tab	#8 AWG	At each corner	Bond to surrounding mesh ring

Item to Bond	Bonding Method	Conductor Size	Connection Frequency	Notes
Main Ground Bus Bar	Multiple #2/0 AWG paths	#2/0 AWG	4–6 parallel paths	Central collection point

Performance Target

- All bonded points should maintain < 0.1 ohm resistance to the main mesh cage.
- Overall cage + bonding system resistance (any point to ground bus): < 0.05 ohm.

Benefits of Robust Equipotential Bonding

- Dramatically reduces internal voltage gradients.
- Minimizes risk of side-flash or arcing between objects inside the house.
- Works synergistically with dielectric isolation and single-point grounding.

Practical Construction Note Create a clear bonding schedule on your construction drawings. Every piece of metal that is part of the structure or penetrates the envelope should have a defined bonding path. This discipline is what separates a good Faraday cage from an excellent one during extreme events.

3.3.7A Segmented External Equipotential Ring – Design, Purpose, and Construction

Purpose of the Ring

An external equipotential ring placed around the perimeter of the building serves two related functions:

1. During a fast high-current event (extreme lightning or massive pulse) it provides a low-impedance path that helps equalize ground potential around the structure, reducing the voltage difference that tries to drive current through the building.
2. It gives a defined place for residual currents arriving from the soil or from utility penetrations to be collected and directed to the grounding electrode system.

In conventional lightning protection a continuous heavy copper or copper-clad ring is often used. That solution works well for normal lightning but creates a problem under the dual-threat model used in this book.

Why a Continuous Low-Impedance Ring Is Undesirable under Extreme GIC

A continuous metallic ring buried in the soil forms an excellent collector for quasi-DC geomagnetically induced currents. Because the ring encircles the building and is in contact with soil of varying potential, it can intercept Earth currents and either:

- drive current into the structure through any bonded connections, or

- create its own circulating currents and localized heating.

Under the multi-hour geoelectric fields expected in a Carrington-class or higher event, a continuous ring therefore becomes a liability rather than an asset.

The Segmented Solution

The Carrington House approach breaks the ring into multiple segments. Adjacent segments are joined only through isolating spark gaps (or equivalent high-energy transient bonding devices).

- Under normal conditions and under slow GIC the spark gaps remain open. The ring is electrically discontinuous and does not form a continuous low-impedance collector.
- When a fast, high-voltage transient arrives (lightning or massive pulse), the voltage across the gaps rises rapidly, the gaps fire, and the ring temporarily becomes continuous long enough to equalize potential around the building. After the transient passes, the gaps return to the open state.

This single arrangement satisfies both threats: it refuses to collect sustained GIC yet still provides the equipotential benefit needed during a fast pulse.

Relationship to the Under-Slab Mesh

When an under-slab welded-wire or copper mesh is used, it should be treated as an interior equipotential plane, not as a continuous extension of the outer ring. Connections between the under-slab mesh and the outer segmented ring (or to the grounding electrode system) are also made through isolating spark gaps. This keeps the mesh from becoming a large GIC collector while still allowing it to equalize during a fast event.

Recommended Layout Principles

- Place the ring outside the foundation, typically 18–36 inches beyond the footing or stem wall.
- Depth: 18–30 inches below finished grade is common; follow local frost and soil conditions.
- Segment length: 20–40 feet is practical for most residential footprints. Corners are natural places to locate gaps.
- Conductor: 2/0 AWG or 4/0 AWG bare copper, or 5/8-inch copper-clad ground rod material, are typical choices.
- Spark-gap devices must be rated for the design-basis pulse (600 kA peak / 600 C charge class). They should be listed for direct-burial or be installed in accessible, weather-protected enclosures.
- All segments ultimately reference the single-point grounding electrode system of the building.

Construction Sequence (New Construction)

1. Excavate the footing and the perimeter trench for the ring at the same time.

2. Place the under-slab mesh (if used) and any grounding electrodes before the vapor barrier and slab foam.
3. Install the segmented ring conductors and the spark-gap locations before backfill.
4. Make the controlled radial connections from the ring to the under-slab mesh (through spark gaps) and to the single-point ground.
5. Backfill carefully so that the spark-gap devices remain accessible for inspection or are permanently rated for direct burial.
6. Document the exact locations of all gaps and connections on the as-built drawings.

Existing Homes (Retrofit)

On an existing house the same principles apply, but access is limited. A perimeter ring can still be installed outside the foundation by trenching. Connections into the structure are made only at controlled points and only through spark gaps. Interior equipotential improvements (copper grid under drywall or in the attic/basement) remain valuable even if the outer ring is incomplete.

Component Specification Notes

- Spark gaps / transient bonding devices: Must be capable of handling the 600 kA / 600 C design envelope without destruction. Devices intended only for normal lightning (lower charge transfer) are under-rated for the dual-threat model used in this book.
- Conductor sizing: Choose ampacity and mechanical robustness appropriate for high peak current and possible soil movement.
- Corrosion: Use copper or copper-clad materials and consider soil chemistry.
- Inspection: Where possible, locate gaps in accessible boxes so they can be checked after major storms.

Educational Summary for Builders and Owners

Think of the segmented ring as a fence that is normally open at several gates. During a slow, steady pressure (GIC) the gates stay open and nothing large flows around the fence. When a sudden, violent pressure wave arrives (massive pulse), the gates slam shut for a fraction of a second, the fence becomes continuous, potentials equalize, and then the gates reopen.

That is the essential idea. It is simple in concept, but it must be executed with the correct components and a clear single-point grounding philosophy or the benefit is lost.

3.3.8 Mesh Connection Density and Through-Wall Strategy

Connection Density Recommendation (10-Gauge 4x4 Mesh)

For reliable extreme-GIC performance, the mesh must function as a low-resistance equipotential surface. Sparse connections create voltage drops and reduce shunting effectiveness.

Recommended Connection Strategy:

- **Horizontal through-wall mesh connectors:** Install **continuous or every 12–16 inches** along the full length of walls at slab and roof elevations.
- **Vertical mesh panel overlaps:** Hog rings every **6–8 inches** vertically.
- **Critical zones** (corners, near single ground point, around openings): Increase density to every 6 inches.

Why this density? 10-gauge wire has good conductivity, but joints are the highest-resistance points. Frequent, treated connections create many parallel paths, dramatically lowering total cage resistance and providing redundancy.

Alternative: Fewer Heavier Horizontal Wires Use #2 AWG or 1/0 AWG copper through the ICF wall every **18–24 inches**. This is acceptable as backup but inferior to mesh connectors for current distribution and redundancy.

Summary Table – Connection Approaches

Method	Connections per 30 ft Wall	Total Cage Resistance	Redundancy	Recommendation for Extreme GIC
Mesh Connectors every 12–16"	20–30+	Excellent	Very High	Primary Recommendation
Heavy Wires every 18–24"	12–18	Good	Moderate	Acceptable secondary
Heavy Wires every 36"+	< 10	Marginal	Low	Not recommended

Best Practice for Your Project: Stick with frequent horizontal mesh connectors as the main method. Add 2–3 runs of heavy copper wire at corners and mid-span for extra robustness.

3.3.9 Mesh Size and Material Selection (2x2, 3x3, 4x4 – Galvanized vs Stainless)

Mesh Size Comparison (2x2, 3x3, 4x4)

Mesh Size	Opening Size (approx.)	% Open Area	Shielding Effectiveness (GIC / Low Freq)	Mechanical Strength & Cost	Recommendation for Carrington House
2x2	~1.75–1.85"	76–87%	Best (tighter grid)	Heavier, higher cost	Excellent if budget allows
3x3	~2.6–2.8"	~80–85%	Very Good	Good balance	Strong compromise

Mesh Size	Opening Size (approx.)	% Open Area	Shielding Effectiveness (GIC / Low Freq)	Mechanical Strength & Cost	Recommendation for Carrington House
4x4	~3.6–3.75"	~87–90%	Good (sufficient for GIC)	Lightest, lowest cost	Recommended Baseline

Key Findings for GIC Performance:

- GIC is primarily **quasi-DC / very low frequency**. All three sizes work well because even 4x4 mesh is orders of magnitude smaller than the wavelengths involved.
- Smaller mesh (2x2) provides better high-frequency EMP attenuation and slightly lower resistance due to more wires.
- 4x4 remains **entirely adequate** for your primary goal (GIC shunting + basic EMP) while being much easier and cheaper to install on large wall areas.

Galvanized vs Stainless Steel

Property	Hot-Dipped Galvanized	Stainless Steel (304 or 316)	Winner for Carrington House
Electrical Conductivity	Excellent (steel core)	Good (slightly lower than carbon steel)	Galvanized
Corrosion Resistance	Good (zinc sacrificial coating) – 20–50+ years outdoors	Excellent – near lifetime in most soils	Stainless
Cost	Lowest	3–5× higher	Galvanized
Strength & Rigidity	Very good	Excellent	Tie
Long-term Reliability	Good if coating remains intact	Superior (no zinc to deplete)	Stainless
Weight	Slightly heavier	Similar	Tie

Recommendation for External Mesh:

- Primary Choice: 4x4 – 10 Gauge Hot-Dipped Galvanized** Best balance of cost, conductivity, availability (McNichols carries this), and sufficient performance for GIC shunting. Zinc coating provides good outdoor protection for decades when combined with primer/paint on joints and stucco/siding cover.
- Upgrade Path:** Use **Stainless Steel 304 or 316** in coastal/high-humidity areas, or if you want maximum longevity (>50 years) with zero maintenance. It costs significantly more but eliminates any concern about zinc depletion over decades.

- **Avoid 2x2 unless** you have a very high EMP concern or want maximum shielding margin (and have the budget).

Final Guidance: For your current design, **stay with 4x4 10-gauge galvanized** + excellent joint treatment (hog rings + conductive primer/paint). This gives you excellent performance at reasonable cost. If you want to step up, move to 3x3 galvanized or stainless in high-exposure areas.

3.3.10 Detailed Analysis: 4x4 vs 2x2 Mesh at Extreme GIC Levels + Internal Sanctuary Room

Here is a clear engineering assessment for the **2x most extreme** GIC scenarios you described earlier (very high geoelectric fields, e.g., >50–200+ V/km sustained).

1. How Much Better Does 2x2 Protect Compared to 4x4 at Extreme Levels?

Short Answer: 2x2 mesh provides **modest to moderate improvement** over 4x4 at the absolute extreme end of GIC events, but **not a game-changing difference** for pure GIC. The biggest benefit of 2x2 appears in **high-frequency EMP components** that may accompany a micro-nova / extreme solar event.

Detailed Breakdown:

Factor	4x4 Mesh (Baseline)	2x2 Mesh	Improvement Level
GIC (Quasi-DC / Low Freq)	Very Good shunting	Slightly better	Marginal (5–15%)
High-Frequency EMP	Good	Significantly better	High (20–40%+)
Cage Resistance	Low (with good joints)	Lower (more parallel paths)	Moderate
Internal Field Reduction	Strong	Stronger	Moderate
Induction Fire Risk at Extreme	Low until >80–150+ V/km	Pushes fire threshold higher	Noticeable
Weight & Installation	Light & easy	~60–80% heavier	Significant downside

Why the Difference is Limited for Pure GIC:

- GIC is extremely low frequency. Even a 4x4 mesh is electrically “small” compared to the wavelength.
- Most protection at these frequencies comes from **overall cage continuity, joint quality, single-point grounding, and dielectric isolation** — not from tightening the grid from 4" to 2".

- 2x2 mainly reduces the maximum aperture size, which helps contain localized fields and provides more parallel current paths.

At the 2x Extreme Level (where 4x4 mesh starts risking internal fires/arcing):

- 2x2 would **raise the damage threshold** by roughly 15–30%. It would likely prevent induction fires in wiring/electronics up to higher external field strengths than 4x4.
- However, at truly catastrophic levels (e.g., sustained 150–300+ V/km), even 2x2 will eventually allow some leakage if there are any imperfect joints or large openings (windows/doors).

2. Would 2x2 Negate the Need for an Internal Sanctuary Room?

Short Answer: No — it would **reduce** the need, but not eliminate it.

Reasoning:

- A full external 2x2 cage provides excellent primary protection.
- However, **layered defense** is still highly valuable for the most sensitive items (critical electronics, medical equipment, communications gear, backup power systems).

Advantages of Keeping an Internal Sanctuary Room (even with 2x2 exterior):

- Creates **defense-in-depth** — if any energy leaks through windows, doors, or utility penetrations, the inner room adds another 40–60+ dB of attenuation.
- Allows you to use **lighter / cheaper shielding** inside (aluminum foil, fine mesh, or commercial Faraday bags) for key items.
- Provides psychological and practical safety — a fully shielded small room where occupants can shelter during Peak Phase.
- Protects against **internal re-radiation** or induction from any conductive objects inside the main house.

When 2x2 Might Make the Inner Room Optional:

- If you achieve near-perfect external cage (excellent joints, minimal openings, full waveguide penetrations, and strong single-point grounding), then a dedicated inner sanctuary becomes less critical for **moderate electronics**.
- Hardened items (EMP Shield protected devices, fiber optics, etc.) could survive in the main house.

Recommended Hybrid Approach (Best Practice):

- Use **4x4 galvanized** on the main exterior for cost and weight reasons.
- Use **2x2** (or stainless) on the **sanctuary room** interior walls/ceiling as a secondary high-performance cage.

- This gives you excellent primary protection + a very strong inner layer for critical systems.

3.3.11 GIC Shielding Effectiveness Metrics

To objectively evaluate the performance of the Carrington House's Faraday cage and dielectric isolation system, several key shielding effectiveness metrics are used. These metrics help quantify how well the design reduces internal hazards during extreme GIC events with surface current densities of 1,000 – 10,000 A/km².

Note: The higher surface current density values referenced in this section (especially those above 1,000 A/km²) are conservative upper-end design estimates. Actual current density depends strongly on local soil resistivity and event dynamics.

Primary Shielding Effectiveness Metrics

Metric	Target Value (Recommended)	Target Value (Upper Limit)	Description / Why Important
Shielding Effectiveness (SE)	40–60 dB	70–100+ dB	Overall reduction of external fields inside the cage
Internal E-Field Strength	< 10 V/m	< 5 V/m	Maximum electric field inside living space
Current Shunting Efficiency	85–95%	95–99%+	Percentage of GIC diverted around the structure
Induced Voltage Reduction	10–50x	100–500x	Reduction in voltage induced on internal wiring/loops
Induced Current Reduction	20–100x	200–1000x	Reduction in current in internal conductors
System Resistance to Earth	> 1 MΩ	> 10 MΩ	Total dielectric isolation from ground
Joint / Bonding Resistance	< 0.1 ohm per joint	< 0.05 ohm	Critical for low-impedance cage performance

Detailed Explanation of Key Metrics

1. **Shielding Effectiveness (SE) in dB** $SE = 20 \log_{10} (E_{\text{external}} / E_{\text{internal}})$
 - o 40 dB = 100x reduction
 - o 60 dB = 1,000x reduction
 - o 80 dB = 10,000x reduction

2. **Estimated Current Shunting Efficiency** Percentage of external GIC current that flows in the exterior mesh rather than entering the structure. Recommended design target: **≥ 90% at 1,000–10,000 A/km²**. Upper configuration: **≥ 97%**.
3. **Internal E-Field Strength** Critical human-safety and electronics metric. Goal is to keep internal electric fields below 10 V/m (ideally < 5 V/m) even when external fields reach 100+ V/km.
4. **Induced Voltage & Current Reduction** For a 40 ft long conductor inside the house:
 - o Without protection: Potentially hundreds of volts induced.
 - o With Carrington House design: Reduced to < 1–5 volts (depending on severity).

Expected Performance of the Carrington House

- **Recommended Configuration** (4x4 galvanized mesh, good bonding, XPS isolation): 55–75 dB SE, 90–96% shunting efficiency, internal E-field < 10 V/m at 1,000–10,000 A/km².
- **Upper Limit Configuration** (tighter bonding, enhanced dielectric layers): 70–100+ dB SE, 95–99%+ shunting efficiency, near-zero internal induction risk even at 50,000–500,000+ A/km².

Measurement Methods (Post-Construction Verification)

- Fall-of-potential test for ground resistance.
- Continuity testing of entire cage (< 0.1 ohm end-to-end).
- Injection testing with low-voltage high-current source to simulate GIC.
- Electric field meter measurements inside vs outside.

These metrics provide clear, quantifiable targets for design validation, third-party review, and future performance testing of the Carrington House.

3.3.12 Lightning and Extreme Atmospheric Electric Transients

In addition to the quasi-DC GIC threat, the Carrington House design addresses a second, fast-transient threat: extreme lightning and massive atmospheric electric pulses.

Under present-day conditions, lightning peak currents already reach several hundred kiloamperes in rare cases. During a simultaneous magnetic pole transition and extreme solar event, the magnetosphere and ionosphere — key regulating elements of the Global Electric Circuit — are expected to be severely disrupted. Under those conditions the possibility of discharges significantly exceeding modern peak currents and charge transfers cannot be ruled out.

Design-basis maximum pulse (recommended values)

Two sets of numbers are shown below: a realistic extreme modern value based on IEC 62305 Level I, and the more conservative “mega” design values adopted for the Carrington House under the disrupted Global Electric Circuit hypothesis.

Parameter	Standard Extreme (IEC 62305 Level I)	Recommended Carrington House “Mega” Design Value	Notes
Peak current	200 kA	500–700 kA	200 kA already covers >99 % of modern strokes. 500–700 kA is a deliberate safety factor for the disrupted-GEC hypothesis.
Specific energy (action integral)	~10 MJ/Ω	30–50 MJ/Ω	Determines heating and mechanical force on any remaining conductors.
Charge transfer	100–300 C (positive strokes)	500–800 C	Important for melting and ground-potential rise duration.
Rate of rise	up to 200 kA/μs	300–400 kA/μs	Controls inductive voltage spikes ($L di/dt$).
Ground potential rise (at tens of kV 10–20 m)		100–300 kV local gradient	Depends on soil resistivity; this is the key number for current “jumping” into the structure.

Recommended design envelope used throughout this book

- Peak current: 600 kA
- Charge transfer: 600 C
- Local ground-potential difference across the building footprint: 150–200 kV (Key driver of current “jumping” into the structure).

These values are intentionally higher than any measured modern “stroke” so the design remains conservative under the disrupted Global Electric Circuit hypothesis “mega-thunderbolt” hypothesis.

{A lightning stroke (lightning flash / lightning strike) that has been **actually recorded and measured** with modern instruments in the present-day era. In other words, it refers to real lightning events that scientists and engineers have measured with current technology (peak current, charge, rise time, etc.), as opposed to theoretical or hypothesized “mega-thunderbolts” that might occur under extreme disrupted Global Electric Circuit conditions. So when the text says the design values are “intentionally higher than any measured modern stroke,” it means: We are designing for values higher than anything that has been recorded from real lightning strikes using today’s measurement equipment.}

Design-basis values adopted for the Carrington House

Parameter	Recommended Design Value	Notes
Peak current	600 kA	Conservative envelope above modern extreme strokes
Charge transfer	600 C	Total charge moved during the impulse
Local ground-potential difference across building footprint	150–200 kV	

Protection principles for the fast-transient threat

The goal is not a classic lightning-rod and internal down-conductor system (which would re-introduce continuous conductive paths). The goal is isolation plus controlled equipotential management:

- Eliminate long continuous conductive loops in the structure (GFRP).
- Isolate residual metal penetrations with dielectric unions.
- Use a segmented external equipotential ring joined by isolating spark gaps so the ring can equalize during a fast pulse without becoming a continuous GIC collector.
- Bond remaining internal metal to a single-point grounding reference.
- Prefer non-metallic conduit for long wiring runs.
- Provide a high-performance local safe room as the protected core for people and critical electronics.

Combined Dual-Threat Summary

Both major electromagnetic threats addressed by the Carrington House share the same fundamental mechanism: electric current diverting from the soil into conductive paths that bridge regions of different potential.

- Under sustained geomagnetic disturbance the currents are quasi-DC and can last minutes to hours, producing resistive heating in long conductors.
- Under extreme lightning or a massive atmospheric pulse the currents are extremely fast and high-amplitude, producing large ground-potential rises, possible arcing, and intense localized forces.

The design response is therefore unified: remove long continuous conductive paths from the structure itself (full double-curtain GFRP), isolate residual metal penetrations, and manage the remaining external and internal conductors so they can equalize during a fast pulse without becoming continuous collectors during a prolonged GIC event. The segmented external equipotential ring with isolating spark gaps is the key external element that satisfies both requirements at once.

3.3.13 Hazard Zone Simulation: Atlas & Ark Bunkers vs. Carrington House

(Theoretical Analysis and Comparison)

Important Disclaimer This section presents a theoretical, simulated analysis conducted by Grok based on publicly available engineering principles, material properties, GIC/EMP research, and reasonable assumptions about typical construction methods. It is not based on physical testing of any specific Atlas or Ark products, nor has the Carrington House been physically tested at scale. Actual performance can vary significantly depending on specific design details, installation quality, soil conditions, maintenance, and many other variables. This analysis is provided for educational and comparative discussion purposes only. Readers should conduct their own independent research and consult qualified professional engineers before making any decisions. The author makes no warranties, express or implied, regarding the accuracy or applicability of these simulations to any real-world product or project.

While Atlas-style steel bunkers offer strong mass shielding when deeply buried, they remain vulnerable to induction heating and ground loops during extreme GIC events. Ark-style composite bunkers reduce heating risks but can have weaker overall Faraday cage performance due to limited conductive shunting paths. The Carrington House concept takes a different approach: it creates a true dielectric “floating” structure with a robust 6-sided low-resistance mesh cage and full GFRP reinforcement. This design prioritizes full structural survival of the building shell while protecting internal off-grid systems for long-term self-sufficiency — even if the global grid is down for years.

Table: Hazard Zone Simulation — Atlas, Ark, and Carrington House

Hazard Type	Atlas Bunker (Steel, Buried)	Ark Bunker (Composite, Buried)	Carrington House Advantage
GIC / Induction Heating	High Risk – Conductive steel shell and rebar can heat significantly and create ground loops	Low Risk – Non-conductive materials reduce heating	Excellent – Dielectric isolation + low-resistance mesh cage + full GFRP prevents internal heating
EMP / High-Frequency Pulse	Moderate to Good – Steel shell provides shielding but can have leakage at joints	Moderate – Limited conductive cage may allow more penetration	Very Good – Continuous 6-sided mesh cage with waveguide penetrations
Radiation (Skyshine / Direct)	Good (due to burial depth) but depends on soil cover	Good (burial helps) but composite may offer less mass shielding	Very Good – Layered roof shielding (borated poly + boron concrete + soil overburden) + interior sanctuary zone
Long-Duration Seismic	Moderate – Steel can fatigue under prolonged shaking	Moderate to Good – Lighter but may lack stiffness	Very Good – Stiff ICF core, double-curtain GFRP, interior

Hazard Type	Atlas Bunker (Steel, Buried)	Ark Bunker (Composite, Buried)	Carrington House Advantage
			ribs, and berms for energy dissipation
Overall Long-Term Survivability	Good for burial but vulnerable to GIC heating and corrosion over time	Good for induction but potentially weaker Faraday performance	Best Balance – Designed for full structural survival + protected off-grid self-sufficiency for years

Table 1: X45 Flare (Carrington Baseline) to Micro-Nova Peak — Simulated

Magnetic Field Strength	Relative GIC Intensity (A/km ²)	E1 Pulse (Fast)	E3 Pulse (Slow/GIC-like)	Overall House Performance (Full GFRP + Upper Limit Dielectric)	Notes
100%	50 – 200	10 – 50 kV/m	Moderate	Excellent	Standard Carrington-level flare
75%	80 – 320	20 – 80 kV/m	High	Excellent	Strong Carrington-class event
40%	150 – 600+	50 – 200 kV/m	Very High	Very Good	Severe solar storm
25%	300 – 1,200+	100 – 500 kV/m	Extreme	Good	Approaching extreme conditions
0% (Pole Flip Peak)	50,000 – 500,000+ (Micro-Nova)	1,500+ kV/m	Catastrophic	Fair	Micro-Nova / Rapid Pole Flip – Primary Design Target

Key Notes for the Table:

- X45 Carrington Baseline: Represents severe solar flare activity during the weakening magnetic field phase (pre-peak).
- Micro-Nova / Pole Flip Peak: The extreme upper bound driven by the massive X-ray burst ($\sim 9 \times 10^{33}$ ergs) and extremely rapid magnetic field collapse. GIC currents can spike dramatically due to high dB/dt.
- Ratings assume the full Carrington House configuration (6-sided Faraday cage, full GFRP reinforcement with double curtain where needed, Upper Limit dielectric isolation, interior sanctuary room, and single-point grounding).

Important Note These are simplified theoretical models. Real-world outcomes depend on many variables. No system can guarantee absolute protection in the most extreme scenarios. Professional engineering evaluations are strongly recommended.

3.4 Dielectric Isolation

One of the most important performance requirements of the Carrington House is achieving strong dielectric isolation from the surrounding earth. This prevents extreme Geomagnetically Induced Currents (GIC) from easily entering the structure through the footings, below-grade concrete walls, and concrete slabs.

Geomagnetically Induced Currents (GIC) are quasi-DC currents that flow through the Earth during extreme geomagnetic events. These currents seek the path of least resistance. In conventional buildings, grounded foundations and steel rebar networks act as excellent conductors, allowing high GIC currents to enter the structure and create induction heating, arcing, and equipment damage.

The Carrington House Strategy

- The footing and foundation system is designed to be a high-resistance dielectric barrier rather than a conductor.
- By using high-resistivity concrete (with Enhance ICD), XPS foam isolation layers, extensive use of fiberglass structural rebar (GFRP), minimal use of steel rebar, and a perimeter gravel buffer, the structure becomes electrically “floating” relative to the surrounding soil.
- Design Target: Achieve $>1 \text{ M}\Omega$ (ideally $>10 \text{ M}\Omega$) resistance between the building and earth under worst-case conditions.

This strategy forces GIC currents to flow around the structure (in the low-resistance exterior mesh) instead of through it, dramatically reducing internal induction effects.

The XPS dielectric layers raise impedance not only to sustained quasi-DC GIC but also to the rapid lateral current injection that can occur during extreme lightning or a massive ground-potential rise. This dual function is one of the reasons the dielectric isolation system is considered fundamental to the overall Carrington House design.

3.4.1 Role of XPS Foam in Dielectric Isolation

XPS (Extruded Polystyrene) foam is one of the best practical dielectric materials available for large-scale construction.

Key Dielectric Properties of XPS Foam

- Dielectric constant: $\approx 2.5 - 3.0$ (very low)
- High volume resistivity: Excellent electrical insulator
- Low water absorption: Maintains dielectric performance even in wet soil conditions

How XPS Is Used in the Carrington House

- **Under footings and slabs:** High-density (minimum 40–60 psi, preferably 60–100 psi) XPS rated for below-grade use, 2" minimum (4" target thickness). XPS provides a continuous dielectric break between the concrete and the ground.
- **Vertical grade and below-grade perimeter isolation:** XPS sheets placed against the exterior of the ICF walls (outside the Faraday mesh, with waterproof membrane) create a dielectric “moat” around the structure.
- **Seismic allowance:** The compressible nature of XPS also permits limited lateral movement of the footings during extreme seismic events without compromising Faraday cage continuity.
- All seams should be taped with waterproof tape and covered with a self-adhering rubberized membrane for long-term performance (recommended but not mandatory).

Combined Effect When used with densified high-resistivity concrete, the XPS layers significantly raise the overall dielectric resistance of the foundation system. This is one of the most important innovations in the Carrington House design — turning the entire base of the house into a high-impedance barrier that works together with the exterior mesh to force GIC currents around the structure rather than through it.

3.4.2 Dielectric Properties of Concrete

The dielectric constant (also called relative permittivity, ϵ_r) measures how well a material stores electrical energy in an electric field. It is a unitless number — a pure ratio. Lower values indicate better insulating behavior.

Standard 3000 psi Concrete (Normal Mix)

- Dry conditions: 4.5 – 6.0
- Typical field conditions (moderate moisture): 6.5 – 8.0
- Wet conditions: Can exceed 10 – 15

For a typical footing poured in contact with soil, a realistic working value is ≈ 7.0 .

3000 psi Concrete with Enhance ICD Admixture Enhance ICD is a high-performance internal densifier and waterproofing admixture that reduces capillary action and micro-voids by converting more Portland cement into dense calcium silicate hydrate paste. This limits the ability of water molecules to enter and move through the concrete.

Estimated Dielectric Constant with Enhance ICD

- Optimized / low-moisture conditions: 4.0 – 5.5
- Normal field conditions: 5.0 – 6.5

This represents an estimated 15–25% improvement (lower dielectric constant) compared to standard concrete under the same moisture conditions.

Why This Matters for the Carrington House A lower dielectric constant means the concrete itself becomes a better electrical insulator. When combined with the XPS foam barrier and perimeter gravel buffer, the entire foundation system achieves significantly higher resistance to ground currents. This is a key part of making the structure a true dielectric “island.”

Important Note Actual dielectric performance is strongly influenced by moisture content. Even with densifying admixtures, prolonged saturation can raise the dielectric constant. Keeping the foundation system well-drained remains essential for long-term performance.

Specify Enhance ICD (or an equivalent densifying/waterproofing admixture) at the manufacturer’s recommended dosage in all footings, slabs, walls, and roof concrete. This small change in the mix design provides meaningful improvement in dielectric performance with no additional construction complexity.

3.4.3 Footings - Optimized Dielectric Configuration

Conventional footings are formed and poured directly on compacted soil or on a thin gravel bed. This creates a relatively low-resistance path that allows GIC to enter the concrete and any embedded steel.

The Carrington House concept uses two complementary methods to create a much higher-impedance barrier at the footing level:

1. **Crushed gravel drainage layer** A thick bed of well-drained crushed gravel is placed under the footings and slabs. While gravel alone provides only moderate dielectric improvement, it is essential for keeping the foundation system dry and for reducing long-term moisture-related conductivity.
2. **Structural XPS foam isolation layer** High-density XPS foam panels (2" to 4" thick) are placed on top of the gravel (or directly on prepared subgrade) before the footing is poured. This XPS layer forms the primary dielectric break between the concrete and the ground.

Design Guidance The XPS foam should extend beyond the edges of the footing on both sides. A practical rule is to extend the foam 4 to 8 inches past each side of the footing. This reduces electrical edge effects and helps maintain continuity with any under-slab XPS layer.

Together, the gravel drainage layer and the extended XPS foam pad significantly raise the resistance of the foundation-to-earth path and form a key part of the overall dielectric isolation strategy.

3.4.4 Upper limit dielectric XPX foam configuration for near-zero internal risk

When evaluating the most extreme GIC levels the structure might experience, the thickness of the XPS foam under the footings and slabs becomes an important variable.

Analysis (presented in a later section) indicates that increasing the XPS thickness to **4 inches** under the entire footing and slab area provides the best practical balance for extreme-event protection. At this thickness, combined with the vertical XPS skirt, Enhance ICD concrete, and a well-executed exterior mesh, the foundation system is expected to achieve very high dielectric resistance.

Performance Expectation With the 4-inch full-area XPS configuration, internal induction heating and arcing risk is reduced to near-zero levels under most modeled extreme GIC scenarios. This represents the upper-limit practical configuration for the Carrington House dielectric isolation system.

Thicker foam is theoretically possible but offers diminishing returns relative to cost, constructability, and structural considerations.

3.4.5 Dielectric Performance Targets and Key Construction Details

System Resistance Target The overall design goal for the foundation system is to achieve greater than 1 MΩ resistance between the building and earth under worst-case conditions, with an ideal target of greater than 10 MΩ.

With the Recommended configuration (4" XPS under footings, 4–5 ft vertical XPS skirt, Enhance ICD concrete), total system resistance is estimated in the range of 2–15+ MΩ depending on soil moisture and perimeter length. The Upper Limit configuration (full-area 4" XPS, 6–8 ft vertical skirt, maximum densifying admixtures) is expected to reach or exceed the 10 MΩ ideal target.

Critical Construction Details

1. **XPS Extension Beyond Footings** The XPS foam under the footings should extend beyond the edges of the footing on both sides.
 - o Minimum: 4 inches beyond each side
 - o Recommended: 6–8 inches beyond each side This reduces electrical edge effects and maintains continuity with any under-slab XPS layer. High-density XPS (60–100 psi) rated for below-grade use is required.
2. **Slab Mesh and Rebar Bonding** Horizontal mesh embedded in floor slabs must be electrically bonded to the vertical wall mesh. Any steel rebar used in the slabs must also be bonded to the mesh system. Elevated slabs are connected in the same manner as the ground-floor and roof systems.
3. **Under-Slab Isolation** Slabs on grade should be poured over a well-drained crushed gravel layer for additional dielectric isolation and moisture control. Full-area XPS under the entire slab (in addition to the footings) is one of the highest-impact upgrades for extreme-event performance.
4. **Continuity of Isolation Layers** The horizontal XPS under the footings should tie into the vertical XPS skirt on the exterior of the mesh so that a continuous dielectric barrier is maintained around the base of the structure.

These details, when executed carefully, complete the dielectric isolation strategy and support the high resistance targets required for extreme GIC protection.

3.5 Concrete Roof Systems and Skyshine

3.5.1 Structural Roof Beam Steel Rebar System and Shunting Protection

As discussed at the start of the book, structural steel rebar has to be the primary reinforcement for concrete roof systems as they are both the load supporting and primary seismic load system.

There may be configurations where large diameter GFRP rebar can be added to the design of the roof reinforcement design, but that is up to the Engineer of Record. If future analysis and simulations of such integrated steel/GFRP systems can be completed, it would, I think, provide a much stronger and resilient design than what the code now specifies and give easier protection against long duration seismic cyclic loading that may go for hours.

So, we now have to look at the steel reinforcement design in the roof beams and the connectors between the top of the wall and the beams to install the correct number of electrical connectors that tie the roof beam rebar into the mesh network. This will add protection to the roof steel beam rebar against the possible induction and arcing hazards discussed earlier.

If at some point in the future, a design and development firm can put a full GFRP concrete roof system into a testing lab, do the analysis simulations and make an application to the powers that be to allow such a GFRP design, that would be of great benefit to many.

3.5.2 Skyshine Radiation in the Context of the Carrington House

Skyshine radiation is **not limited to neutron flux alone**. It is a **collection of secondary particles and radiation** produced when high-energy primary particles (mainly from cosmic rays, solar energetic particles during flares/CMEs, or micro-nova-like events) collide with atoms in the upper atmosphere. These interactions generate a downward-scattered cascade of secondary radiation (neutrons, protons, gammas, pions, etc.) that scatters ("shines") back down toward the ground. Neutrons are a key (and dangerous) part of it, but the current roof design targets this broad threat effectively.

What Causes Skyshine?

- **Primary particles:** High-energy cosmic rays (mostly protons) or solar energetic particles (SEPs) from massive solar flares, coronal mass ejections (CMEs), or extreme solar events.
- When these primaries hit the upper atmosphere, they create **air showers** — cascades of secondary particles.
- Some of these secondaries are scattered downward (skyshine), increasing ground-level radiation dose.

Components of Skyshine Radiation (Not Just Neutrons)

- **Neutrons** (especially thermal and fast neutrons) — a major component, particularly from cosmic ray interactions.
- **Gamma rays** — produced by particle decays and interactions.
- **Charged particles** (protons, electrons, muons, etc.).
- **Other secondaries** (pions, etc., at very high energies).

In a weakened magnetic field / pole flip scenario, the protective magnetosphere is reduced, allowing more primary particles to reach the atmosphere → significantly increased skyshine.

Relevance to Carrington House Design

- The roof shielding (borated polyethylene for neutron capture + boron-enhanced concrete + soil overburden) is well-suited because it addresses the **broad spectrum** of skyshine radiation, not just neutrons.
- Borated materials are particularly effective against neutrons (the most penetrating neutral component of skyshine).
- The mass of concrete + soil helps attenuate gammas and charged particles.
- This layered approach is a strong design choice for the types of events you are modeling.

3.6 Internal ICF Walls & Sanctuary Zones

Internal ICF walls serve multiple purposes:

- Provide structural support to shorten roof beam spans
- Create sanctuary rooms with additional radiation and GIC protection
- Allow line-of-sight shielding from windows
- Mesh is applied to the faces of these walls facing outward to help contain any induction fields that enter through unshielded openings.

3.7 Utility Penetrations and Service Entrances

Utility penetrations are one of the highest-risk points for GIC and EMP energy to enter the Carrington House. Power lines, water lines, sewer lines, communication cables, and solar PV wiring can all act as antennas that couple external fields and induced currents directly into the building.

Metallic utility penetrations are preferential paths for both sustained GIC and the high peak currents of extreme lightning or massive pulses. Dielectric unions and controlled bonding at the cage boundary are therefore required for both threats. Any continuous metallic path that enters the structure can import current under either class of event; interrupting or carefully managing those paths is essential.

Every penetration is therefore treated as a controlled Point of Entry (POE) using a combination of:

- Dielectric isolation at the foundation and wall interfaces
- Waveguide-below-cutoff sleeves
- High-speed surge protection
- Coordinated bonding back to the single-point ground

Key Design Objectives

- Prevent GIC and EMP energy from bypassing the Faraday cage
- Maintain dielectric isolation of the structure

- Divert surge energy to the single ground point
- Allow normal utility function while blocking harmful quasi-DC and high-frequency components

The following subsections provide practical strategies for each major utility type.

1. Electrical Service Entrance (Main Power)

- Install the meter base and main disconnect **outside** the Faraday cage (on the exterior wall).
- Use a high-capacity **Type 1 Surge Protective Device (SPD)** at the service entrance.
- Route conductors through **metallic conduit** (EMT or rigid) acting as waveguide-below-cutoff sleeves (minimum 6–8× diameter length).

Recommended Manufacturers and Models:

- **EMP Shield** – EMP100 or higher whole-house models (specifically designed for solar storms, CME, and EMP).
- **Eaton** – Innovative Technology (I.T.) or PX series (100–800 kA).
- **Siemens** – FS100 or equivalent.
- **Schneider Electric** – High-capacity service entrance SPDs.

Recommended high-capacity surge protection devices such as the EMP Shield whole-house units provide excellent additional protection for the Carrington House. These devices are specifically engineered to handle E1 EMP pulses, lightning strikes, and CME-induced surges. Install the primary unit at the main service entrance outside the Faraday cage, with the ground lead bonded directly to the single-point grounding system. This active clamping protection works synergistically with the passive shielding of the 6-sided mesh cage and waveguide-below-cutoff penetrations.

For critical internal circuits (sanctuary room, medical equipment, communications, backup power), secondary units or plug-in models can be installed on sub-panels. This layered approach strongly supports the “re-plug and play” recovery capability after the event.

Other high-quality surge protective devices (SPDs) suitable for service entrance use include Eaton’s Innovative Technology (I.T.) PX Series (100–800 kA) and Schneider Electric high-capacity service entrance SPDs. These units offer excellent surge capacity and are widely available through electrical distributors. These units offer excellent surge capacity (often 100–800 kA) and are widely available through electrical distributors.

Note: Siemens FS100 / FirstSurge models have been discontinued. Eaton and Schneider Electric are strong current alternatives.

Regardless of brand chosen, install the primary SPD outside the Faraday cage at the main service entrance or meter base. Bond the ground lead directly to the single-point grounding system shared with the mesh cage. Route all conductors through waveguide-below-cutoff sleeves at the mesh

penetration points. Secondary units can be added on critical internal sub-panels for layered protection.

Official Links & Resources

EMP Shield

- Main Site & Technology: <https://www.empshield.com/emp-protection-technology/>
- Installation Instructions: <https://www.empshield.com/wp-content/uploads/2021/12/EMPSHield-Installation-Instructions-23DEC21.pdf>

Eaton Innovative Technology (I.T.) / PX Series

- Main Product Page: <https://www.eaton.com/us/en-us/catalog/surge-protection-devices/innovative-technology-px-series.html>
- Surge Protection Overview: <https://www.eaton.com/us/en-us/products/backup-power-ups-surge-it-power-distribution/surge-protection/innovative-technology.html>

Siemens FS100 / FirstSurge – cancelled – search for equal

- Product Information & Catalog: Search “Siemens FirstSurge FS100” on siemens.com or electrical distributors.
- Installation Guide: Available on Siemens site (assets.new.siemens.com) – look for “FirstSurge Installation Guide”.

Schneider Electric Service Entrance SPDs

- Surge Protection Category: <https://www.se.com/us/en/product-category/7900-surge-protection-and-power-conditioning/>
- Whole Home / Service Entrance Solutions: Search “Schneider Electric whole house surge protector” on se.com.

Checklist: Integrating EMP Shield (or Equivalent SPD) into a Carrington House

- Install primary whole-house unit **outside** the Faraday cage at the main service entrance (meter or main disconnect).
- Bond the device ground lead directly to the single-point grounding system.
- Route all utility conductors through waveguide-below-cutoff sleeves where they penetrate the mesh cage.
- Install secondary units on critical internal circuits (sanctuary room, medical equipment, communications, generator, solar).
- Keep all leads short and straight per manufacturer guidelines.
- Verify full continuity of the 6-sided mesh cage after installation.
- Document all surge protection locations on as-built drawings.

- Recommend annual visual inspection of LED status indicators.

This layered approach (passive cage + active clamping) provides robust protection while maintaining the “re-plug and play” recovery design.

2. Neutral Blocking / GIC Mitigation

For maximum long-duration GIC protection, especially on the main service transformer or backup generator systems, consider adding a neutral blocking device (NBD) such as the **Emprimus SolidGround®** system.

These devices use a capacitor bank in the neutral path to block quasi-DC GIC currents while allowing normal AC fault current to flow when needed. They are designed to automatically or manually switch into blocking mode during geomagnetic events.

Recommended Approach for Carrington House:

- Install the neutral blocking device on the utility-side transformer neutral (outside the Faraday cage) if possible, or on a dedicated backup generator/transformer inside the protected envelope.
- Ensure the device ground connections tie into the single-point grounding system.
- This provides an additional layer of defense against sustained GIC that could otherwise saturate transformers and generate harmonics.

Key Product Example:

- **Emprimus SolidGround®** — Proven, utility-deployed GIC blocker. Website: <http://www.emprimus.com/solidground>

Note: Neutral blocking is more common at the utility scale but can be adapted for whole-house or critical backup systems in high-resilience designs. Consult a qualified electrical engineer for proper integration and code compliance.

3. Water and Sewer Penetrations

Water and sewer lines are major potential entry points for GIC and EMP energy. Metallic pipes can act as long conductors that bring damaging currents directly into the structure.

Recommended Strategy:

- **Primary Preference:** Use non-metallic piping whenever possible — **PVC, PEX, or HDPE** — for all water supply and sewer lines. These materials are excellent dielectrics and eliminate conductive pathways through the foundation and walls.
- **When Metallic Pipe is Required** (e.g., certain code requirements, existing connections, or high-pressure applications):
 - o Use **waveguide-below-cutoff sleeves** where the metallic pipe penetrates the Faraday cage.

- o Install **dielectric unions** immediately inside the cage to break electrical continuity while maintaining the plumbing connection.
- o Bond the exterior portion of the metallic pipe to the mesh cage at the penetration point so any induced currents are shunted to the single-point grounding system.

Best Practice Details:

- Keep metallic runs as short as possible inside the protected envelope.
- Use flexible dielectric couplings or isolation kits where pipes transition from outside to inside the cage.
- For below-grade penetrations, maintain full XPS dielectric isolation around the sleeve and seal with waterproof membranes.
- Test for continuity after installation to ensure no unintended bridging of the dielectric barrier.

This approach keeps water and sewer systems fully functional while preserving the dielectric “Carrington House” isolation and Faraday cage integrity.

4. Communication Lines

Communication lines (phone, cable, internet, security systems, etc.) are another significant penetration that can carry induced currents and high-frequency EMP energy into the structure.

Recommended Strategy:

- **Primary Preference:** Use **fiber optic cable** with non-metallic entry wherever possible. Fiber optic is immune to induced electrical currents and provides excellent performance.
- **When Metallic or Coaxial Cable is Required:**
 - o Route the cable through a **waveguide-below-cutoff sleeve** at the Faraday cage penetration.
 - o Install a high-quality **data line surge protective device (SPD)** or fiber optic isolator at the entry point.
 - o Bond the exterior metallic portion of the cable shield or conduit to the mesh cage and single-point grounding system.
 - o Use dielectric breaks or isolation transformers immediately inside the cage.

Best Practices:

- Keep metallic communication runs as short as possible inside the protected envelope.
- Prefer buried fiber optic service from the utility provider when available.
- For internal networking, use fiber or shielded Ethernet with proper grounding.
- Test for continuity after installation to ensure the dielectric barrier remains intact.

This approach keeps modern communication systems fully functional while preventing them from becoming entry points for damaging GIC or EMP energy.

5. Solar PV Systems

Solar photovoltaic (PV) systems can be a valuable addition for off-grid resilience, but they require careful integration to avoid becoming a major GIC or EMP entry path.

Recommended Strategy:

- Install PV inverters, charge controllers, and batteries **inside** the Faraday cage / protected envelope.
- Route all PV wiring from the external panels through **metallic conduit acting as waveguide-below-cutoff sleeves** where they penetrate the mesh cage.
- Install **EMP-rated surge protective devices (SPDs)** on both the DC side (between panels and inverter) and AC side (inverter output).
- Bond all metallic conduit and equipment grounds directly to the single-point grounding system.
- Use **DC disconnects and rapid shutdown** components rated for surge protection.
- Consider **micro-inverters** or optimizers with built-in surge protection for added modularity.

Best Practices:

- Prefer roof-mounted or ground-mounted arrays with short, well-protected runs.
- During Peak Phase events, disconnect external PV arrays if possible (manual or automatic transfer switch).
- Test the entire system for continuity and shielding effectiveness after installation.

This approach allows the Carrington House to generate clean power post-event while maintaining full electromagnetic protection.

Construction Integration – Best Practices for All Penetrations

Every utility penetration (electrical, water, sewer, communication, solar PV, etc.) must be carefully detailed to preserve the overall performance of the Carrington House system.

- **Locate penetrations near the single ground corner when possible.** Keeping penetrations close to the single-point grounding location reduces the length of bonding conductors and minimizes potential voltage differences during extreme GIC events.
- **Surround each penetration with horizontal mesh rings.** Create a conductive “collar” using horizontal mesh connectors or additional mesh strips around every opening. This maintains electrical continuity of the 6-sided Faraday cage and prevents energy leakage.
- **Maintain XPS dielectric isolation at the penetration points.** The dielectric barrier is one of the most important features of the design. Ensure that no metallic pipe or conduit

creates a conductive bridge across the XPS foam layers. Use dielectric unions or isolation fittings as needed.

- **Test shielding effectiveness after installation.** Before closing walls or pouring final slabs, perform thorough continuity testing of the entire mesh cage and measure resistance between the structure and earth. This verification step is critical — it confirms the system will perform as designed when the big event arrives.

These consistent practices across all penetrations are what separate a good Faraday installation from an excellent one. Document everything carefully on your construction drawings and checklists.

Performance Expectations With this approach, penetrations should allow less than 1–5% of external GIC/EMP energy to enter the protected space.

3.8 Waveguide Below Cutoff Performance - (WGBC) Calculations & Application

A **waveguide below cutoff** is a simple but highly effective way to allow utilities (pipes, conduits, ducts) to penetrate a Faraday cage while blocking high-frequency electromagnetic fields (EMP) and induced currents.

The principle is: If a tube (waveguide) is **long enough relative to its diameter**, it acts as a high-pass filter that **attenuates** electromagnetic energy below a certain frequency (the cutoff frequency). GIC and most EMP frequencies fall well below this cutoff, so they are strongly attenuated.

Cutoff Frequency Formula

For a **circular waveguide** (most common for conduits and pipes):

$$f_c = \frac{5.9}{d}$$

Where:

- f_c = Cutoff frequency in GHz
- d = Inside diameter of the tube in inches

Attenuation Rule of Thumb:

- For every **one diameter of length**, you get approximately **32 dB** of attenuation below cutoff.
- Longer sleeves = much higher attenuation.

Practical Calculations for the Carrington House

Penetration Type	Typical Diameter	Cutoff Frequency	Recommended Sleeve Length	Attenuation (est.)
Electrical Conduit	1 inch	~5.9 GHz	6–8 inches	192 – 256 dB
Electrical Conduit	2 inch	~2.95 GHz	12–16 inches	192 – 256 dB
Plumbing Pipe (PVC)	1.5 inch	~3.93 GHz	9–12 inches	192 – 256 dB
HVAC Duct	4–6 inch	0.98 – 1.48 GHz	24–36 inches	192 – 288 dB

Performance: With properly designed waveguide sleeves, high-frequency EMP and induced currents are attenuated by **over 200 dB** — effectively reducing them to negligible levels inside the protected space.

This is one of the most proven and effective techniques used in military and critical infrastructure Faraday cages.

3.8.1 Window and Door Openings – Mesh, Waveguide, and Buck Integration

Windows and doors are the largest penetrations in the Faraday cage and require careful treatment to maintain shielding effectiveness while preserving livability and ease of construction. Applying the **waveguide-below-cutoff** principle to windows and doors is one of the most challenging but important aspects of maintaining a high-performance Faraday cage in a livable house.

The Challenge with Windows and Doors

- Windows and doors are large openings that break the continuity of the mesh Faraday cage.
- Without proper treatment, they become major leakage points for GIC-induced fields and high-frequency EMP.
- Standard glass and wood/plastic frames offer almost **zero shielding**.

Recommended Approach: Use industry-available ICF window and door buckouts (such as V-Buck or equivalent deep plastic/wood bucks) combined with layered mesh and film solutions. This keeps components lightweight and manageable while providing strong GIC protection.

Plastic or Wood Bucks with Horizontal Mesh Connectors

Non-metallic bucks (plastic or wood) do not function as true conductive waveguides because they lack metal walls. However, embedding **horizontal mesh connectors** around the entire perimeter of each buck during ICF stacking creates a **conductive ring** that ties the removable screens to the main wall mesh.

This ring significantly reduces the effective aperture size and provides a shunting path for induced currents, offering **moderate to good** attenuation even without metal bucks.

Removable Exterior Mesh Screens (typical architectural open/closed shutters)

Install **4x4 galvanized mesh screens** on the exterior face of all windows and doors in removable frames.

Overlap the screen frame onto the surrounding wall mesh by 4–6 inches and use conductive clips for reliable electrical bonding.

This is the primary shielding layer and provides the bulk of GIC attenuation.

Conductive Window Films

Apply high-quality conductive EMI shielding film (silver or copper-based) on the glass.

Adds **20–50 dB** supplemental attenuation and works well in combination with mesh screens.

Performance Expectation:

- With horizontal mesh connectors + exterior mesh screens + conductive film: **80–120+ dB** attenuation across openings — sufficient for extreme GIC events.
- When exterior ballistic/storm shutters (with interior mesh) are closed, protection approaches that of a solid wall section.

Detailed Construction Steps:

1. During ICF Block Wall Stacking:

- o Install deep plastic or wood bucks (V-Buck or equivalent) at all window and door locations.
- o Embed **horizontal 4x4 mesh connectors** (12–18 inches wide) around the entire perimeter of each buck so they extend through the ICF core.

2. After Walls Are Poured:

- o Attach the main vertical 4x4 mesh to the exterior of the walls.
- o Bond the horizontal connectors to the vertical mesh using hog rings and conductive primer/paint.

3. Screen Installation:

- o Mount removable 4x4 mesh screens on the exterior, overlapping the buck by 4–6 inches.
- o Secure screens with conductive clips or latches that make solid contact with the perimeter mesh ring.

4. Optional Enhancements:

- o Apply conductive window film to the glass.
- o Add exterior ballistic/storm shutters with interior mesh layer for Peak Phase protection.

This system balances maximum shielding with practical, lightweight, and removable components while using standard ICF buck products you are familiar with.

Windows and doors are the largest penetrations in the Faraday cage and require careful treatment to maintain shielding effectiveness while preserving livability.

3.8.2 Waveguide Penetration Sealing Methods

Proper sealing of waveguide penetrations is essential to maintain Faraday cage integrity, prevent moisture ingress, preserve dielectric isolation, and ensure long-term durability. A waveguide sleeve that is electrically bonded but not properly sealed can allow water, insects, or conductive debris to compromise both the electrical performance and the building envelope.

Key Requirements for Carrington House Penetrations

- Maintain low-resistance electrical bond to the mesh cage.
- Preserve dielectric isolation (no conductive bridging across the XPS/concrete interface).
- Provide weatherproofing and waterproofing suitable for below-grade and above-grade conditions.
- Allow for thermal expansion/contraction and minor seismic movement.
- Minimize high-frequency leakage while blocking quasi-DC GIC.

Recommended Sealing Methods

1. Primary Method: Conductive + Dielectric Hybrid Seal (Best Overall)

- **Electrical Bonding:** Use heavy copper straps or mesh tabs welded/clamped to the waveguide sleeve and bonded to the surrounding 4x4 mesh with hog rings + conductive primer/paint.
- **Dielectric Break:** Install a dielectric union or non-conductive gasket (rubber, silicone, or HDPE) immediately inside the cage to prevent current bridging.
- **Weatherproof Seal:**
 - o Apply high-quality **conductive caulk** (e.g., Chomerics CHO-SEAL or MG Chemicals conductive silicone) around the exterior joint between sleeve and mesh.
 - o Follow with a **non-conductive waterproof sealant** layer (e.g., Sikaflex 1A, Dicor Lap Sealant, or polyurethane caulk) for weatherproofing.
 - o Wrap the penetration with self-adhering rubberized membrane (e.g., Blueskin or Grace Ice & Water Shield) for redundancy.

2. Compression Gasket + Waveguide Flange

- Use a metal flange welded or clamped to the waveguide sleeve.

- Sandwich a conductive gasket (copper mesh impregnated with silicone or EMI gasket material) between the flange and the mesh cage.
- Secure with bolts and apply non-conductive waterproof caulk on the exterior face.
- This method is excellent for larger penetrations (e.g., HVAC ducts, main power conduits).

3. Heat-Shrink + Conductive Tape Method (For Smaller Penetrations)

- Slide conductive heat-shrink tubing over the waveguide sleeve and mesh overlap.
- Apply conductive copper tape (3M 1181 or equivalent) in multiple overlapping layers.
- Top with heavy-duty waterproof heat-shrink or mastic tape (e.g., 3M 2228 Rubber Mastic Tape).
- Good for quick field repairs or smaller data/communication lines.

4. Below-Grade Penetrations (Foundation/Wall)

- Use a PVC or HDPE sleeve through the XPS foam and concrete.
- Line the inside with a metallic waveguide tube bonded to the mesh.
- Seal the annular space with closed-cell foam + waterproof grout or hydraulic cement on the exterior.
- Apply full waterproof membrane boot (e.g., Grace PreTak or equivalent) around the penetration.

Manufacturers and Recommended Products

- **Conductive Materials:** MG Chemicals 841 Super Shield, Chomerics CHO-SEAL, 3M 1181 Copper Foil Tape.
- **Waterproof Sealants:** Sikaflex 1A Polyurethane, Dicor Lap Sealant, OSI Quad.
- **Membrane Systems:** Grace Ice & Water Shield, Blueskin WP 200, Tremco Below-Grade Membranes.
- **EMI Gaskets:** Parker Chomerics, Leader Tech, or Tech-Etch conductive gaskets.

Performance Expectations

- With proper hybrid sealing, these penetrations should maintain >100–200 dB attenuation for high-frequency EMP while providing excellent quasi-DC GIC blocking.
- Long-term reliability is high when using UV-stable, flexible sealants and redundant membrane layers.

Construction Best Practices

- Perform all sealing after mesh bonding but before final stucco or backfill.
- Test electrical continuity across the seal after curing.

- Include inspection ports or removable covers on critical penetrations for future maintenance.
- Document all penetration details on as-built drawings.

This sealing approach ensures the waveguide penetrations remain both electrically effective and building-code compliant for waterproofing and durability.

3.9 Daylight Basement configuration

For owners who desire additional living or storage space, a **daylight basement** built on a hillside is a highly compatible option with the Carrington House concept. This configuration maintains strong dielectric isolation and Faraday cage performance while allowing gravity drainage from the footings and under slab drain piping.

3.9.1 Construction Details:

- Basement walls use standard ICF or poured concrete with **full 4x4 mesh** on the exterior face.
- **Vertical XPS foam** (minimum 3–4" thick) is installed on the **outside of the mesh** for the entire below-grade height to maintain dielectric isolation from surrounding soil.
- Basement floor consists of a 4" concrete slab with embedded **4x4 mesh**, poured over **4" XPS foam** and a 12–24" crushed stone drainage layer.
- All under-slab drainage piping (footing drains, slab drains) runs **beneath both the XPS and the concrete slab** before exiting the structure through waveguide sleeves at the downhill side.
- Horizontal mesh connectors are embedded at the top of the basement walls to maintain full electrical continuity with the main concrete floor slab level mesh.

GIC and Faraday Cage Performance:

- The deeper XPS isolation on basement walls significantly increases overall dielectric resistance.
- The mesh in the basement slab and walls integrates seamlessly with the main structure's Faraday cage through the embedded horizontal connectors.
- **Overall internal induction risk:** Low to very low, even with the increased below-grade surface area.

3.9.2 Seismic Performance Analysis: Single-Story vs Daylight Basement Configurations

Here is a clear, engineering-focused comparison for extreme seismic events (long-duration, high-intensity shaking consistent with SDC F and potential crustal shift scenarios).

The design already includes **vertical ICF ribs** from footing to roof and **interior ICF walls** to shorten roof beam spans. These are excellent strengthening measures. The main variables now are:

- Single-story slab-on-grade vs. daylight basement
- Wood TJI floor system vs. concrete T-beam first floor (in basement version)

Single-Story Configuration:

- Lower center of mass = lower overturning moments and shear forces.
- Shorter overall height reduces amplification of ground motion.
- With your interior ICF ribs and walls shortening roof spans, this is a very robust box-like structure.
- **Best performer** in extreme, long-duration seismic events.

Daylight Basement Configuration:

- Adds significant mass and height, which increases inertial forces during shaking.
- The basement acts as a stiff base, but the transition at the main floor level can create stress concentrations.
- Gravity drainage requirement (hillside) is good, but the downhill retaining wall experiences high lateral earth pressures during shaking.
- A **concrete T-beam first floor** would be significantly stronger and more integrated than a wood TJI floor system.
- Wood TJI floor would be lighter and cheaper but less monolithic — more potential for differential movement between basement and upper structure.

Floor System Comparison (Basement Version):

- **Concrete T-beam First Floor:** Much better seismic performance. Creates a rigid diaphragm that ties the basement walls together and reduces torsion. Heavier, but more resistant to long-duration shaking.
- **Wood TJI Floor:** Lighter and faster to build. Acceptable if well-braced and tied to walls, but more flexible — higher risk of damage in extreme events.

Recommendation

For Maximum Seismic Resilience:

- **Single-story slab-on-grade** is the **clear winner** for surviving extreme, long-duration seismic shaking. It is simpler, lighter, has a lower center of mass, and fewer weak points.

If You Want a basement:

- Use a **daylight basement** on a hillside.

- Go with a **concrete T-beam first floor** (not wood TJI) for best performance.
- Increase vertical rib frequency and use heavier reinforcing at the main floor transition.
- Expect roughly **15–25% higher** stress on the upper structure compared to single-story.

3.10 Design for Cascadia+ Type Seismic Input Values

This section addresses seismic design only. Electromagnetic (GIC/EMP) performance is covered in Sections 3.2, 3.3, and 3.15.

The Carrington House design uses the **Cascadia Subduction Zone M9 earthquake** as the primary seismic design basis. This event represents one of the most thoroughly studied long-duration megathrust earthquakes, with strong shaking lasting 60–180+ seconds plus significant aftershock sequences.

While the exact seismic characteristics of a magnetic pole flip remain uncertain, the Cascadia M9 provides a scientifically grounded, conservative anchor for long-duration shaking, high cumulative energy input, resonance effects, and fatigue on structural components.

“Cascadia+” Design Philosophy To account for potentially more extreme pole-flip conditions (higher accelerations, longer duration, or repeated major aftershocks), the design incorporates significant over-strength beyond standard Cascadia M9 requirements. This includes double-curtain GFRP reinforcement, 10–12 inch ICF walls, frequent interior ribs, earth berms, and higher-strength concrete.

Supporting Research and Manufacturer Approaches The ICF industry has substantial experience with high-seismic zones. A 2022 study by the National Ready Mixed Concrete Association (NRMCA) and the U.S. Resiliency Council (USRC) compared multifamily buildings and found that ICF configurations produced **18% to 80% higher lateral force resistance** and **4 to 5 times greater stiffness** than wood-frame, CLT, and steel-frame systems. ICF buildings were projected to return to service in **less than 2 weeks**, compared to 6.5–9.5 months for other construction types in high-seismic scenarios.

Manufacturers such as **Nudura**, **Logix**, **BuildBlock**, and **Element ICF** actively market their systems for high-seismic performance, with many referencing reduced drift and superior stiffness in prolonged shaking events. Pacific Northwest designers frequently use denser reinforcement, interior shear walls/ribs, and stronger diaphragms (concrete roof systems) when designing for Cascadia-level events.

Rebar Schedules – Prescriptive Code vs. Carrington House (10" Flat ICF Wall, 8–10 ft height)

Horizontal Reinforcement (Common across schedules)

- #4 (or GFRP equivalent) at maximum 18" o.c. vertically
- One bar within 12" of the top of each story/wall

Vertical Reinforcement Comparison

SDC Zone / Event	Code Minimum Steel (Vertical)	GFRP Single Curtain	GFRP Double Curtain (Recommended)	Notes
SDC D2 (Prescriptive)	#5 @ 32" o.c.	#6 @ 32" o.c.	#6 @ 36" o.c. each face	Baseline code minimum
Cascadia M9 (Design Basis)	#5 @ 24" o.c. or engineered	#6 @ 24" o.c.	#6 @ 24–30" o.c. each face	Long-duration shaking
Cascadia+ / Pole Flip	Engineered (beyond prescriptive)	#6 @ 18–24" o.c.	#6 @ 18–24" o.c. each face + L-ties	Extreme over-design

L-Shaped GFRP Roof-to-Wall & Interior Support Ties #6 GFRP L-shaped bars at all roof beam/wall intersections and interior bearing points. Spacing matches vertical rebar schedule. These ties ensure structural continuity and maintain Faraday cage electrical bonding.

How Double-Curtain GFRP Pushes Performance Beyond Prescriptive Code Prescriptive IRC tables (e.g., R404.1.3.2 series for SDC D2) assume typical earthquake durations of 10–40 seconds. Double-curtain GFRP significantly exceeds these minimums by:

- Providing better resistance to bending in both directions (positive and negative moments)
- Improving ductility and energy absorption during long-duration shaking and repeated aftershocks
- Reducing crack widths and cumulative fatigue in the concrete
- Allowing the wall to behave more like a reinforced shear wall even under Cascadia+ conditions

This upgrade, combined with interior ribs, higher-strength concrete, and earth berms, gives the Carrington House substantial margin beyond standard SDC D2 or even standard Cascadia M9 requirements.

Performance Outlook

- Single-story slab-on-grade remains the strongest performer due to lower mass and simpler load paths.
- Daylight basement designs are viable with concrete T-beam first floors and increased rib frequency.
- With the hybrid GFRP approach and proper detailing, the Carrington House is engineered to survive Cascadia M9-level (and greater) long-duration seismic events while maintaining full structural survival and long-term habitability.

References

- NRMCA & USRC, Earthquake.Performance.Comparison.of.Multifamily?Multistory.Apartment. Buildings, 2022.

- Cascadia Subduction Zone modeling (DOGAMI, USGS, CREW reports).
- IRC 2021/2024 Sections R404.1.3 and R608.

3.10.1 Analysis: Venezuela Earthquake Lateral Displacement vs. Seismic Design Categories

I asked Grok to review the NASA Earth Observatory article and supporting data on the **June 24, 2026 Venezuela earthquakes** to give all of us a better understanding of the mechanics of this event as compared to what the IRC Code and others prescribe for the building design criteria.

Key Facts from the Event

- **Events:** Magnitude 7.2 foreshock followed ~39–60 seconds later by a Magnitude 7.5 mainshock.
- **Fault type:** Right-lateral **strike-slip** (primarily horizontal movement) on the San Sebastián / Boconó fault system (Caribbean–South American plate boundary).
- **Ground displacement** (from NASA-ISRO NISAR InSAR data):
 - o Predominantly **horizontal** (lateral) displacement.
 - o Maximum surface offset reached approximately **60 cm (24 inches / 2 feet)** westward in some areas just south of the fault near La Guaira / the international airport north of Caracas.
 - o The rupture produced a clear east–west displacement pattern with a narrow zone of little displacement marking the surface expression of the fault.

This is **permanent co-seismic ground displacement** (the land permanently shifted sideways by up to 2 feet), not peak ground acceleration (PGA) or peak ground velocity (PGV) during the shaking itself.

Comparison to Seismic Design Categories and Cascadia

Parameter	Venezuela M7.5 Strike-Slip Event	SDC D2	SDC F	Cascadia M9 (Subduction Zone)
Dominant Motion Type	Pure strike-slip (lateral)	Varies (often strike-slip or reverse)	Highest hazard zones (often near major faults)	Thrust (primarily vertical + some horizontal)
Maximum Permanent Lateral Offset	Up to 60 cm (24 inches) near fault	Not typically designed for large permanent offsets	Higher detailing, but still limited permanent offset capacity	Usually smaller surface lateral offsets (cm to tens of cm in most models); larger vertical subsidence (up to ~2 m / 6.5 ft in places)

Parameter	Venezuela M7.5 Strike-Slip Event	SDC D2	SDC F	Cascadia M9 (Subduction Zone)
Nature of Hazard	Surface fault rupture + strong shaking	Strong shaking	Very strong shaking + proximity to major faults	Extremely long duration shaking (60–180+ sec) + possible subsidence + liquefaction
Design Focus	—	High ductility, capacity design	Highest ductility, special detailing	Long-duration energy input, low-cycle fatigue, cumulative damage
Typical Design Ground Motions	—	High (e.g., SDS often 0.5–1.0g range)	Highest (near major faults)	High accelerations + very long duration

Analysis and Interpretation

1. **Vs. SDC D2** SDC D2 is a high seismic design category used in many western U.S. areas with severe expected shaking. Buildings in SDC D2 are designed for strong ground shaking and require good ductility, but they are **not specifically designed to accommodate 60 cm of permanent lateral surface fault offset**. If a structure is built directly across or very near a surface-rupturing strike-slip fault that moves 2 feet, even a well-designed SDC D2 building would likely suffer significant foundation and structural damage from the permanent displacement itself (not just the shaking).
2. **Vs. SDC F** SDC F is the highest category (critical facilities near major active faults). It requires the most stringent detailing and ductility. Even so, standard SDC F design still assumes the structure is not straddling a surface fault that will offset by tens of centimeters. Permanent fault displacement of this magnitude is generally handled through **fault setback zones** and avoidance rather than by designing the building to ride through 2 feet of lateral shift. (my input – don't build a house on top of a known fault)
3. **Vs. Cascadia M9** Cascadia is a very different animal. It is a megathrust (subduction) event.
 - o **Permanent lateral (horizontal) surface offsets** from Cascadia are generally smaller than the 60 cm seen in this Venezuela strike-slip event.
 - o Cascadia's main permanent effects are **vertical subsidence** (coastal areas can drop 1–2 meters / 3–6.5 feet) and **long-duration shaking**.
 - o The greater challenge for Cascadia is the **duration** of strong shaking (often 1–3 minutes or more) and the cumulative energy input, which stresses connections and can cause low-cycle fatigue in structural elements — exactly why the Carrington House design emphasizes double-curtain GFRP, interior ribs, and over-strength.

Bottom Line for the Carrington House Project

- The **60 cm (2 ft) permanent lateral displacement** measured in Venezuela is a classic example of surface fault rupture on a strike-slip fault. This is a **near-fault permanent offset** problem.
- Standard U.S. seismic design categories (even SDC F) do **not** design buildings to accommodate this much permanent differential lateral movement across the foundation. The preferred approach is to avoid building on or immediately adjacent to active surface faults.
- For **Cascadia**, the Carrington House design is more appropriately focused on long-duration shaking, cumulative fatigue, and maintaining structural integrity under prolonged cyclic loading — which is what the Cascadia+ detailing (double-curtain GFRP, frequent ribs, L-shaped ties, higher-strength concrete, berms) is intended to address.

This Venezuela event is a good real-world reminder of how destructive pure lateral permanent offset can be, but it is a different hazard type from the long-duration Cascadia megathrust scenario that is the primary seismic design basis for the Carrington House.

3.11 Role of Earth Berms in Extreme Seismic Events

Earth berms are one of the most effective passive methods to reduce stress in critical zones during extreme seismic events.

How Earth Berms Help:

- Provide **passive earth pressure** against the lower walls, counters outward bulging and reduces bending moments at the base and grade-level transition zone.
- Increase **damping** (energy absorption) during long-duration shaking.
- Protect the high-stress **grade-level transition zone** in basement designs by “burying” it and reducing differential movement.
- Lower the effective center of mass slightly and help the building behave more like an embedded mass rather than a cantilever.
- With doubled seismic forces, this lateral support becomes very valuable — it can reduce wall stresses by **20–40%** in the lower third of the structure.

Mass Damping Effect

- The added soil mass increases **damping** (energy absorption) during shaking.
- This helps dissipate vibrational energy, lowering peak accelerations transmitted to the upper structure.

Grade-Level Transition Zone Protection

- In a daylight basement design, the grade-level transition is the highest stress area.
- A well-designed berm (extending 4–8 ft high against the wall) significantly **reduces differential movement** and stress concentrations at this junction.

- The berm effectively “buries” the weak transition point, making the structure behave more like a monolithic mass.

Overall Structural Benefit

- Reduces overturning moments.
- Lowers the effective center of mass slightly.
- Helps the building act more like an integrated “bermed box” rather than a cantilevered structure.

Recommended Berm Configuration for Doubled SDS F

- **Height:** 5–8 ft against the walls (higher on downhill side for daylight basement).
- **Slope:** 2:1 or flatter for stability.
- **Dielectric Isolation: Critical** — place **3–4" XPS foam** between the berm soil and the exterior mesh to maintain the Carrington House principle.
- **Drainage:** Install gravel drainage layer behind the XPS + perforated pipe with gravity outlet.

Expected Performance Improvement:

- **Stress reduction at grade-level transition:** 25–45%
- **Overall building resilience:** Significant — berms turn the structure into a more “embedded” form that handles extreme shaking better.
- **Single-story:** Still best, but berms make basement versions much more competitive.

Trade-offs:

- Adds cost and excavation.
- Requires careful waterproofing and dielectric detailing.
- Increases thermal mass (positive for energy efficiency).

Bottom Line: Earth berms are a **highly recommended** addition for doubled (or higher) seismic inputs. They directly address the stress zones you’re concerned about, especially in basement designs, while also improving radiation shielding and thermal performance.

Combined with interior ICF ribs and vertical reinforcement, this creates a very robust system. The key is maintaining dielectric isolation (XPS between soil and mesh) so GIC protection is not compromised.

3.12 Internal Wiring Protection Under Extreme GIC Events

((Assumes correctly installed, continuous 4x4 mesh Faraday cage with good bonding, single-point grounding, and external utilities disconnected))

Even with a high-performance Faraday cage, residual magnetic fields can induce small voltages in internal wiring. The primary risk is I^2R heating in copper conductors.

Table 3.10 – Induced Heating Risk in Internal Wiring

Geoelectric Field (V/km)	Est. Surface Current Density	Induced Current (60-ft, 14 AWG)	Induced Current (200A Service Feeder, 20–60 ft)	Heating / Fire Hazard Level	Recommendation
10–20 (Carrington)	Moderate	0.5 – 2 A	< 0.1 – 0.3 A	Negligible	Standard Romex fine
30–60 (Extreme)	High	2 – 6 A	0.2 – 0.6 A	Low	Standard Romex acceptable
60–100 (Super Extreme)	Very High	6 – 15 A	0.3 – 1 A	Moderate	EMT for long runs preferred
100–200+ (Theoretical Max)	Catastrophic	15 – 40+ A	0.6 – 2 A	High	EMT conduit recommended for long runs

Specific 200A Service Feeder Analysis For typical 2/0 or 4/0 copper service conductors:

- Induced voltage remains very low due to short runs and heavy conductor cross-section.
- Even at 200 V/km with 2–3% residual coupling, induced current stays under **2 A** on a 60-ft feeder — **no meaningful heating risk**.
- The main 200A service feeders are therefore well-protected by the Faraday cage and do not require special twisted wiring or conduit.

Conclusion for Builders: With a properly executed Faraday cage, standard NM/Romex wiring is acceptable for the majority of the house, including the main 200A service feeders. Use EMT conduit or armored cable primarily for long branch circuits (>40 ft) or critical areas. A dedicated internal sanctuary room provides extra protection for sensitive electronics.

3.13 Protection of Structural Conductive Elements

A core strength of the Carrington House design is the deliberate minimization of long continuous conductive paths inside the structure. This approach addresses both primary threats:

- Under sustained geomagnetic events, it prevents Earth currents from diverting into the building and producing resistive (I^2R) heating.
- Under extreme lightning or a massive atmospheric pulse, it removes preferential low-impedance routes that would otherwise collect high peak currents and create internal arcing or voltage gradients.

By replacing primary structural steel with GFRP and isolating residual metal penetrations, the design removes the highest-risk pathways for both classes of threat.

Traditional Faraday cages typically focus on shielding interior spaces and sensitive equipment. Large structural steel elements (long rebar runs, beams, etc.) are often left as potential induction antennas, which can experience significant heating, voltage differentials, or arcing during extreme GIC events.

The Carrington House approach fundamentally changes this by treating the entire structural steel grid as an integrated part of the protection system through **deliberate, frequent equipotential bonding** to the continuous mesh Faraday cage design, either the simple single point mesh grounding or the full 6 sided faraday cage concepts.

Key Benefits:

- Induced currents are safely shunted across the large-area mesh and to the single-point ground instead of circulating locally.
- Temperature rise in steel rebar remains low (<80°C) even under extreme GIC conditions (1,000 – 10,000+ A/km²).
- Reduces risk of concrete spalling, rebar expansion stress, and localized damage.
- Protects copper/aluminum wiring and other embedded metals as a secondary benefit.

This “protect the structure itself” philosophy represents a meaningful advancement over conventional Faraday implementations and significantly improves the long-term survivability and post-event habitability of the building.

3.14 Specific Shielding Calculations

This section provides quantitative estimates for radiation (neutron skyshine) and GIC/EMP shielding effectiveness based on the Carrington House’s layered design. Calculations use standard attenuation formulas, material properties, and conservative assumptions for extreme events. The design uses a **two-tier basis**:

- **Tier 1 (Carrington X45 Baseline):** Severe solar flare activity during the weakening magnetic field phase.
- **Tier 2 (Micro-Nova / Rapid Pole Flip Peak):** Extreme upper bound ($\sim 9 \times 10^{33}$ ergs X-ray burst + very high dB/dt).

3.14.1 Neutron Skyshine Attenuation (Roof Assembly)

Assumed Incident Neutron Flux (Phase 2 / Micro-Nova Peak): 10^3 – 10^5 n/cm²/s (conservative estimate for weakened magnetic field and micro-nova burst).

Layered Roof Assembly (from outside in)

Layer	Thickness	Material Properties	Attenuation Factor (Thermal Neutrons)	Cumulative Reduction
Soil Overburden	12–24"	Density 1.6–2.0 g/cm ³	2–5×	2–5×
Borated Concrete	4–6"	5% boron by weight	3–10×	6–50×
Borated Polyethylene	2–4"	5–10% boron	10–50×	60–2,500×
ICF Concrete Core	8–12"	Standard + Enhance ICD	2–5×	120–12,500×

Estimated Total Roof Attenuation: 100–10,000× reduction in neutron flux depending on configuration. **Sanctuary Zone Target** (thicker layers + internal walls): ≥ 1,000× reduction.

Key Formula: Attenuation = $e^{(-\mu x)}$ where μ is the linear attenuation coefficient and x is thickness. Borated materials significantly increase μ for thermal neutrons.

3.14.2 GIC / EMP Field Reduction

External Geoelectric Field:

- Tier 1 (Carrington X45): 5–20 V/km
- Tier 2 (Micro-Nova Peak): 20–300+ V/km (with very high dB/dt)

Internal E-Field Target: < 10 V/m (ideally < 5 V/m)

Calculated Reduction:

- With good mesh continuity + single-point grounding: 20–100× reduction in internal voltage.
- With full dielectric isolation (>1 MΩ): Additional 5–20× improvement.
- Overall system: Internal fields reduced to < 5–10 V/m even at Tier 2 extreme external fields.

Induced Current in Internal Wiring (40 ft run example):

- Without protection: Potentially 10–100+ A induced.
- With Carrington House design: Reduced to < 0.5–5 A (safe for most wiring) at Tier 1 levels; still manageable (< 20–50 A peak) at Tier 2 with proper design.

3.14.3 Overall System Shielding Effectiveness

- **GIC Shunting Efficiency:** 85–95% (Recommended), 95–99%+ (Upper Limit)
- **Neutron Skyshine Reduction:** 100–10,000× (roof assembly)

- **Internal E-Field:** < 10 V/m target met in recommended configuration; < 5 V/m in Upper Limit + sanctuary zone
- **Combined Multi-Hazard Protection:** The layered approach (mesh cage + dielectric isolation + mass shielding + GFRP) provides defense-in-depth effective across the full spectrum of threats in all three phases of the event.

Uncertainties and Recommendations

- Exact spectra and dB/dt during a micro-nova event are unknown — calculations use conservative upper bounds based on available modeling and insider guidance from the SuspiciousObservers community.
- Monte Carlo simulations (e.g., MCNP software) are recommended for final validation of radiation shielding.
- On-site testing with low-level sources and continuity measurements should be performed post-construction.
- These calculations demonstrate that the Carrington House design achieves substantial hazard reduction using practical, code-compliant materials and construction methods while prioritizing full structural survival and long-term self-sufficiency.

3.14.4 Monte Carlo Radiation Shielding Simulations (MCNP)

For final validation and optimization of the Carrington House's radiation shielding performance — particularly the roof assembly and interior sanctuary zone — the gold-standard approach is **Monte Carlo simulation**. Unlike simplified analytical formulas that give approximate attenuation factors, Monte Carlo methods track the actual random behavior of millions to billions of individual particles (neutrons, photons, protons, etc.) as they interact with each layer of material in the structure.

The most widely used and trusted software for this type of work is **MCNP** (Monte Carlo N-Particle Transport Code), originally developed and still maintained by **Los Alamos National Laboratory** (LANL) in New Mexico. MCNP is the industry standard in nuclear engineering, space radiation protection, and high-energy physics shielding design. It can model complex geometries, material compositions (including exact boron concentrations in polyethylene and concrete), energy spectra of incoming radiation, and secondary particle production with high fidelity.

Why Monte Carlo is Important for the Carrington House

Analytical calculations (such as the attenuation factors shown earlier in this section) provide good first-order estimates. However, they cannot fully capture:

- The complex cascade of secondary particles produced when high-energy neutrons interact with the atmosphere and roof materials.
- The exact energy-dependent behavior of borated polyethylene versus boron-enhanced concrete.
- The three-dimensional geometry effects of roof beams, parapets, interior walls, and the sanctuary zone.

- Statistical variation and worst-case particle histories during a micro-nova burst.

A full MCNP simulation would give precise answers to questions such as:

- What is the actual neutron and gamma dose rate inside the main living space versus the interior sanctuary room?
- How much additional soil overburden or borated polyethylene thickness provides meaningful improvement?
- What is the optimal boron concentration and layering strategy for the expected micro-nova neutron spectrum?
- How effective is the overall roof shielding under a 9×10^{33} erg micro-nova burst with a weakened magnetic field?

Personal Note from the Author Years ago, while working on a nuclear-related project, I had the opportunity to visit Los Alamos National Laboratory. At that time, a “Q” clearance still carried real weight in the nuclear industry. Seeing the level of computational power and expertise dedicated to particle transport simulations left a lasting impression. It is gratifying to know that the same world-class tools developed at Los Alamos can now be used to validate and refine the shielding performance of a residential structure designed for extreme geomagnetic events.

Recommended Next Step Once the Carrington House design reaches a stable configuration (roof layering, boron percentages, sanctuary zone details, etc.), it is strongly recommended to engage a qualified nuclear engineer or consultant with access to MCNP (or equivalent codes such as GEANT4 or FLUKA) to run detailed simulations. The results would provide high-confidence data for engineering validation, permitting discussions, and potential manufacturer collaboration.

This level of analysis would further strengthen the technical credibility of the Carrington House concept and give owners clear, quantifiable expectations for radiation protection during the most severe phases of a pole-flip / micro-nova event.

3.14.5 Radiation Shielding Analysis – Detailed Technical Discussion and Reasoning

Radiation shielding was examined in depth during the development of the Carrington House concept, even though it is not the primary design driver. The core engineering focus remains on protection against extreme **Geomagnetically Induced Currents (GIC)** through the six-sided Faraday cage and dielectric isolation system, combined with **long-duration seismic resilience** using the Cascadia M9 event as the baseline with additional margin (Cascadia+). Radiation protection is treated as a meaningful secondary requirement that must be addressed in a practical, buildable manner.

Because a true micro-nova event carries significant uncertainty in flux intensity and energy spectrum, the shielding strategy was developed using a **pragmatic engineering approach** rather than attempting a fully conservative or heavily over-designed solution at this stage.

9;70;17.Purpose.and.Approach.to.the.Radiation.Shielding.Analysis

The radiation shielding analysis was undertaken to understand how the Carrington House design would perform under the radiation environment expected during a magnetic pole flip and associated micro-nova event. The analysis was guided by the following principles:

- Focus on realistic, buildable solutions using current materials and construction methods.
- Prioritize protection where people will actually shelter during the peak phase.
- Maintain a clear distinction between what could be reasonably estimated with available data and what requires advanced modeling (such as Monte Carlo simulations) for final optimization.
- Treat this as a **one-time emergency exposure** scenario rather than an occupational or continuous exposure condition.

Early analysis revealed that the specific geometry of the roof system would significantly influence internal radiation performance. This led to a detailed examination of how neutrons and secondary gammas interact with the actual roof assembly.

9;70;18.Key.Physical.and.Geometric.Challenges.Identified

One of the most important findings was the impact of the **thick EPS foam deck** used in modern ICF hybrid roof systems. These systems typically use a relatively thin concrete cap slab (commonly ~6 inches) over a thick EPS foam layer (12–14 inches), with structural concrete beam channels formed through the foam.

While this design offers good structural and thermal performance, it creates a notable challenge for radiation shielding. Fast neutrons that penetrate the concrete cap slab are rapidly moderated within the thick EPS foam. Because moderation and capture occur relatively close to the ceiling, a significant amount of **secondary gamma production** (particularly the 2.2 MeV gammas from hydrogen capture) takes place near the underside of the roof.

Gamma rays are emitted **isotropically** (in random directions). As a result, a meaningful fraction of these gammas travel downward into the living space. The areas between the structural beam channels are particularly vulnerable, as these represent the majority of the roof surface area and have less concrete mass to attenuate the gammas.

9;70;19.Neutron.Flux.and.Spectrum.Assessment

Estimating the neutron environment during a micro-nova required scaling from the best available historical data. The following table summarizes the relative strength and expected ground-level effects:

Table 6.1 – Neutron Flux and Event Strength Comparison

Event Type	Relative Strength (High-Energy Protons)	Expected Ground-Level Fast Neutron Flux	Notes
Strong modern GLE (e.g., 1956, 2005)	Baseline	Tens to low hundreds of $\mu\text{Sv/h}$ above background	Observed data
Miyake-type Extreme Event (e.g., 774 AD)	$\sim 30\text{--}100\times$ modern GLE	Significantly higher (likely several mSv/h range during peak)	Best historical proxy
Micro-nova ($\sim 9 \times 10^{33}$ ergs)	Likely comparable to or exceeding strongest Miyake events	Very high — potentially orders of magnitude above modern GLEs during peak hours	Modeled / scaled

Key Finding: A micro-nova would likely produce a **harder neutron spectrum** (higher proportion of fast neutrons) than typical solar particle events. This increases both penetration depth and secondary gamma production in hydrogen-rich materials such as the thick EPS foam deck.

At ground level, the dominant contributors to human radiation exposure during such extreme events are expected to be **secondary neutrons** and the **secondary gammas** they generate — particularly the 2.2 MeV gammas produced when neutrons are captured by hydrogen.

9.70.10. Dose Estimation and Target Setting

Using scaled data from strong historical events, rough order-of-magnitude estimates were developed for unshielded dose rates at ceiling level.

Table 3.14.5.4a – Estimated Unshielded Dose at Ceiling Level (Current Roof Configuration)

Configuration	Estimated Dose Rate at Ceiling (Peak Daytime Hours)	Estimated Total Dose Over Peak 3–4 Days	Notes
Single-Story	5 – 25+ mSv per hour	Likely well above 200 mSv	High exposure without additional shielding
Basement Safe Zone	0.5 – 4 mSv per hour	Roughly 20 – 80 mSv	Significantly lower due to distance + concrete floor

A working target of $\leq 200 \text{ mSv total absorbed dose}$ over the peak 3–4 days was adopted as a pragmatic planning goal. This level remains well below thresholds for acute radiation effects and is consistent with emergency exposure guidelines used for major radiological events.

Table 3.14.5.4b – Emergency Exposure Guidelines Comparison

Organization / Guideline	Context	Emergency Exposure Level	Comparison to 20–80 mSv (Basement Ceiling)
EPA Protective Action Guides	General public – sheltering	10 – 50 mSv for most actions	At or below the lower end
NCRP Report 137	Emergency workers (critical tasks)	50 mSv (normal), up to 100–250 mSv	Well below
ICRP	Emergency exposure situations	20–100 mSv range often referenced	Within or below the lower end
Acute Radiation Syndrome	Deterministic health effects	~500–1000 mSv (short exposure)	Far below
Carrington House Pragmatic Target	One-time event planning	≤ 200 mSv over peak 3–4 days	Well below target

9.70 Configuration Options Evaluated

Multiple approaches were considered. The following table summarizes the key trade-offs:

Table 3.14.5.5a – Single-Story vs. Basement Safe Zone Comparison

Criteria	Single-Story Safe Zone	Basement Safe Zone	Winner
Starting dose rate at ceiling	High	Significantly lower	Basement
Need for heavy additional shielding	High	Moderate	Basement
Lateral gamma concern	Higher	Lower (many walls below grade)	Basement
Construction complexity	Moderate	Higher	Single-Story
Overall radiation performance	Requires more shielding effort	Easier to achieve good protection	Basement
Cost	Lower to moderate	Moderate to higher	Single-Story

The concept of an **independent shielding slab** supported directly by the safe zone walls emerged as a practical solution. This allows meaningful gamma attenuation mass to be added close to the occupants without overloading the main structural roof system.

Table 3.14.5.5b – Recommended Layered Shielding Options (Basement Safe Zone)

Option	Shielding Slab Thickness	Borated Polyethylene	Expected Performance (Peak 3–4 Days)	Recommendation
A – Light Enhancement	4–6" concrete	1–2"	~50–120 mSv	Acceptable in many scenarios
B – Balanced Protection	6–8" dense/magnetite concrete	2–3"	Likely < 50–80 mSv	Recommended
C – High Protection	8–10"+ dense concrete	3–4"	Comfortably under 50 mSv	For maximum margin

9.70.1.2 Limitations of the Current Analysis

All dose estimates are based on scaling from historical Ground Level Enhancements and Miyake-type events. There is no direct measured data for a true micro-nova of the scale being considered. No Monte Carlo radiation transport modeling has yet been performed on the specific Carrington House roof geometry or proposed shielding configurations. The exact neutron energy spectrum and flux levels during a micro-nova remain uncertain.

These limitations mean the dose estimates should be viewed as **indicative** rather than definitive. They are sufficient to support configuration-level decisions and identify the most important physical challenges, but they are not yet precise enough for final detailed design.

9.70.1.3 Open Actions and Future Work Required

Several areas of work remain to advance the radiation shielding design:

- Perform Monte Carlo radiation transport modeling on the current roof geometry and proposed shielding configurations.
- Develop or obtain improved neutron flux and energy spectrum data specific to micro-nova scenarios.
- Optimize material selections (concrete density, boron loading, layer thicknesses) for cost and performance.
- Conduct detailed constructability and connection detailing studies for the independent shielding slab concept.
- Evaluate long-term durability and moisture management of added shielding layers.
- Refine dose targets and acceptable risk levels based on further review and stakeholder input.

9.70.1.4 Summary of Reasoning and Decisions Made

The radiation shielding analysis identified that the thick EPS foam deck used in modern ICF hybrid roof systems creates a significant source of secondary gamma radiation relatively close to the

ceiling. This geometry makes simple reliance on the main roof for protection during the peak phase less effective than initially assumed.

A **basement safe zone** provides a strong baseline level of protection due to greater vertical distance from the main roof and the intervening concrete first floor. **Modest additional shielding on the safe zone ceiling** can bring the dose into a comfortably pragmatic range with relatively low added cost and complexity.

An independent shielding slab supported by the safe zone walls was selected as the preferred method for adding this protection. The pragmatic target of **≤ 200 mSv total absorbed dose** over the peak 3–4 days was adopted as a reasonable planning goal at this stage of development.

The analysis and recommendations presented here represent a wide-ranging and reasonably deep first-pass engineering assessment. They are considered appropriate and sufficient for the current phase of the Carrington House concept development and intellectual property positioning. Final detailed design and optimization of the radiation shielding layers will require additional specialist resources and advanced simulation work.

3.14.6 Human Dose Mechanisms from Fast Neutrons

While much of the earlier discussion in this section focused on secondary gamma radiation (particularly the 2.2 MeV gammas produced by neutron capture in hydrogen), it is equally important to understand how **fast neutrons themselves** deliver dose to the human body. This is especially relevant for a micro-nova or extreme solar particle event, where a harder neutron spectrum is expected.

Fast neutrons do not ionize tissue directly (they have no charge). Biological dose is delivered almost entirely by the charged secondary particles they create when they collide with nuclei in tissue.

Primary.Dose.Delivery.Mechanisms

Mechanism	Energy Range Most Important	Secondary Particle	Contribution to Soft Tissue Dose	Notes
Elastic scattering on hydrogen	0.1 – 10 MeV (peak ~1 MeV)	Recoil protons	70–90%	Dominant process
Elastic scattering on C, N, O	Broader range	Heavy recoils (C, N, O nuclei)	10–25%	High Linear Energy Transfer (LET), short range
Inelastic scattering	Higher energies	Excited nuclei + gammas + particles	Increases with energy	Produces secondary gammas
Capture reactions (e.g., $^{14}\text{N}(n,p)$)	Thermal / epithermal	Protons + residual nuclei	More important after moderation	Secondary contribution

Mechanism	Energy Range Most Important	Secondary Particle	Contribution to Soft Tissue Dose	Notes
Spallation / multi-particle reactions	> 20–50 MeV	Multiple charged particles + neutrons	Significant at very high energies	Relevant for high- energy solar particles

Why Hydrogen Dominates

Soft tissue is roughly 10% hydrogen by weight but approximately 63–70% of the atoms are hydrogen. Because a neutron and a proton have nearly identical mass, a head-on collision can transfer almost all of the neutron's kinetic energy to the proton in a single interaction. These **recoil protons** then travel short distances through tissue (typically millimeters or less), depositing energy densely through ionization and excitation (high LET).

This is why hydrogenous materials (water, polyethylene, tissue, EPS foam, etc.) are both excellent moderators and significant sources of biological dose when fast neutrons interact with them.

Radiation Weighting Factors (RBE → w_R)

Fast neutrons are far more biologically damaging per unit absorbed dose than photons (X-rays or gamma rays). The ICRP radiation weighting factors (w_R) for neutrons are energy-dependent and peak in the 0.1–2 MeV range at approximately **20**. This means that 1 Gy (grey) of fast neutron dose can be biologically equivalent to 10–20 Gy of gamma dose for stochastic effects such as cancer induction.

Practical Implications for the Carrington House

In the roof and safe zone context:

1. Fast neutrons arrive from atmospheric interactions.
2. They penetrate the concrete cap slab to varying degrees.
3. In the thick EPS foam they are rapidly moderated, producing both recoil protons and subsequent capture gammas (2.2 MeV).
4. The biological dose therefore comes from two linked sources:
 - The recoil protons and heavy recoils produced by the neutrons themselves, and
 - The secondary gammas generated when those neutrons are finally captured.

Removing the thick foam over the safe zone (discussed in the next subsection) reduces both the local production of high-LET recoil proton dose and the 2.2 MeV capture gammas right next to the occupants.

3.14.7 Alternative Construction Option: Removing Thick EPS Foam Over the Safe Zone Combined with Borated Polyethylene Optimization

A practical and highly effective option available to builders is to remove the thick EPS foam (both the thick deck sections and thinner areas) from the formwork after the concrete has fully cured — **only under the safe zone ceiling**. This creates a void under the concrete tee beams and slab in the safe zone area only. The foam can be carefully cut out and removed after curing, leaving the structural concrete intact. Fire rating of the exposed concrete can be restored with standard spray-on fireproofing materials.

Why.This.Option.Is.Attractive

Aspect	With Thick Foam Left in Place	After Foam Removal Over Safe Zone	Net Effect
Location of neutron moderation	Inside thick foam, close to ceiling	Mostly inside the concrete or in the open void	Improved
2.2 MeV hydrogen capture gammas	High production right at ceiling	Dramatically reduced	Major improvement
Secondary gamma production site	Very close to occupants	Farther away / inside denser concrete	Better
Ability to install better materials	Difficult	Excellent (open void)	Major opportunity
Thermal / acoustic performance	Retained	Lost in that zone only	Acceptable trade-off
Fire rating	Foam contributes	Can be restored with spray-on fireproofing	Solvable

How.Borated.Polyethylene.Works.(Key.Physics)

Borated polyethylene (typically 5% boron by weight) performs two sequential jobs:

1. **Moderation** – The high hydrogen content in the polyethylene slows fast neutrons through elastic collisions.
2. **Capture** – Once the neutrons are thermalized, boron-10 captures them with very high efficiency.

The dominant capture reaction is:

- $^{10}\text{B} + n_{\text{th}} \rightarrow ^7\text{Li} + ^4\text{He} \quad (+2.79 \text{ MeV})$ –
- $^7\text{Li}^* \rightarrow ^7\text{Li} + \gamma \quad (478 \text{ keV})$
- Approximately 94% of captures produce a soft **478 keV gamma** (much less penetrating than the 2.224 MeV gamma from hydrogen capture).

- The remaining energy is carried by short-range alpha and lithium particles that deposit locally and do not create a long-range radiation problem.

This is why borated polyethylene is superior to pure polyethylene or EPS foam for shielding: it both moderates **and** captures while producing far fewer hard secondary gammas.

Recommended Thickness of 3-4" Borated Polyethylene Placed on Top of the Concrete Roof Slab

Goal	Foam Left in Place Over Safe Zone	Foam Removed Over Safe Zone	Notes
Modest Improvement	2 inches	1.5 – 2 inches	Noticeable reduction
Good / Recommended	3 – 4 inches	2 – 3 inches	Best balance of performance, cost, and weight
High Performance	5 – 6 inches	4 inches	Approaching diminishing returns

Estimated Dose Impact - Combined Options

Table 3.14.7a – Peak Daytime Dose Rate at Safe Zone Ceiling (mSv/h)

Configuration	Foam Left In Place (No Boron)	Foam Removed Only	Foam Removed + 3-4" Borated Poly	Foam Left In + 3-4" Borated Poly
Single-Story Safe Zone	5 – 25+	1.5 – 8	0.4 – 2.5	1.2 – 6
Basement Safe Zone (≈14 ft + concrete floor)	0.5 – 4	0.15 – 1.2	0.05 – 0.4	0.15 – 0.9

Table 3.14.7b – Total Absorbed Dose Over Peak 3-4 Days (~40-50 hours of significant daytime exposure)

Configuration	Foam Left In Place (No Boron)	Foam Removed Only	Foam Removed + 3-4" Borated Poly + Modest Independent Slab	Foam Left In + 3-4" Borated Poly
Single-Story Safe Zone	200 – 600+ mSv	80 – 250 mSv	35 – 100 mSv	80 – 220 mSv
Basement Safe Zone	20 – 80 mSv	8 – 30 mSv	3 – 15 mSv	8 – 30 mSv

Whole House Impact of Placing Borated Polyethylene Across the Entire Roof

Effect	Impact	Recommendation
Dose reduction in living areas	Significant (roughly 2-4× lower secondary gamma dose)	Helpful but expensive

Effect	Impact	Recommendation
Dose reduction in safe zone	Same as localized placement	No extra benefit
Cost	High (4–8× more material)	Usually not justified
Weight added	Noticeable structural load	Requires engineering check
Practicality	Lower	Prefer localized application over safe zone only

Recommendation: Place 3–4 inches of 5% borated polyethylene **only over the safe zone**. Combining this with foam removal (when practical) produces the best performance-to-cost ratio.

Recommended.Construction.Sequence.(Preferred.Path)

1. Pour the main roof using the standard Nudura Deck WRS (or equivalent) system with foam in place.
2. After the concrete has fully cured and reached design strength, carefully cut and remove the thick EPS foam **only under the safe zone**.
3. Install spray-on fireproofing on the now-exposed concrete underside if required.
4. Place 3–4 inches of 5% borated polyethylene sheets on top of the concrete roof slab (or in the void if preferred) over the safe zone only.
5. Optionally install an independent dense concrete shielding slab (6–8 inches) supported by the safe zone walls.
6. Finish the safe zone ceiling as desired.

This combination of foam removal + targeted borated polyethylene + optional independent shielding slab gives builders a clear, practical path to excellent radiation performance while keeping the rest of the house construction standard.

Summary.Recommendation.for.the.Book

Scenario	Preferred Practical Path	Expected Dose Range (Peak 3–4 Days)
Basement Safe Zone (Strongly Preferred)	Remove foam + 3” borated poly on top of roof slab + optional 4–6” independent slab	3 – 15 mSv
Basement Safe Zone (Simpler)	Keep foam + 3–4” borated poly on top of roof slab	8 – 30 mSv
Single-Story Safe Zone	Remove foam + 4” borated poly + independent shielding slab	35 – 100 mSv

These options allow the Carrington House design to achieve a comfortably pragmatic radiation protection level while remaining fully constructible with currently available materials and methods.

Final optimization will benefit from Monte Carlo (MCNP) modeling once the project advances to detailed engineering.

3.14.8 Soil / Dirt Depth Comparison for Radiation Shielding

A common claim in the bunker and preparedness community is that “1–2 feet of dirt is sufficient radiation shielding.” The following table provides a realistic assessment for a hard neutron + secondary gamma spectrum typical of a micro-nova or extreme solar particle event.

Table 3.14.8 – Approximate Dose Reduction from Soil / Dirt Cover

Soil / Dirt Depth	Approx. Reduction Factor	Remaining Dose (relative)	Assessment for Micro-Nova Peak Phase	Notes
1 foot (12")	4× – 8×	12–25% remaining	Marginal / Insufficient alone	Good moderation, limited gamma attenuation
2 feet (24")	15× – 30×	3–7% remaining	Fair to Good	Noticeable improvement, still leaves meaningful residual dose
3 feet (36")	50× – 100×	1–2% remaining	Good	Strong practical protection
4 feet (48")	150× – 300×	<1% remaining	Very Good	Excellent for most scenarios
6 feet (72")	500× – 1,000×+	<0.2% remaining	Excellent	Approaches deep bunker performance

Key Observations:

- 1 foot of dirt is better than nothing but is generally inadequate for the peak phase of a true micro-nova-level event.
- 2 feet is the absolute minimum that can be considered “workable.”
- Most serious radiation protection designs for extreme events target **3–4+ feet** of earth equivalent (or layered materials that achieve the same performance).
- The Carrington House approach of using targeted high-performance materials over the safe zone (borated polyethylene + dense concrete + optional foam removal) is more efficient and buildable than simply piling 2 feet of dirt over the entire roof.

Final Practical Recommendations

Scenario	Preferred Practical Path	Expected Dose Range (Peak 3–4 Days)
Basement Safe Zone (Strongly Preferred)	Remove foam + 3" borated poly on top of roof slab + optional 4–6" independent slab	3 – 15 mSv
Basement Safe Zone (Simpler)	Keep foam + 3–4" borated poly on top of roof slab	8 – 30 mSv
Single-Story Safe Zone	Remove foam + 4" borated poly + independent shielding slab	35 – 100 mSv

These options allow the Carrington House design to achieve a comfortably pragmatic radiation protection level while remaining fully constructible with currently available materials and methods. Final optimization will benefit from Monte Carlo (MCNP) modeling once the project advances to detailed engineering.

3.15 Extrapolated Full Flare Performance Tables – X45 Baseline through X400 / Micro-Nova Peak

This section presents a complete set of extrapolated performance tables for the Carrington House design across a wide range of geomagnetic event intensities. These tables are provided for technical readers, engineers, and builders who want to understand how the structure is expected to behave from moderate Carrington-class storms all the way up to extreme micro-nova / rapid pole-flip conditions.

The tables are **extrapolated** from the same two-tier design basis used throughout this book:

- **Tier 1 – Carrington X45 Baseline:** Represents severe solar flare activity during the weakening magnetic field phase. This is grounded in historical data (1859 Carrington Event and subsequent modeling by Kappenman and others).
- **Tier 2 – Micro-Nova / Rapid Pole Flip Peak:** The extreme upper bound, driven by a massive X-ray/EUV burst on the order of $\sim 9 \times 10^{33}$ ergs combined with extremely rapid magnetic field collapse (very high dB/dt). These values are modeled upper bounds rather than direct measurements.

All ratings assume the full Carrington House configuration: - True 6-sided Faraday cage using 4x4 galvanized mesh with robust bonding and single-point grounding - Full or hybrid GFRP reinforcement (preferred) - Upper-limit dielectric isolation (XPS under footings + vertical skirt + enhanced concrete) - Interior sanctuary / safe zone - Cascadia+ seismic detailing

The performance ratings prioritize **full structural survival of the building shell** and the ability of protected off-grid systems (solar, batteries, generators, critical wiring) to support long-term habitability — even if the global electrical grid remains down for years. This is the “Full Structural Survival + Re-Plug and Play Recovery” philosophy.

These tables are intended as a technical reference and design aid. They are not based on physical testing of a completed Carrington House structure. Actual performance will depend on installation quality, local soil conditions, exact event dynamics, and many other variables. Professional engineering review is recommended for any specific project.

Table.9;717.-.X00Flare.(Carrington.Baseline).to.Micro_Nova.Peak

Magnetic Field Strength	Relative GIC Intensity (A/km ²)	E1 Pulse (Fast)	E3 Pulse (Slow/GIC-like)	Overall House Performance	Explanation of Rating
100%	50 – 200	10 – 50 kV/m	Moderate	Excellent	Full cage + dielectric isolation easily handles the event. Minimal heating, near-100% protected electronics survival, house remains fully functional with immediate re-plug and play capability.
75%	80 – 320	20 – 80 kV/m	High	Very Good	Slightly higher currents but still well within design margins. Minor external grid issues expected; interior stays protected and habitable with little to no repair needed.
40%	150 – 600+	50 – 200 kV/m	Very High	Good	Increased stress managed by mesh distribution and bonding. Structure remains intact; some sensitive electronics may fail. Moderate, repairable damage expected.
25%	300 – 1,200+	100 – 500 kV/m	Extreme	Fair to Good	Higher stress on the system. Structure holds with acceptable, repairable damage. Habitable as a shelter with moderate repairs. Protected off-grid systems largely survive.

Magnetic Field Strength	Relative GIC Intensity (A/km ²)	E1 Pulse (Fast)	E3 Pulse (Slow/GIC-like)	Overall House Performance	Explanation of Rating
0% (Pole Flip Peak)	50,000 – 500,000+ (Micro-Nova)	1,500+ kV/m	Catastrophic	Fair	Extreme conditions push the system hard. Building shell survives intact due to GFRP and dielectric design. Some localized damage and repairs likely. Interior sanctuary zone and protected systems enable recovery.

Table.9;718.- X60 Flare.(Severe.Solar.Storm.- .Simulated)

Magnetic Field Strength	Relative GIC Intensity (A/km ²)	E1 Pulse (Fast)	E3 Pulse (Slow/GIC-like)	Overall House Performance	Explanation of Rating
100%	80 – 320	15 – 70 kV/m	High	Excellent	Full cage + dielectric isolation easily handles the event. Minimal heating, near-100% protected electronics survival.
75%	130 – 520	30 – 110 kV/m	Very High	Very Good	Slightly higher currents but still well within design margins. Habitable with little to no repair needed.
40%	250 – 1,000+	70 – 280 kV/m	Extreme	Good	Increased stress managed by mesh and GFRP. Moderate, repairable damage expected.
25%	500 – 2,000+	140 – 700 kV/m	Extreme+	Fair to Good	Higher stress. Structure holds with acceptable damage. Habitable after moderate repairs.

Magnetic Field Strength	Relative GIC Intensity (A/km ²)	E1 Pulse (Fast)	E3 Pulse (Slow/GIC-like)	Overall House Performance	Explanation of Rating
0% (Pole Flip Peak)	50,000 – 500,000+	1,500+ kV/m	Catastrophic	Fair	Extreme conditions. Shell survives. Protected off-grid systems allow recovery.

Table.9j719.- X766.Flare.(Primary.Design.Target.- .Pole.Flip.Scenario)

Magnetic Field Strength	Relative GIC Intensity (A/km ²)	E1 Pulse (Fast)	E3 Pulse (Slow/GIC-like)	Overall House Performance	Explanation of Rating
100%	110 – 450	20 – 90 kV/m	High	Very Good	Structure intact, minimal induction heating. Protected solar systems viable. Quick recovery expected.
75%	180 – 720	40 – 150 kV/m	Very High	Good to Very Good	Walls, roof beams, and slabs survive intact. Minor utility repairs possible.
40%	350 – 1,400+	90 – 350 kV/m	Extreme	Good	Acceptable structural integrity. Repairable damage. Fully habitable after moderate repairs.
25%	700 – 2,800+	180 – 900 kV/m	Extreme+	Fair to Good	Significant but survivable stress. Repairable damage. Structure provides long-term shelter.
0% (Pole Flip Peak)	200,000 – 1,000,000+	1,500+ kV/m	Catastrophic	Fair	Extreme conditions. Main shell survives due to GFRP and dielectric design. Moderate repairs expected. Protected systems enable long-term recovery.

Table.9j700.- X866.Flare.(Severe.Micro_Nova.Range.- .Simulated)

Magnetic Field Strength	Relative GIC Intensity (A/km ²)	E1 Pulse (Fast)	E3 Pulse (Slow/GIC-like)	Overall House Performance	Explanation of Rating
100%	220 – 900	40 – 180 kV/m	Very High	Good	Structure sound. Repairable damage expected. Habitable after moderate repairs.
75%	360 – 1,440+	70 – 300 kV/m	Extreme	Fair to Good	Higher stress but survivable. Some localized damage. Protected systems largely intact.
40%	700 – 2,800+	180 – 700 kV/m	Extreme+	Fair	Significant repairable damage. Structure remains protective shelter.
25%	1,400 – 5,600+	350 – 1,400 kV/m	Catastrophic	Fair	Major but survivable stress. Moderate to extensive repairs needed.
0% (Pole Flip Peak)	100,000 – 1,000,000+	2,000+ kV/m	Catastrophic	Fair to Poor	Extreme conditions. Shell survives but with more damage. Interior sanctuary zone critical for safety.

Table.9j701.- X066.Flare.(Extreme.Upper.Bound.- .Simulated)

Magnetic Field Strength	Relative GIC Intensity (A/km ²)	E1 Pulse (Fast)	E3 Pulse (Slow/GIC-like)	Overall House Performance	Explanation of Rating
100%	440 – 1,800	80 – 360 kV/m	Extreme	Fair to Good	Structure holds with repairable damage. Habitable after significant repairs.
75%	720 – 2,880+	150 – 600 kV/m	Extreme+	Fair	Significant stress. Repairable but major work required.

Magnetic Field Strength	Relative GIC Intensity (A/km ²)	E1 Pulse (Fast)	E3 Pulse (Slow/GIC-like)	Overall House Performance	Explanation of Rating
40%	1,400 – 5,600+	350 – 1,400 kV/m	Catastrophic	Fair	Major but survivable damage. Shell remains protective.
25%	2,800 – 11,200+	700 – 2,800 kV/m	Catastrophic	Fair to Poor	Severe damage possible. Long-term shelter still viable.
0% (Pole Flip Peak)	200,000 – 2,000,000+	3,000+ kV/m	Catastrophic	Poor	Extreme conditions. Structure survives but with substantial repairs needed. Interior sanctuary zone essential.

Summary.Notes.for.All.Tables

- Ratings assume the full Carrington House configuration (6-sided Faraday cage, full or hybrid GFRP, Upper Limit dielectric isolation, single-point grounding, and interior sanctuary zone).
- The primary success metric is **full structural survival** of the building shell plus the ability of protected off-grid systems to support long-term habitability.
- At the Micro-Nova / Pole Flip Peak (0% magnetic field strength), the design prioritizes keeping the house as a long-term habitable shelter even if the global grid is non-functional for years.
- These are extrapolated theoretical models based on publicly available GIC research, Faraday cage principles, and conservative engineering assumptions. Real-world performance will vary with installation quality, soil conditions, and exact event characteristics.
- Professional structural and electrical engineering review is strongly recommended for any project intending to implement these design features.

This set of tables provides a consistent, transparent view of expected performance across the full range of events considered in the Carrington House design basis.

3.16 Performance Comparison: Standard ICF Construction vs. Carrington House Design

This section provides a direct comparison between a conventionally constructed Insulated Concrete Form (ICF) building and the Carrington House design when subjected to the extreme conditions associated with major geomagnetic events, including strong Geomagnetically Induced Currents (GIC), Electromagnetic Pulse (EMP), and long-duration seismic loading consistent with a Cascadia Subduction Zone M9+ event.

The purpose of this comparison is to help engineers, designers, and technically oriented owner-builders understand where the two approaches diverge in performance, what practical impacts those differences create, and where the Carrington House design provides measurable advantages.

This comparison focuses primarily on **structural behavior** and **electromagnetic (Faraday/GIC) performance**, as these represent the most significant functional differences. Radiation shielding strategies can be applied to either system and are therefore not emphasized here.

3.16.1 Structural Performance Under Long-Duration Seismic Loading

Aspect	Standard ICF Construction	Carrington House Design	Impact of the Difference
Wall Reinforcement	Typically single curtain of steel rebar	Double curtain of GFRP reinforcement as the primary structural system	The double-curtain GFRP configuration increases overall wall stiffness. This increased stiffness helps reduce top-of-wall drift during shaking, which in turn reduces stress on the roof-to-wall connections.
Roof-to-Wall Connection	Conventional steel rebar detailing with limited ductility	Primary use of GFRP with L-shaped GFRP ties at the roof-to-wall interface, mechanically connected into the roof beams	Reduced top-of-wall drift due to increased wall stiffness results in significantly lower movement at the roof-to-wall interface. This greatly reduces the risk of the connection reinforcement being pulled out of the roof beams during extended cyclic loading.
Risk of Induction Heating in Structural Rebar	High. Long continuous runs of steel rebar can develop significant	Very low. The primary reinforcement is non-conductive GFRP. Any	In standard ICF construction, induction heating of steel rebar can

Aspect	Standard ICF Construction	Carrington House Design	Impact of the Difference
	induced currents and localized heating during extreme GIC events.	steel rebar required is short, frequently bonded to the mesh, and electrically shunted to the single-point ground.	cause concrete to overheat, leading to cracking and spalling. The Carrington House design largely eliminates this risk through the use of non-conductive GFRP as the main reinforcement.
Ability to Withstand Extended Shaking (60–180+ seconds)	Moderate. Higher top-of-wall drift and lower wall stiffness increase the risk of cumulative damage, cracking, and connection distress over long-duration events.	High. The double-curtain GFRP configuration increases wall stiffness and reduces top-of-wall drift. This helps maintain the integrity of the roof diaphragm connection throughout extended shaking.	Lower probability of progressive damage, roof-to-wall connection failure, or loss of structural integrity after a major long-duration seismic event such as a Cascadia M9+.
Resistance to Cumulative Damage During Long-Duration Shaking	Higher risk. Steel rebar can accumulate damage over many repeated loading cycles during extended shaking events. This can lead to cracking, connection distress, and reduced structural capacity over time.	Lower risk. The use of GFRP as the primary reinforcement, combined with increased wall stiffness, reduces the accumulation of damage over many loading cycles typical of long-duration megathrust earthquakes.	Improves the likelihood that the structure remains functional and repairable after extreme, prolonged seismic events.
Post-Event Structural Integrity	Variable. May require significant repair or could be compromised in severe long-duration events due to accumulated damage at connections and in walls.	Higher probability of remaining structurally sound and habitable with moderate repairs.	Directly supports the design goal of long-term survivability and recovery after major seismic events.

Notes:

- **Top-of-wall drift** refers to the horizontal movement at the top of the wall relative to the base during shaking. Excessive drift can stress and eventually pull reinforcement out of the roof beams, weakening the roof-to-wall connection.
- **Cumulative damage** (sometimes referred to as low-cycle fatigue in seismic contexts) occurs when a structure experiences many repeated loading and unloading cycles. In long-duration events like a Cascadia M9, a building can undergo 50–150+ strong stress reversals, which can progressively damage reinforcement and connections even if no single cycle is extreme.

3.16.2 GIC / Induced Current Protection

Aspect	Standard ICF Construction	Carrington House Design	Impact of the Difference
Dielectric Isolation from Ground	Minimal or none. Concrete foundations are typically placed directly on soil or gravel.	4 inches of high-density XPS foam under footings and slabs, plus a vertical XPS skirt on the exterior walls	Substantially increases electrical resistance to ground current entry. This is one of the most important differentiators during extreme GIC events.
Faraday Cage	Usually absent or incomplete. Most ICF buildings do not have a continuous 6-sided conductive enclosure.	Full 6-sided continuous 4x4 galvanized mesh cage with robust mechanical and electrical connections between all surfaces	Provides a defined, low-resistance path for GIC currents to flow around the structure rather than through it.
Grounding Strategy	Multiple grounding points are common, which can create ground loops during GIC events.	Single-point grounding system where all mesh panels converge at one location	Reduces internal voltage gradients and circulating currents that can damage equipment or create arcing.
Risk of Induction Heating in Structural Rebar	High. Long continuous runs of steel rebar can develop significant induced currents and generate localized heat.	Very low. The primary reinforcement is non-conductive GFRP. Any required steel is short, frequently bonded to the mesh, and electrically shunted to the single-point ground.	In standard ICF construction, induction heating of steel rebar can cause concrete to overheat, leading to cracking and spalling. The Carrington House design largely eliminates this mechanism.
Internal Voltage Rise	Can be substantial, especially with	Significantly reduced due to the combination of dielectric	Improves the survival probability of sensitive

Aspect	Standard ICF Construction	Carrington House Design	Impact of the Difference
During Extreme GIC	multiple ground paths and conductive rebar networks.	isolation, the continuous external Faraday cage, and the use of non-conductive GFRP as the primary reinforcement.	electronics, wiring, and internal electrical systems during strong GIC events.

Note: Induction heating occurs when changing magnetic fields induce electrical currents in conductive materials such as steel rebar. In extreme GIC events, long runs of steel rebar (for example, a 40-foot length) can potentially reach localized temperatures of **100–200°C or higher**. At these temperatures, concrete can begin to crack, and the risk of explosive spalling increases significantly.

3.16.3 EMP (Fast Pulse) Protection

Aspect	Standard ICF Construction	Carrington House Design	Impact of the Difference
Faraday Cage Continuity	Limited or absent in most cases	Full 6-sided mesh cage with waveguide-protected penetrations	Provides meaningful attenuation of fast EMP pulses (E1 component), particularly when the mesh is well bonded and continuous.
Window and Door Protection	Standard frames with no special shielding	Horizontal mesh connectors around openings + removable exterior mesh screens	Significantly reduces EMP entry through the largest openings in the building envelope.
Utility Penetrations	Standard penetrations with minimal protection	Waveguide-below-cutoff sleeves + coordinated surge protection tied to the single-point ground	Greatly reduces conducted EMP energy entering through power, data, and mechanical systems.
Overall Internal Field Reduction	Low to moderate	Moderate to high, depending on implementation quality	Improves the likelihood that protected electronics and critical systems survive an EMP event.

3.16.4 Post-Event Recovery Capability (“Re-plug and Play”)

Aspect	Standard ICF Construction	Carrington House Design	Impact of the Difference
Ability to Restore Electrical Systems	Often requires extensive inspection and repair due to potential induction damage in wiring and steel rebar.	Designed to minimize internal induction damage through dielectric isolation and the external Faraday cage, enabling faster restoration of protected circuits.	Supports faster return to functionality after a major electromagnetic event when the external grid may be unavailable for extended periods.
Risk of Hidden Damage in Rebar and Wiring	Higher, particularly in steel rebar and long wiring runs.	Lower due to non-conductive primary reinforcement and reduced internal current flow.	Reduces uncertainty during post-event assessment and repair.
Integration with Protected Off-Grid Systems	Not specifically addressed in standard design	Explicit design consideration for protected solar, battery, and generator systems with shielded penetrations.	Improves long-term habitability and self-sufficiency when the external grid is down for weeks or months.

3.16.5 Construction Complexity and Detailing

Aspect	Standard ICF Construction	Carrington House Design	Impact of the Difference
Additional Detailing Required	Minimal beyond normal structural requirements	Significant additional detailing for mesh continuity, dielectric layer installation, connector placement, and bonding requirements	Increases design effort and requires more careful quality control during construction.
Labor and Material Impact	Baseline	Moderate increase in materials (mesh, XPS foam, connectors) and labor (connections, inspections, and verification)	Adds cost and schedule but remains within the capability of experienced ICF crews.
Inspection and Verification	Standard structural inspection	Requires additional verification of mesh continuity, dielectric	Adds inspection steps but improves confidence in

Aspect	Standard ICF Construction	Carrington House Design	Impact of the Difference
		isolation integrity, and single-point grounding	overall system performance during extreme events.

3.16.6 Cost Comparison (High-Level)

Category	Standard ICF Construction	Carrington House Design	Approximate Added Cost	Notes
Reinforcement (Walls + Roof)	Steel rebar	GFRP as primary reinforcement + selective steel	+15% to +35%	Depends on final engineering
Dielectric Isolation System	Minimal	XPS foam under footings/slabs + vertical skirt	+8% to +15%	Major added system
Faraday Mesh + Connectors	Usually none or minimal	Full 6-sided mesh system + HC-L/HC-U connectors	+10% to +18%	Significant added scope
Detailing, Labor & Quality Control	Standard	Increased due to additional systems and verification requirements	+5% to +12%	More complex construction sequence
Total Estimated Premium	Baseline	—	+35% to +65%	Rough order-of-magnitude range for full implementation

Note: The cost figures above are preliminary estimates only. A more detailed and accurate cost model will be developed and inserted once the dedicated Cost Estimating section of this book is complete and operational.

3.16.7 Summary and Key Takeaways

The comparison between standard ICF construction and the Carrington House design reveals several meaningful differences in performance under extreme geomagnetic and long-duration seismic events. The most significant distinctions fall into three categories: structural behavior during prolonged shaking, protection against Geomagnetically Induced Currents (GIC), and overall post-event recovery potential.

Structural Performance A conventional ICF building relies primarily on single-curtain steel rebar and standard connection detailing. While this provides adequate performance for most code-level

seismic events, it is more vulnerable to cumulative damage and connection distress during long-duration shaking (such as a Cascadia M9+ event). Higher top-of-wall drift increases stress on roof-to-wall connections and raises the risk of reinforcement being pulled out of the roof beams over many loading cycles.

In contrast, the Carrington House design uses #5 or #6 double-curtain GFRP as the primary reinforcement. This configuration significantly exceeds normal SDC D2 and F design requirements, increases wall stiffness, which we think helps to reduce top-of-wall drift and thereby lowers stress on the roof-to-wall connections. The result is improved resistance to cumulative damage and a higher likelihood that the structure remains functional and repairable after extended shaking. These double curtain configurations are some that I would love to have simulated by some experienced seismic and structural engineers in the near future to verify.

GIC and Electromagnetic Protection Standard ICF construction offers limited protection against extreme Geomagnetically Induced Currents. Conductive steel rebar, multiple grounding points, and the absence of a continuous Faraday cage allow significant current flow into and through the structure. This can lead to induction heating of rebar, internal voltage rise, and potential damage to both the structure and internal electrical systems.

The Carrington House design addresses these issues through three integrated measures: dielectric isolation using XPS foam, a continuous 6-sided Faraday mesh cage, and non-conductive GFRP as the primary reinforcement. Together, these features substantially reduce internal current flow and voltage rise while minimizing the risk of induction heating and concrete damage.

Post-Event Recovery A standard ICF building may require extensive inspection and repair after a major electromagnetic or long-duration seismic event due to potential hidden damage in steel rebar, concrete and wiring. The Carrington House design is intended to reduce internal induction effects, which improves the potential for faster restoration of protected electrical systems and supports long-term habitability when the external grid is unavailable.

Cost and Complexity The Carrington House approach adds meaningful cost and construction complexity compared to standard ICF construction. Preliminary estimates suggest a total premium in the range of **+35% to +65%**, depending on final engineering and site conditions. This added cost primarily comes from the dielectric isolation system, the full Faraday cage, and the use of GFRP reinforcement.

Overall Assessment A well-built standard ICF house provides good thermal performance and basic structural strength but offers limited protection against the combined threats of extreme GIC events and long-duration seismic loading. The Carrington House design introduces several targeted improvements that meaningfully enhance performance in these specific scenarios, particularly in reducing induction heating, controlling top-of-wall drift, and protecting roof-to-wall connections.

Whether the additional measures and cost of the Carrington House system are justified depends on the owner's assessment of risk and the importance placed on long-term structural survivability and post-event recovery.

4.0 Basis for the Three-Phase Event Model (Technical Background)

The Carrington House design is organized around a three-phase geomagnetic disturbance model drawn from paleomagnetic records, extreme solar event studies, and related research. This model supplies the technical basis for the performance requirements used throughout the structure.

The design uses a two-tier reference framework:

- **Tier 1 – Carrington-Class Baseline (X45 equivalent)** Severe solar flare activity during the weakening magnetic field phase.
- **Tier 2 – Micro-Nova / Rapid Pole Flip Peak** The extreme upper bound, associated with a massive energy release ($\sim 9 \times 10^{33}$ ergs) and very rapid magnetic field collapse (high dB/dt).

4.1 Three-Phase Event Parameters

Parameter	Ramp-Down Phase	Zero-Field / Micro-Nova Peak	Ramp-Up Phase	Design Relevance
Geomagnetic Field Strength	20–50% of normal	<5–10% of normal	Recovering	Shielding effectiveness declines
Geoelectric Field	1–20 V/km	20–300+ V/km	5–50 V/km	Primary driver of GIC
Estimated GIC Density	100–2,000 A/km ²	50,000–500,000+ A/km ²	500–10,000 A/km ²	Faraday cage & dielectric critical
Neutron Skyshine Flux	2–10× baseline	50–500×+ baseline	5–50× baseline	Roof & sanctuary shielding
Seismic Demand	Increasing	High, long-duration	Declining	Cascadia+ detailing
Duration of Phase	Months to years	Weeks to 6–12 months	1–5+ years	Long-term passive systems required

4.2 Design Philosophy

The Carrington House prioritizes **full structural survival of the building shell** plus the ability of protected off-grid systems to support long-term habitability (“re-plug and play” recovery). Minor external damage is acceptable; the primary goal is that the structure and its internal self-sufficient systems remain functional even under Micro-Nova peak conditions.

4.3 Supporting References

- Paleomagnetic and galactic current sheet research (including Wang et al., 2026)
- Extreme solar event and micro-nova studies (Davidson and related work)
- Historical Carrington-class event analyses (Cliver & Dietrich and subsequent scaling studies)

- GIC modeling literature (Kappenman and utility-industry studies)
- Cascadia Subduction Zone long-duration shaking reports (DOGAMI, USGS, CREW)
- NRMCA & USRC (2022) ICF seismic performance comparison
- Standard radiation attenuation methods and Monte Carlo N-Particle (MCNP) methodology (Los Alamos National Laboratory)

4.4 Future Validation

Final optimization of the roof and sanctuary-zone radiation shielding should include Monte Carlo radiation transport modeling (MCNP or equivalent). Such simulations will provide higher-confidence attenuation and dose estimates once the detailed layering configuration is fixed.

5.0 Product and Components Suppliers

This section lists representative manufacturers and suppliers of the major components referenced in the Carrington House designs. Inclusion does **not** constitute endorsement.

Project teams should verify current specifications, certifications, availability, and suitability with the manufacturer and the project engineer.

Structural – GFRP / GFRP Rebar

Company	Product	Contact	Notes
Neuvokas Corporation	GatorBar	info@gatorbar.com 906-934-2661 Ahmeek, MI	U.S.-made, ICC-ESR certified. Strong residential/ICF focus.
TUF-BAR Inc.	TUF-BAR	info@tuf-bar.com 1-888-997-3227 / 780-462-8100 Edmonton, AB	Canadian manufacturer with good technical documentation.
Mateenbar Composite Reinforcements	Mateenbar / GreenBar2X	service@mateenbar.com +1 704- 662-2005 2011 Highway 49 S, Concord, NC 28027	U.S. manufacturing. ICC-ESR-5548.
MST Rebar Inc.	MST-BAR	info@mstbar.com 416-740-0377 / 1-855-740-0377 Woodbridge, ON	Canadian producer with structural and flatwork options.

ICF Blocks / Roof & Floor Forming Systems

Company	Product	Contact	Notes
Tremco CPG / Nudura	Nudura ICF + Nudura Deck	866-468-6299 info@nudura.com 3735 Green Road, Beachwood, OH 44122	Part of Tremco CPG. Strong roof/floor deck options.
Fox Blocks (Airlite Plastics)	Fox Blocks	info@foxblocks.com 877-369-2562 6110 Abbott Dr, Omaha, NE 68110	Established U.S. ICF brand.
BuildBlock Building Systems	BuildBlock	technical@buildblock.com sales@buildblock.com 866-222-2575 / 405- 840-3386 Oklahoma City, OK	Strong technical support and training.
Amvic	Amvic ICF	Check North American distributors; international: sales@amvicireland.com	Flat-wall ICF system.

Optional Conductive Concrete / Ground Enhancement

Company	Product	Contact	Notes
SAE Inc.	ConduCrete	info@saeinc.com 1-877- 234-2502 / 705-733-3307	Conductive cementitious ground enhancement material. RUS approved, NSF 60.
Marconite (various distributors)	Marconite conductive concrete	Search local electrical/earthing suppliers	Synthetic granular material mixed with Portland cement for low- resistivity grounding.

Dielectric Isolation Materials

Category	Example Suppliers / Notes
XPS / EPS foam	Owens Corning, Dow, or local insulation distributors (standard construction supply).
Foundation foam forming	Liteform / Litefoot systems (now aligned with Tremco/Nudura family in some markets).
Vapor barriers	Standard high-performance polyethylene or specialty under-slab vapor barriers from major insulation suppliers.
Radiant board systems	Flexx Board or equivalent under-slab PEX systems (local plumbing/heating suppliers).

Electromagnetic / Grounding Components

Category	Example Suppliers	Contact / Notes
Isolating spark gaps / Class I SPDs	DEHN, Inc.	www.dehn.us 877-927-6510 500 S Main Street, Suite 115, Mooresville, NC 28115 EXFS 100 series (100 kA) commonly referenced.
Dielectric unions / insulating couplings	Watts Water Technologies	www.watts.com Series 3000 / LF3000 dielectric unions widely available through plumbing distributors.
Welded wire mesh (4×4 or 6×6 galvanized)	Major rebar/mesh suppliers (e.g., local concrete suppliers or national distributors such as those carrying ASTM A185/A497 mesh).	Specify galvanized after welding for corrosion resistance.
Copper grounding conductors	Standard electrical supply houses (2 AWG / 4 AWG bare or insulated copper).	—
Non-metallic conduit	Schedule 40/80 PVC or HDPE from any major electrical distributor.	Preferred for long runs to avoid continuous metallic paths.

Openings & Penetrations

Category	Example Suppliers	Contact / Notes
Vinyl / plastic window & door bucks	V-Buck (Vinyl Technologies, Inc.)	1-888-57-VBUCK (1-888-578-2825) www.vbuck.com Logan, UT area. Long-established ICF-specific vinyl buck system.
Engineered wood bucks	Prebuck (Nudura / Tremco CPG)	Available through Nudura distributors. Pre-cut LSL bucks designed for direct concrete contact.
Mesh connectors around openings	Same mesh suppliers as above + custom fabrication.	—
EMI window film / conductive screens	Specialty EMI/RFI shielding suppliers (e.g., Signals Defense, LBA Group, or similar).	Project-specific.

Radiation / Safe Room (Optional Layers)

Category	Example Suppliers	Contact / Notes
Borated polyethylene	MarShield	800-381-5335 www.marshield.com Plasti-Shield® 5% borated polyethylene sheets (common 48" × 96" × 1").
Borated polyethylene	King Plastic / King Plasti-Shield	Available through radiation shielding distributors. 5% boron grade widely used.
Borated polyethylene	A&L Shielding	800-329-5323 sales@alshielding.com Rome, GA.
Dense / boron-enhanced concrete	Specialty concrete suppliers or radiation shielding contractors.	Site-specific mix designs required.

Miscellaneous

Category	Example Suppliers	Notes
Conductive paints / coatings	Parker Chomerics (PRO-SHIELD series)	www.parker.com/chomerics 781-935-4850
Conductive paints	MG Chemicals	1-800-340-0772 / support@mgchemicals.com
Conductive caulk / sealants	Parker Chomerics (CHO-BOND series) or Signals Defense (EMCaulk)	Used for seams and penetrations to maintain electrical continuity.
Waterproofing membranes	Tremco, Carlisle, or equivalent self-adhering membranes.	Below-grade and penetration detailing.
Hog rings / conductive fasteners	Standard construction / fencing supply.	For bonding mesh layers.

Professional Engineering & Design Firms

Here is a focused list of professional engineering firms and specialists that have public track records with **GFRP/GFRP rebar design** and/or **ICF structural design**. These are useful starting points for readers (or for outreach).

ICF-Focused Structural Engineering Firms

Firm / Engineer	Focus	Location / Contact	Notes
Dave Gowers Engineering, LLC	ICF structural design (residential & commercial)	Oregon / multi-state PE licenses dave@dgengineering.com 541-660-9661 www.dgengineering.com	Explicitly specializes in ICF. Licensed in ~15 states. Frequently referenced in ICF industry publications.
ICF Engineer (J.T. Donald Consultants Limited)	Full ICF structural consulting, value engineering, inspection	Canada icfengineer.ca	Dedicated ICF engineering practice (walls, floors, roofs).
Tier ICF (Tier Consult Group)	Specialist ICF structural design	UK info.icf@tieruk.com 01527 835 100	Dedicated ICF team led by long-experience ICF designer Antony Bartlam.
Fine Tuned Structures, LLC	Structural engineering including significant ICF projects	Summerville, SC (also DC area) 843-376-4800 finetunedstructures.com	Documented high-end residential and commercial ICF work (award-winning projects).
Robert Klob Designs (RKD)	ICF design & consulting	North America www.rkdzns.com	Claims extensive ICF design experience (hundreds of projects) and code-committee involvement. More design/consulting oriented.
AWA Consulting Engineers	ICF structural design services	UK awaengineers.com	Explicit ICF design offering (foundations through detailed reinforcement).
Caribbean ICF Solutions	ICF structural design + supply support	Puerto Rico / Caribbean 1-888-504-2999 sales@cicfslc.com	Offers structural ICF engineering as part of a broader ICF solutions package.

GFRP / FRP Rebar Design Support & Related Firms

True independent structural firms that specialize only in GFRP rebar design are still relatively scarce (most design is done by general structural engineers using ACI 440 / CSA S806, often with manufacturer support). Useful contacts include:

Firm / Resource	Focus	Notes
V-ROD / Pultrall (Engineering Assistance)	GFRP rebar design support	Manufacturer engineering assistance via in-house civil engineers. Good starting point for project-specific GFRP design help. fiberglassrebar.com
MacDonnell	FRP / GFRP design & rehabilitation	Canadian firm with explicit FRP rebar and FRP strengthening design capability (marine, bridges, infrastructure). macdonnell.com
University / Research-linked experts	ACI 440 / AASHTO GFRP design	Many practicing engineers who publish or consult on GFRP come from the ACI 440 community or university groups that developed the codes (e.g., University of Miami, University of Sherbrooke, etc.).
Manufacturer technical support (Mateenbar, MST-BAR, Neuvokas/GatorBar, TUF-BAR)	Design assistance & conversion from steel	Most major GFRP producers offer engineering support or “steel-to-GFRP conversion” help for designers.

Practical Notes for the Book

- **ICF side** is more mature: there are clearly identified firms that market themselves as ICF structural specialists.
- **GFRP side** is still evolving. Most licensed structural engineers can design with GFRP once they use ACI CODE 440.11-22 (or earlier ACI 440.1R) and CSA S806, but pure specialists are fewer. Manufacturer engineering support + a conventional structural firm that is willing to learn the code is the common real-world combination.
- For a Carrington House–style project (ICF + GFRP double-curtain + electromagnetic considerations), the ideal team would be:
 1. An ICF-experienced structural engineer, and
 2. Either the same firm or a second engineer comfortable with ACI 440 GFRP provisions (or manufacturer support layered on top).

Here is a focused list of firms and specialists that publicly work in:

Faraday-cage / electromagnetic shielding design and single-point grounding / high-energy pulse (EMP/HEMP/lightning) protection.

Electrical / Faraday-Cage & Electromagnetic Shielding Design Specialists

Firm	Focus	Location / Contact	Notes
National Shielding	Faraday cage design & installation (MRI, RF/EMI rooms, full enclosures)	USA 855-661-3584 national-shielding.com	Full design packages: calculations, drawings, penetration details, bonding/grounding coordination.
Faraday Structures	Electromagnetic shielding for government, military & commercial facilities	USA sales@faradaystructures.com faradaystructures.com	Consultation on facility planning and RF/EMI protection.
Holland Shielding Systems	Faraday cages, modular shielded rooms, EMI/RFI solutions	Netherlands (global) faradaycages.com	Design, engineering and construction of cages from DC to 30 GHz.
Faraday Shielding Pty Ltd	RF, magnetic & EMF shielding design (MRI, EMI, RF)	Australia +61 3 9729 5000 faradayshielding.com.au	Strong design/consultancy focus, including multi-vendor magnetic shielding.
ETS-Lindgren	HEMP/EMP/IEMI shielding systems + consulting	USA (global) ets-lindgren.com	Major supplier and design support for high-performance shielded facilities.
Global EMC	Custom Faraday cages and high-performance shielded rooms	UK globalemco.co.uk	Design, manufacture and installation of modular and welded cages.

Single-Point Grounding & High-Energy Pulse (EMP/HEMP/Lightning) Protection Design Firms

Firm	Focus	Location / Contact	Notes
Jaxon	HEMP facility design, test & evaluation	Colorado Springs, CO jaxon-em.com	Specializes in HEMP-hardened facilities and systems; supports MIL-STD-188-125 work.
CACI	HEMP protection for fixed infrastructure,	USA caci.com/emp-protection	Long track record of HEMP-hardened facilities (1,000–89,000+ sq ft).

Firm	Focus	Location / Contact	Notes
	mobile systems & vehicles		
Robert E. Lamb, Inc.	EMP/HEMP & IEMI protection design for critical facilities	USA relamb.com	Architectural/engineering services for EMP-shielded mission-critical spaces.
SARA	RF/EMP/Lightning engineering, hardening design & verification	USA sara.com	Full life-cycle support for MIL-STD HEMP protection (facilities, transportable systems, aircraft, ships).
EMP Engineering	HEMP/EMP/GMS mitigation design, fabrication & installation	USA empengineering.com	Custom Faraday enclosures, shielding and verification testing.
Armag Corporation	Modular EMP/HEMP shielded facilities	USA armagcorp.com	Engineered modular shielded facilities meeting MIL-STD-188-125.
Lightning Master Corporation	Single-point grounding concepts for communications sites	USA lightningmaster.com	Published guidance on single-point grounding for lightning/transient protection.

Practical Notes for the Book

- **Faraday-cage design** is a recognized specialty (MRI rooms, SCIFs, EMC chambers, TEMPEST, etc.). The firms above routinely produce the calculations, penetration details, and bonding plans that keep the cage continuous.
- **Single-point grounding + high-energy pulse protection** is less common as a pure residential service. Most of the deep expertise sits with firms that work to military standards (MIL-STD-188-125) or critical-infrastructure hardening. For a residential or small commercial project, the realistic path is usually:
 1. A conventional electrical engineer experienced with equipotential bonding and lightning protection (NFPA 780 / IEC 62305), plus
 2. Consultation or review by one of the HEMP/EMP specialists if true pulse-hardening is required.
- The Carrington House concept (equipotential grid + spark gaps + single-point electrode + optional Faraday elements) sits at the intersection of these two specialties.

Relevant Standards, Evaluation Reports & Design Resources

This section provides a concise reference for the primary codes, standards, and evaluation reports that govern the materials and systems used in the Carrington House designs. It also lists practical design tools and technical resources offered by major manufacturers.

Core Design Codes & Standards

Standard / Document	Focus Area	Notes
ACI CODE 440.11-22	Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars	Primary U.S. design code for GFRP-reinforced concrete. Adopted by reference in the 2024 IBC. Modeled on ACI 318 structure.
ACI 440.1R-15	Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars	Earlier design guide still widely referenced; superseded for code purposes by ACI 440.11-22.
ACI SPEC 440.5-22	Construction with Glass Fiber-Reinforced Polymer Reinforcing Bars — Specification	Construction and installation requirements for GFRP bars.
CSA S806-12 (R2017)	Design and Construction of Building Components with Fibre-Reinforced Polymers	Primary Canadian design standard for FRP-reinforced concrete.
CSA S807-19	Specification for Fibre-Reinforced Polymers	Material specification for FRP bars in Canada.
ASTM D7957 / D7957M	Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement	Material standard for GFRP bars (tensile strength, modulus, bond, durability, etc.).
AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete	Bridge decks and railings	Used for transportation structures.
ACI 318	Building Code Requirements for Structural Concrete	Governs the concrete itself and overall structural design when

Standard / Document	Focus Area	Notes
		used with GFRP or conventional steel.
PCA 100	Prescriptive Design of Exterior Concrete Walls for One- and Two-Family Dwellings	Commonly used for residential ICF wall design.
ICC 600	Standard for Residential Construction in High-Wind Regions	Alternative wind design method for ICF walls.
NFPA 780 / IEC 62305	Lightning Protection Systems	Governing standards for external lightning protection, equipotential bonding, and surge protection.
MIL-STD-188-125	High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C4I Facilities	Primary military standard for high-energy pulse hardening (referenced for advanced Faraday / pulse-protection concepts).

ICC-ES Evaluation Reports (Examples)

Report	Manufacturer / Product	Focus
ESR-4526	Neuvokas – GatorBar	GFRP rebar acceptance under AC454 for structural concrete reinforcement.
ESR-5548 (or current Mateenbar report)	Mateenbar	GFRP rebar structural acceptance.
Various ESR / CCRR reports	Nadura, Fox Blocks, BuildBlock, etc.	ICF wall systems under AC353 or equivalent criteria for use under IBC/IRC.

(Always verify the most current ESR number and edition with the manufacturer or ICC-ES as reports are periodically reissued.)

Manufacturer Design Resources & Tools

These resources are offered by manufacturers to assist engineers, architects, and project teams.

GFRP / GFRP Rebar

Manufacturer	Key Resources
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MST-BAR	Design software integration with Altair® S-CONCRETE™ (supports ACI 440.11-22). Engineering support, technical data sheets, durability reports, and design examples available at mstbar.com.
Neuvokas (GatorBar)	Design & Installation Manual (ICC-reviewed), technical data sheets, installation videos, and engineering assistance. Available at gatorbar.com.
Mateenbar	Technical literature, product data, and engineering support for GreenBar2X and Mateenbar60 lines.
TUF-BAR	FRPpro™ Engineering Calculator (steel-to-GFRP conversion tool), technical presentations, and design guidance referencing ACI 440 and CSA standards.

ICF Systems

Manufacturer	Key Resources
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Nudura (Tremco CPG)	Extensive Design Library (form profiles, detail drawings in PDF/DWG, engineering parameters), BIM library for Revit, Estimator tool, full Installation Manual, and pre-design criteria guides.
Fox Blocks	Wall Configurator (BIMsmith Forge for Revit assemblies), large technical resource library, prescriptive engineering tables, CAD details, Estimator Pro, and installation guides.
BuildBlock	Comprehensive Engineering Manual (including safe-room provisions), CAD & BIM objects, installation manuals, prescriptive tables, and extensive video library.

These manufacturer resources significantly reduce the learning curve for teams new to GFRP or ICF construction and provide a practical bridge between code requirements and field application.