The University of British Columbia Okanagan Campus
Faculty of Applied Science, School of Engineering

Developing Thermal-Controlled Formwork for Winter Concrete Pours

ENGR 499 Final Design Report: Team Infrastructure and Structures - A

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1.0 Problem Specification

1.1 Context

The annual population Growth rate in British Columbia reached an estimated 3.3% in 2023; the highest recorded since 1971 (Quarterly Population Highlights, 2024). This growth is especially concentrated in the Lower Mainland and the Southern Interior, creating an unprecedented demand for rapid infrastructure development. In particular the growing housing requirements mean that construction of residential complexes must continue throughout the winter, in sub-zero ambient conditions.

The average temperatures over the months of January and February in the Okanagan in 2025 were -1.6°C and -4°C respectively (Historical Data, 2025). Such conditions present economic and technical challenges when pouring concrete for foundations, especially for multi-unit residential projects. According to CSA A23.1, the Canadian Building Code, concrete must be maintained at a minimum of 10°C during the *curing period* [1] to ensure sufficient structural integrity (see Appendix A for details). Even so, concrete cured in -5°C for the full seven day period can lose up to 41% of its potential strength (Husem, 2005).

During cold snaps, when the temperature might drop to -10°C, this necessitates a 20°C temperature gradient between the area in contact with the concrete and ambient air. Achieving this standard requires either the input of thermal energy and hence increased material and labor costs, or project timeline delays to allow for cold weather to pass. Both possibilities incur additional and often significant costs.

1.2 Problem Statement

A way to address the difficulties of ensuring proper curing of concrete for foundation walls in Canadian residential buildings for temperatures below 10°C, where such temperatures compromise structural integrity, and increase construction timelines and cost.

1.3 Project Scope

The scope of the project is confined to the maintenance of an appropriate temperature range, as per the CSA A23.1 standard, during the curing of foundational concrete walls in

[1] Curing period is defined as a minimum of 7 days at a minimum of 10°C for the relevant exposure class AND for the time necessary to attain 70% of the specified 28-day compressive strength; as set out by CSA A23.1:19

multi-family rental developments during the winter months in the Okanagan. We will focus exclusively on the heating of concrete during the curing process. The primary objective is to develop a solution that is maximally efficient with minimal cost.

2.0 Needs and Constraint Identification

The following section identifies the primary stakeholders, their needs and the primary constraints that this project abided by over the course of its development.

2.1 Stakeholder Identification and Stakeholder Needs

This project is host to a variety of stakeholders, each with distinct needs that directly influence the design constraints.

2.1.1 Primary Client – Traine Construction & Development

The primary stakeholder of the project is Traine Construction & Development. As the commissioning client, Traine has a vested interest in a cost-effective and efficient solution that integrates seamlessly with their established construction practices. Their direct financial contribution of $500 CAD and significant time investment highlight their commitment to a successful outcome. Traine's primary needs are as follows:

- **Need for Cost-Effectiveness:** Traine has emphasized the need for a solution that is economically viable. The solution must be price-competitive with existing methods to justify adoption. Traine can be either negatively or positively affected by the solution's cost-effectiveness.
- **Need for Compatibility:** The solution must integrate with Traine's current use of Peri gang formwork to avoid additional costs and workflow disruptions. If achieved, Traine stands to benefit from a custom-made solution that better integrates with their workflows.
- **Need for Efficiency:** The solution must be efficient in its use in energy to minimize operational costs and environmental impact through energy used, with an inefficient solution negatively affecting both Traine through additional costs of use and the environment through the additional energy generated to perform the task.

2.1.2 Design Team

Another major stakeholder of the project is the design team. As the designers of the project, the design team is responsible for the development of the solution, ensuring it adheres to the project scope, constraints and client needs. Needs include:

- **Need for Adherence to Course Requirements:** The design team must meet course expectations for technical rigor, clear and professional documentation and timely completion by the respective due dates of each deliverable. Such requirements are outlined in the criteria for each project deliverable.
- **Need for Budget Management:** The design team must adhere to the $1000 CAD project budget by balancing material costs, testing expenses and potential revisions to the design.

2.1.3 Contractors, Site Supervisors and Construction Workers

The contracting companies, site supervisors and construction workers are the primary end-users of the heating solution, responsible for the product's deployment and operation on a construction site. It is important to ensure that the needs of said end-users are well understood when developing the solution. Needs include:

- **Need for Usability and Durability:** Workers require a system that is easy to install, operate and maintain. The design must also withstand rough handling and harsh weather conditions on active job sites. This need was explicitly expressed by KRM, a concrete contractor in close collaboration with Traine, when discussing practical design parameters. Construction workers stand to benefit from an easy-to-use solution that is quick to set up as such a solution has the potential to reduce overall construction times and worker frustration while installing the product.
- **Need for Safety:** Workers require a solution that minimizes electrical risks and follows relevant safety standards as dictated by statute, for instance those of WorkSafeBC's OHS Regulations.
- **Need for Reliability:** The product must produce consistent results every time it is used. It is important that minimal time and money is used in troubleshooting product errors, or, in a worst case, dealing with inadequately cured concrete because of a non-reliable or defective product.

2.1.4 Faculty Advisors and the University of British Columbia

Faculty advisors provide mentorship throughout the design process, ensuring technical accuracy and alignment with engineering best practices. Additionally, the university has provided financial support to fund project development. The primary need is:

- **Need for Technical Excellence and Professionalism:** Faculty advisors expect the team, as representatives of UBC and as imminent professionals in industry, to adhere to UBC's Student Code of Conduct and policies on academic integrity, observe key ethical tenets as outlined by organizations such as Engineers and Geoscientists BC, and respect industry norms. Additionally, the faculty advisors expect the team to create the solution in accordance with relevant industry standards such as CSA A23.1 and the BC Building Code.

2.1.5 Environmental and Societal Stakeholders

Although not directly involved in the project's execution, environmental concerns are relevant due to the construction industry's growing emphasis on sustainability and environmental concern. The primary need is:

- **Need for Sustainable Design:** The solution must be made of sustainable materials to reduce environmental impact during its lifecycle. Such materials should also not be toxic or otherwise be innately damaging to the environment, as such properties increase the difficulty of end-of-life product disposal. Additionally, the solution needs to be durable to reduce the frequency at which it needs to be replaced. Finally, the solution should be efficient in its energy use to best align with broader industry goals of reducing environmental impact and mitigating climate change through reduced energy usage.

2.2 Design Constraints

The scope of this project is to develop a modular solution that maintains the temperature of freshly poured concrete within the acceptable range as defined by the CSA A23.1 standard for foundational concrete walls in multi-family developments during the winter months in Kelowna, BC. Additionally, this project focuses exclusively on the heating, not cooling, of concrete during its curing process. The project and the solution was developed by closely listening to stakeholder needs and adhering to the project constraints.

With the key stakeholders and their needs identified, the design constraints can be clearly defined. This project is subject to several technical, financial and practical constraints:

- **Time Constraint:** The developed solution and its supporting documentation must be ready to present by the relevant deliverable deadlines in late March or early April, 2025. Due to the nature of the project, any delays to the project's internal schedule must be resolved without delaying the product's final presentation date.
- **Financial Constraint:** The developed solution and its associated development costs must not exceed $1000 CAD, with $500 CAD being provided from the school and $500 CAD provided by Traine.
- **Building Code/Industry Standard Constraint:** The developed solution must adhere to the CSA A23.1 standard and the BC Building Code to ensure the solution is technically fit for safe use and that the cured concrete achieves sufficient strength and durability for safe operation.
- **Compatibility Constraint:** The solution must be tailored to fit the Peri gang formwork system to ensure integration into the client's workflow without requiring modifications, as such modifications may require a significant amount of time and money.
- **Modularity Constraint:** In order to achieve scalability for larger curing areas, the design must be modular in its implementation. More specifically, the product must be able to be easily connected to copies of itself to adequately cover the curing concrete.
- **Efficiency Constraint:** The solution must demonstrate competitive or improved energy efficiency compared to current methods in order to realize a reduction in operational costs and environmental impact.
- **Maintenance Constraint:** Because the product is to be deployed in construction sites and is thus likely subject to rough handling/environments, it is important that the device is easy to maintain to reduce downtime and ensure long-term reliability. Components should be replaceable or repairable with minimal specialized tools or training.

3.0 Design Process and Solution Selection

3.1 Existing Remedies Survey

There are commercially available techniques to minimize the impact cold-weather concrete curing has on scheduling and downtime. As was iterated in the conceptual design report, these techniques aim to maintain a temperature above 10°C inside and around concrete forms before and throughout the curing period. This ensures that the concrete develops sufficient compressive/shear strength, durability, and thus adheres to CSA standards. Industry advancements continue to introduce solutions that are either mechanically or chemically based, or a combination as illustrated in the next section.

There are several major classes of existing solutions on the market. These existing solutions present a gap in the solution landscape which will be detailed below.

3.1.1 Concrete Blankets

Concrete blankets insulate curing concrete by retaining heat from the hydration reaction and/or providing additional energy. They come in two types: passive and active.

Passive blankets typically resemble tarps, sometimes enhanced with insulating foams or air bubbles, but they do not actively heat the concrete. Instead, they rely solely on the release of heat from the hydration reaction, which can be insufficient when the ambient temperature drops below freezing. Active blankets use electrically powered resistive elements to provide heat. This circumvents the obstacle of sub-zero temperatures. However, they are expensive, non-modular and often not thermally efficient. This inefficiency can lead to wasted energy in warmer conditions or inadequate heating in colder environments.

3.1.2 Temporary Enclosures

Temporary enclosures involve wrapping the entire pour area in a thin tarp and using space heaters to warm the interior. This method benefits both the concrete and workers by maintaining a climate controlled interior and shielding against ambient weather conditions. However, it poses challenges such as poor air quality, high costs and significant setup time (Havel, 2017). Additionally, much of the energy is wasted on heating the large volume of air inside the enclosure rather than the concrete itself. In comparison to the heated blanket method, temporary enclosures are less cost/energy effective and may threaten respiratory complications for at-risk individuals.

3.1.3 Concrete Additives

Chemical additives lower the ambient temperature needed for proper curing by modifying the concrete mixture. Basic approaches include injecting hot water, which is cost-effective, while more demanding conditions require specialized chemical admixtures such as accelerators, air-entraining agents and superplasticizers (Liebmann, 2019; Thompson, 2017). However, these admixtures can be expensive and require technical expertise to ensure proper chemical interactions during hydration, often necessitating engineering oversight. On average, this method is also more costly than using heated blankets, and in spite of their primary utility, they can degrade the structural integrity of the concrete all the same.

3.1.4 Existing Remedies Summary and Conclusion

Currently, concrete curing in cold weather poses significant challenges that available solutions have yet to fully address. The aforementioned methods suffer from high costs and diminished efficiency. Additionally, these solutions are often tailored for general use applications rather than being used for specific formwork designs, which limits their practicality and efficiency. As a result, there is significant opportunity to improve the cost-effectiveness and practical usability of low-temperature concrete curing solutions, which is what this project aims to address. The combination of a detailed survey of current literature regarding cold weather concrete curing and deliberations with our client, Traine Construction led us to consider a design tailored to their existing operational conventions.

From the pool of existing solutions, the **concrete blanket** shows the greatest promise in its effectiveness, while leaving room for improvement by the design team. This is because they are not invasive to the concrete properties as are chemical additives, and don’t waste vast amounts of power as do temporary enclosures. Yet the design team is presented with an opportunity to improve thermal efficiency, modularity, ease of setup/use and cost-effectiveness of the blanket solution.

3.2 Technical Parameters

Based on the existing solutions discussed in Section 3.1, the needs and constraints discussed in Section 2 and the project scope discussed in Section 1.4 the main differentiators of our solution must be increased thermal and electrical efficiency, lower material cost and more specialized applicability, ie. modularity, while simultaneously addressing all aforementioned needs and constraints.

3.2.1 Physical Considerations

As can be seen from Figure B-1 in Appendix B, the Peri gang forms Traine uses to mold concrete can possess unique geometries (Wall Formwork, 2024). As a result, a key focus in the design process was ensuring that the solution is modular, allowing multiple units to be combined to accommodate various concrete curing scenarios. Modularity was heavily considered as it enhances product scalability, adaptability and ease of deployment, which are all critical factors in construction environments where building conditions can vary significantly. More specifically, there are many reasons in favor of the use of a modular solution design including:

- **Differing Shapes and Sizes:** Construction sites and their concrete formations vary in size and layout per project. A modular design enables the solution to be easily deployed across different concrete curing areas and geometries by combining multiple units. This ensures flexibility without requiring a custom-sized or custom-shaped solution for each project while also assuring complete form (and thus concrete) coverage.
- **Ease of Transport and Storage:** Large, fixed-sized heating solutions are cumbersome to move and store. Additionally, this solution is likely to be reused on multiple locations on the same project. By breaking down the solution into smaller, modular pieces, transportation and storage of the individual solution becomes much less of a concern.
- **Simplified Maintenance and Replacement:** In the event of damage or malfunction, the use of smaller, more modular units allow for independent replacement without significantly affecting the integrity of the whole. Additionally, the cost of replacement for any one module is much less compared to having to replace one larger solution.

3.2.2 Design Dimension Considerations

Due to the variations in geometries of Peri Gang forms discussed above, it is not optimal to design a blanket which covers an entire 16’ by 11’-6” form. Rather, the blanket should be made small enough that it easily conforms to the surface (skeleton) of the form with minimal distance between the concrete itself and the heated blanket. It is most sensical, then, to design a blanket which seamlessly covers an irreducible section of formwork, and avoids laying overtop of the form support structure (the 45° bars that keep the form upright). Refer to Appendix F.1 sheets 2 and 3 for a visual representation of Peri gang form geometry and form dimensions including the support structure.

To minimize the free volume enclosed by the blanket(s), they must fit in between each support lever. Therefore, the width was constrained to a maximum of 3’-2”. No such restriction was placed on the height of the blanket save for what is possible to install easily with minimal worker exertion. Therefore, the restriction on height was that it must simply be greater than 11’-6” so that it covers the height of the form fully and thus minimizes the installation complexity and time.

3.3 Electrical Properties Selection

3.3.1 Geographic Considerations

The average temperatures in Kelowna for January and February 2025 were -1.6°C (low of -11.8°C) and -4°C (low of -19.4°C), respectively (Historical Data, 2025). Since these extremes occur at night, a conservative design ambient temperature of -10°C is used. This sets an upper bound for insulation and active thermal transfer to meet the CSA curing standard of 10°C over a typical 7-day period, resulting in a 20 K temperature gradient for the thermal model.

3.3.2 Thermal Modeling

Snelson et al. (2008) estimate that curing concrete releases up to 500 kJ/kg due to the exothermic hydration reaction. Using a conservative adjustment, industry-standard Portland Concrete is expected to release 90% of this value, or 450 kJ/kg.

According to Traine, the bracing is designed for a concrete density of $\rho = 24\ kN/m^3$. This is the density used for calculations regarding concrete mass and thermal energy. In familiar units we have $\rho = 2447.32\ kg/m^3$. This results in a total energy release of $450\ kJ/kg \times 2447.3\ kg/m^3 \times 3.474\ m^3 = 3.83\ GJ$ for a single form (see Appendix B). Assuming this energy is released over 7 days (the time required to reach specified strength), the average power output is:

$$P_{concrete,\,total} = 6.32\ kW$$

However, this overestimates actual power generation, as the full curing period is closer to 28 days—four times the assumed interval. The following figure illustrates concrete temperature over 180 hours (7.5 days) post-pour.

Referencing Figure 3.3.2-1, since only about 25% of the total heat release occurs within the first 7 days—based on extrapolating the temperature trend over the remaining 20.5 days—it is reasonable to apply a 25% scaling factor. This adjustment yields an updated power output:

$$P_{concrete} = 1.58\ kW$$

This value will be used in the simulation, representing the heat generated by the curing hydration reaction for a single 16’ gang form filled with concrete during the 7-day form retention period. A simple way to model an insulated blanket covering the form, including a 20% allowance for the skeleton and bracing, is as a room with dimensions scaled by a factor of $\sqrt[3]{1 + 20\%}$ on each axis. Online calculators can estimate the required power output to maintain the desired temperature gradient $\Delta T = T_{concrete} - T_{ambient} = 20\ K$ as established in Section 3.3.1. See reference *Thermal Intelligence, 2024* for the calculator.

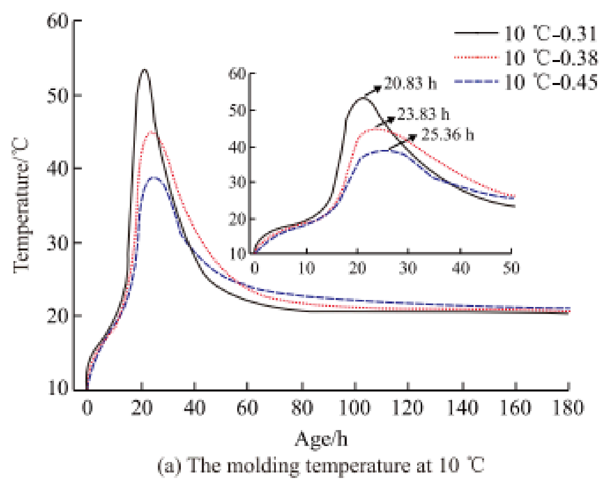

Figure 3.3.2-1: Temperature curves corresponding to time after initial pour for concrete at different ambient temperatures. Credit to Jinpeng, 2024 (see references).

The following assumptions were made:

- All four walls consist of insulated tarps.
- Temperature gradient of 20 °C.
- Maximum relative building tightness (3/3) (this represents the amount of heat leakage of the room, with 3/3 representing the maximum leakage available for the calculator, a reasonable approximation since the blanket is not sealed).
- Enclosed volume of $1.2 \times V_{form}$

The calculated power requirement is:

$$P_{total} = 4.92\ kW$$

This represents the external power needed, accounting for heat loss but excluding heat from curing, to maintain 10°C inside the blanket for 7 days in -10°C ambient conditions. This conservative estimate ensures a logistically safe approach.

Taking the difference between the required power and the heat generated by curing:

$$\Delta P = P_{total} - P_{concrete} = 3.34\ kW$$

This is the additional heat that must be actively supplied to maintain the desired temperature.

The form area is 19.1 m^2, and since the blanket covers both sides, the total covered area is approximately 38.2 m^2. The required areal power density is therefore $\phi_{A,\,in} = 88\ W/m^2$

This is a reasonable estimate, as the 20% surface area increase was not factored in, yet for this design an average of 10 individual blankets are required to cover the complete 16’x11’-6” gang form (5 for each side); since heat loss is concentrated most heavily in the overlaps, the aforementioned 20% is compensated for naturally.

3.3.3 Required Areal Power Density Summary

Using the basic HVAC heat transfer model described above, the required additional areal power density, beyond the heat generated by concrete hydration, is:

$$\phi_{A,\,in} = 88\ W/m^2$$

This necessitates active heating, such as a resistive element network embedded in the blanket. This value is feasible, as some heated blankets can produce up to 3.23 kW/m^2 (Powerblanket, 2024).

3.3.4 Heating Element Screening

To achieve consistent and efficient heating in the insulated concrete curing system, two resistive heating options were considered: heating mats and heating cables. These two categories of product are the most widely available for resistive heating solutions. After a detailed evaluation of cost, weight, energy consumption and scalability, the heating cable was determined to be the superior choice. The comparison is shown in Table 3.3.4-1. The values given in the table represent the approximate average of the products found during research, and are extrapolated to produce per blanket figures. All relevant values are based on a power requirement of 88 W/m^2 (as established in Section 3.3.2) with the provision of 30% additional losses to account for unanticipated real world inefficiencies, and a blanket area of 13’-2” by 3’-2” as established in Section 3.2.2.

Table 3.3.4-1 Comparison of the two leading solutions for resistive heating elements: heating mats and heating cable.

Parameter	Heating Mats	Heating Cable
Unit Cost	$160 for two mats	$1.12 per foot
Total Cost per Blanket	$800	$50.40
Weight per Blanket	88 lbs	2.02 lbs
Power Consumption	1.680 kW	360 W
Heat Output Density	~168 W per 20"×30" mat	~8 W/ft
Amount Needed	10.01 units	45 ft
Scalability	Poor (fixed sizes)	High (custom lengths)
Installation Complexity	Low (plug-and-play)	Moderate (routing required)

3.3.4.1 Cost-Benefit Analysis

Heating mats, while effective in small-scale applications, become prohibitively expensive for heating blankets with dimensions specified in Section 3.2.2. At $800 per blanket, they are 15.9 times more costly than heating cables. Additionally, they consume 4.7 times more power, leading to higher operating costs over time. Therefore heating cables offer a more cost-effective solution.

3.3.4.2 Weight Considerations

A full-size blanket using heating mats weighs 88 lbs, making transportation handling and manual setup cumbersome. In contrast, a heating cable solution weighs only 2.02 lbs per blanket, significantly improving portability and ease of manual handling/setup.

3.3.4.3 Energy Efficiency

Heating cables consume only 360 W per blanket, compared to 1.68 kW for heating mats. This translates to a 79% reduction in power consumption, resulting in vastly improved overall system efficiency and reducing site electrical infrastructure requirements.

To further increase efficiency, weather resistant thermostats often come standard with heating cable technology. This is useful when the ambient temperature exceeds 10 degrees. By selectively activating the units only when the temperature drops below that required by the CSA standards, energy consumption can be minimized, improving overall efficiency and reducing unnecessary power usage.

3.3.4.4 Scalability and Integration

Heating mats are fixed in size and do not scale well to large blanket applications. Conversely, heating cables can be custom-cut to fit any form dimension and allow for series connections between blankets, simplifying deployment across multiple blankets, as is required for a single Peri Gang form.

3.3.5 Resistive Element Heating Selection

Based on cost, energy efficiency, weight and adaptability, heating cables are the superior solution. They offer a lightweight, cost-effective and scalable approach to maintaining curing temperatures while significantly reducing power consumption. This ensures a practical and economical thermal management strategy for large-scale concrete curing applications. In addition, they don't require expertise to install since they simply require a standard outlet, allowing for blanket installation by any tradesman.

3.4 Material Selection Analysis

The material selection process for low thermal conductivity materials such as those intended for thermal insulation is a critical step in this design. Selecting the appropriate materials involves balancing performance with practicality. The primary requirement of low thermal conductivity ensures that the material effectively resists heat transfer which is essential in reducing heat loss and maintaining efficiency. This property is often quantified through the material's thermal conductivity (k-value) where lower values are more desirable. Furthermore, the insulating blanket's thermal resistance (R-value) is quantified as being inversely proportional to the product of its thickness and thermal conductivity k-value, where higher thermal resistance values are more desirable.

3.4.1 Material Selection Considerations

The components that will be focused on in this section are the protective skin and the insulative core. The protective skin protects the inner insulative and electric materials from external factors such as abrasive impacts and wearing, as well as weathering elements. The insulative components keep heat energy within the condition space and keep cool infiltrating air from entering the condition space.

For the protective skin, strength is the most critical consideration to ensure it can withstand mechanical stress such as handling, installation and exposure to external impacts. The material must be durable enough to resist punctures, abrasions and general wear over time. Flexibility is also a key factor as the shell must be able to conform to different Peri Gang form configurations and be easily deployed or stored, especially in cold environments. Weather protection is crucial as well. The protective skin needs to resist exposure to elements such as rain, snow and UV radiation to maintain its effectiveness over time. While thermal resistance is beneficial it is a secondary concern compared to the primary need for strength, flexibility and weather protection.

For the insulative core, thermal conductivity is the most critical factor as the material must trap and retain heat to create a stable curing environment. Strength is still an important attribute to ensure the core maintains its structure while under light to moderate tensile load. Similarly to the protective skin, the core needs to be flexible to conform to Peri Gang form specifications. Tear resistance is not as critical but still plays a role in maintaining the integrity of the insulation over time. However, it is worth restating the main function of the insulative core is to provide ample thermal insulation to ensure that the concrete has a suitable curing environment.

Both the protective skin and the insulative core need to be carefully considered for their weight. The materials used should strike a balance between being light enough for easy handling while still performing effectively in their respective roles. Additionally, cost-effectiveness is a key factor for both components. While performance is important, the materials must meet the required specifications while also keeping production costs within reasonable limits.

3.4.2 Material Research and Software Analysis

This section of the report is a reiteration of the Conceptual Design Report as this stage of the process did not change, but was expanded upon to further evaluate and confirm a pool of potential material candidates. The initial stage of the material selection analysis was to begin researching current materials and new up-and-coming materials that would best be suited for an insulation blanket, which is to be designed to maximize thermal resistance.

As mentioned in the Conceptual Design Report research shows that insulating blankets generally have R-values ranging from 1.5 to 5.7, with some reaching up to 7. Examples of providers are listed in Appendix C.1. R-values depend on the material type and thickness, with blankets typically comprising a protective skin and an insulating core. Common protective skins include woven polyethylene, polyethylene-coated polyester and vinyl polymer-coated polyester. Insulating cores are often made from closed-microcell PE foams. The most popular combination is woven polyethylene skin paired with a PE foam core (see Appendix C.1).

The research findings were validated or expanded upon using GRANTA software, which compares materials and provides an in-depth overview of mechanical and thermal properties as well as additional information about material manufacturing, use and end of life procedures. GRANTA is a widely used and critical software in the material selection process.

3.4.3 GRANTA Analysis

This section focuses on the specific uses of GRANTA for the material selection process. This stage was broken down into sub-stages to ensure material selection was considered effectively and carefully.

3.4.3.1 Preliminary Categorization

Before directly using GRANTA, the two primary components of the thermally insulative blanket (the Protective Skin and the Insulative Core) were categorized in terms of their function, critical objectives to be maximized or minimized, preliminary constraints to meet design requirements and free variables that could be adjusted to optimize performance. This was achieved by creating a table outlining the material functions and requirements which could then be input into GRANTA for initial material screening.

Table 3.4.3.1-1 provides a clear overview of the critical variables that must be considered while choosing adequate materials, and serves as a basic benchmark but does not consider every property. Therefore additional properties must be considered to ensure sufficient functional performance.

Table 3.4.3.1-1 Material Function and Requirements		
	Category	
Requirements	Protective Skin	Insulating Core
Function	Serves as a protective barrier from mechanical stresses and weathering elements.	Insulates heat generated by exothermic reaction and electrical resistance.
Objective	Maximize strength	Minimize thermal conductivity (Maximize thermal resistance)
Constraints	Cost, Area (L*W), Density and Flexibility	Cost, Area (L*W), Density and Flexibility
Free Variable	Choice of material and thickness	Choice of material and thickness

3.4.3.2 Considering Additional Properties

In this design, the primary material selection properties considered for performance were mechanical and thermal properties. Sustainability and ethical considerations were also prioritized to ensure the final product aligns with engineering ethics. This section outlines and defines the key properties evaluated during the material selection process.

Most of the properties listed in Table 3.4.3.2-1 were considered for both the protective skin and insulative core. However, some properties were less relevant or neglected due to their limited impact on the specific function of each component. Additionally, in GRANTA, certain properties were not applicable to all materials. For example polymer foams can be assessed for densification strength due to the free volume between polymer branches whereas in wool fibers densification strength is not considered.

In the material selection process a range of thermal, mechanical, sustainability and ethical properties were evaluated in GRANTA to ensure both optimal performance and environmental responsibility. Thermal properties such as thermal conductivity, glass transition temperature and service temperature ranges were assessed for effective heat management. Mechanical properties including tensile strength, fatigue strength and toughness were considered for durability and resilience under various conditions. Sustainability and ethical considerations such as density, cost, durability, embodied energy, CO2 footprint and end-of-life options (e.g. recyclability, biodegradability or safe landfill disposal) were also prioritized to minimize environmental impact and uphold ethical standards (see Section 4.3). Appendix C.2 includes additional information about each of the properties listed above in Table 3.4.3.2-1.

Table 3.4.3.2-1 Additional properties considered in material selection process

Thermal	Mechanical	Sustainability & Ethical
• Thermal Conductivity • Glass Transition Temperature • Maximum Service Temperature • Minimum Service Temperature • Flammability	• Tensile Strength • Shear Strength • Shear Modulus • Specific Strength • Elongation • Densification Strength • Fatigue Strength • Hardness • Toughness	• Density • Cost • Durability • Embodied Energy • CO2 Footprint • Water Usage • End of Life (Recycling Downcycling Combustion-Recovery Biodegradability Landfill)

3.4.3.3 Free Volume Factor, Mass and Geometry and Density Considerations

GRANTA's material selection software has limitations in accurately calculating densities, particularly for materials such as fibers, natural fibers and particulates. This is because GRANTA primarily considers bulk material properties and does not account for factors such as weave structure or free volume fractions which can significantly influence the overall density of composite materials. As a result, the density values provided for these materials may not reflect their true behavior in specific applications. To address this limitation a free volume fraction factor will be implemented to adjust the density limit, accounting for these structural effects and ensuring more accurate material selection data for the intended blanket design.

Regarding the Free Volume Factor consideration, according to one study: "Predicting the porosity of woven fabric before manufacturing has been a complex and difficult task… areal density but also other factors like fabric thickness, yarn diameter and linear yarn density play pivotal roles in determining fabric porosity" (Rout and Singh, 2023). This means that there is a wide margin of free volume between different thread types, material types and weaving methods. To account for all the different free volume factors is beyond the scope of this design. Therefore, the objective of analyzing this publication's research results is to determine a reasonable free volume factor for the protective skin and insulative core.

In the study by Rout and Singh six different samples of nylon and six of polyester with varying molecular polymer compositions were tested. The study determined fabric composition and pore size, enabling the experimental derivation of porosity percentages for each material. These findings are presented on page 8 of the publication, in Table 3 (see reference). Note $V = SA(t)$ and $\rho = \frac{m}{V}$.

$$\rho_{effective} = \rho_{bulk}\, x\, (1 - Porosity) \quad (Eq.\ 3.4.1)$$

$$m_{total} = m_{prot.\,skin} + m_{insl.\,core} \quad (Eq.\ 3.4.2)$$

$$(\rho V)_{total} = (\rho V)_{prot.\,skin} + (\rho V)_{insl.core} \quad (Eq.\ 3.4.3)$$

The in-depth analysis conducted in Appendix C.3 using the equations listed above determined an average porosity of 39.19%, which was adjusted to 35% to meet design constraints and calculate effective density. Since GRANTA does not account for geometry, surface area constraints were considered separately. The insulating blanket's mass was limited to 45 kg to comply with safety regulations, leading to a density range of 475.5–951.0 kg/m³. Protective skin and insulative core densities were categorized separately, with a conservative thickness assumption to allow flexibility. The final density range was calculated to ensure compliance with weight restrictions and was used for material selection in GRANTA. Figure C.3.1 in Appendix C.3 illustrates the density distribution of the possible density combinations of both the insulative core and protective skin.

3.4.3.4 Preliminary GRANTA Material Screening

To implement GRANTA using Table 3.4.3.1-1, two general materials graphs were generated. One for the protective skin and another for the insulative core. These graphs were created to categorize material families based on key properties. For the protective skin the graph focused on specific strength, helping to identify material families that offer an optimal balance of strength and weight. For the insulative core the graph prioritized thermal conductivity, allowing for the identification of materials with the best insulating properties.

Minor constraints were applied during this process as the primary objective was to get an initial overview of favorable material families. More detailed constraints were applied later in the design process to filter out undesirable materials and ensure the final selections meet all performance and cost requirements.

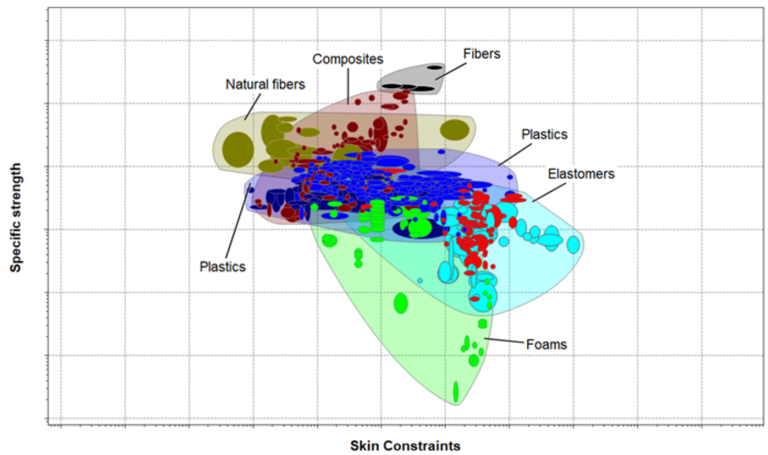

Figure 3.4.3.4-1: Skin objective, Strength vs the Skin Constraints provided in Table 3.4.3.1-1. Image produced using GRANTA. (GRANTA, 2023, Version 23.2.1).

Figure 3.4.3.4-1 illustrates a wide range of material options. The focus is on selecting materials with high strength while minimizing the constraints outlined in Table 3.4.3.1-1, given the fixed area specified in Section 3.4.3.2. As a result, the materials of interest are those located in the top-left corner of Figure 3.4.3.4-1 which include desirable material families such as natural fibers, plastics, fibers and elastomers. It is to be noted that composites were not listed as they are not flexible and would perform well as a thermally insulative blanket.

Similarly, Figure 3.4.3.4-2 presents several material options. To align with the objective and constraints the analysis prioritizes materials in the bottom-left corner of Figure 3.4.3.4-2, which considers thermal conductivity. These materials minimize thermal conductivity while reducing constraints, except for the fixed area. The desirable material families observed are polymer foams, natural fibers, elastomers and plastics.

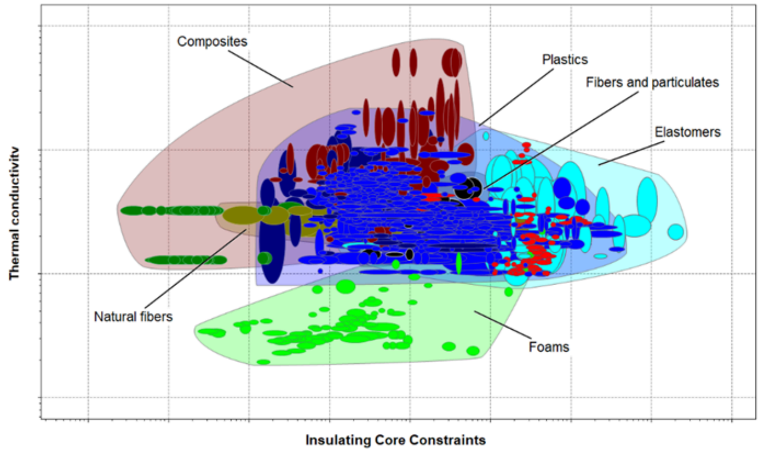

Figure 3.4.3.4-2: Insulating core objective, Thermal Conductivity vs Insulating Core constraints provided in Table 3.4.3.1-1. Image produced using GRANTA. (GRANTA, 2023, Version 23.2.1).

3.4.3.5 Insulative Core Material Screening

The insulative core material was prioritized in the screening process, as maximizing heat insulation is essential for effective concrete curing. Constraints from Section 3.4.3.1 were applied in GRANTA to facilitate material selection, ensuring that thermal, mechanical, physical, and sustainability factors were considered. This systematic approach helped identify materials that best met the thermal insulation requirements while balancing other key properties.

The design constraints were applied to GRANTA to refine the material selection process, resulting in the generation of Figure C.4.1 in Appendix C.4. This graph displays thermal conductivity on the y-axis and elongation on the x-axis, highlighting the trade-off between thermal insulation and flexibility. For this design it is crucial that the material is both thermally insulative and flexible which makes materials in the bottom right of Figure C.4.2 in Appendix C.4, particularly desirable. Polymer foams, in particular, emerge as favorable materials in this region as they offer both low thermal conductivity and the necessary flexibility for the intended application.

Additional constraints were applied in Figure C.4.2, further refining the material selection process and filtering out more materials. Density, elongation and sustainability constraints were specifically applied to ensure the materials meet the necessary performance, flexibility and environmental standards. The purpose of this iterative approach is to continuously apply or manipulate constraints to gradually narrow down the pool of potential materials. By progressively applying more stringent criteria, only those materials that meet or exceed the design requirements remain. The materials that are left after this filtering process can be considered more desirable with a higher likelihood of achieving adequate or even above-adequate performance in the final design. This stepwise refinement ensures that the selected materials are well-suited to meet both the functional and performance objectives of the project.

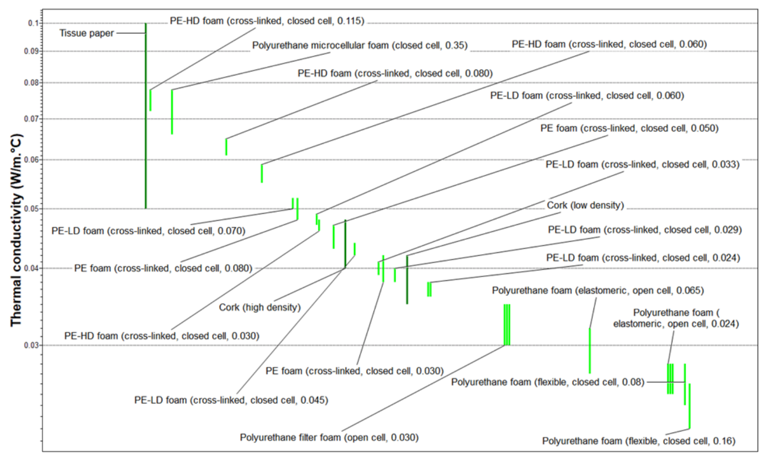

Figure 3.4.3.5-1: Bar chart of materials with the lowest thermal conductivity, or highest thermal resistance. (GRANTA, 2023, Version 23.2.1)

Figure 3.4.3.5-1 was created to identify materials with the lowest thermal conductivity, or highest thermal resistance, as these properties are critical for ensuring effective thermal insulation in the design. While thermal conductivity is not the sole deciding factor in material selection it carries the most weight in the decision-making process due to its direct impact on the overall performance of the design on the worksite. Materials with lower thermal conductivity are prioritized to ensure that the blanket effectively retains heat, maximizing the curing conditions for the concrete. However, other factors such as flexibility, durability and cost are also considered in the final selection process.

3.4.4.1 Insulative Material Pool

The GRANTA analysis led to the generation of potential material candidates by systematically applying the design constraints and screening criteria. By utilizing the software’s material selection tools, a range of materials was evaluated based on key properties such as thermal conductivity, strength, flexibility and sustainability. Through the iterative process of refining constraints, GRANTA filtered out unsuitable materials leaving a smaller pool of candidates that best met the design requirements.

Table 3.4.4.1-1 does not include every material that was considered, as only a few top candidate materials were selected from each material family. These candidates were chosen based on their low thermal conductivity which is the primary concern for the insulative core.

Table 3.4.4.1-1: Pool of potential material candidates for insulative core	
● Polyurethane Foam (flexible, closed cell, 0.16) ● Polyurethane Foam (flexible, closed cell, 0.08) ● Polyurethane Foam (elastomeric, open cell, 0.024) ● Polyurethane Filter Foam (open cell, 0.019) ● PE Low Density (cross-linked, closed cell, 0.018) ● Tissue Paper (cellulose)	● Butyl / halobutyl rubber (IIR, unreinforced) SBS (Shore A50) ● PC+Polyester Transparent amorphous ● Leather ● Acrylic Fiber ● Wool (Weave)

The GRANTA analysis led to the generation of potential material candidates by systematically applying the design constraints and screening criteria. By utilizing the software's material selection tools, a range of materials was evaluated based on key properties such as thermal conductivity, strength, flexibility and sustainability. Through the iterative process of refining constraints, GRANTA filtered out unsuitable materials leaving a smaller pool of candidates that best met the design requirements.

Table 3.4.4.1-1 does not include every material that was considered, as only a few top candidate materials were selected from each material family. These candidates were chosen based on their low thermal conductivity which is the primary concern for the insulative core.

3.4.4.2 Decision Matrix for Insulative Core Materials

The material properties outlined in Table 3.4.3.2-1 were recorded from GRANTA and implemented into Microsoft Excel for further analysis and normalization across materials. This process enabled a consistent comparison of materials by standardizing their properties. Depending on the classification of each property the goal was either to maximize, minimize or achieve an optimal value.

The next step in the process will involve incorporating these weights to adjust the rankings of the materials according to their relative importance in meeting the design objectives.

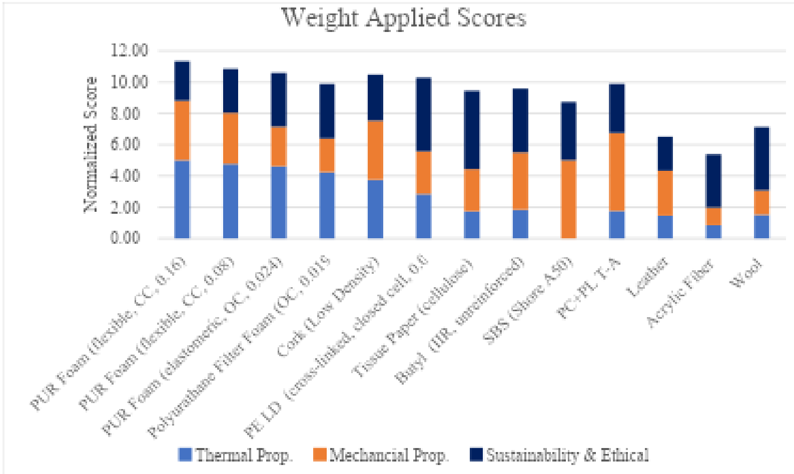

Figure 3.4.4.2-1: Bar chart of weighted and normalized properties in regards to the pool of insulative core materials.

Figure 3.4.4.2-1 presents the results of the weighted matrix as a bar chart, highlighting polyurethane foams as the top-performing materials based on the assigned scores. The scoring system, detailed in Appendix C.6, was used to evaluate and rank candidate materials. The intermediate steps of this process are further expanded in Appendix C.7, which illustrates how thermal, mechanical, sustainability, and ethical properties were systematically considered in the selection.

3.4.4.3 Insulative Core Material Selection

Polyurethane foams were identified as the optimal insulative material due to their superior thermal insulating properties and robust mechanical characteristics. Their high heat retention capability makes them well-suited for the insulative core of the blanket. Although their end-of-life impact presents challenges, they offer multiple disposal pathways, including downcycling, energy recovery through combustion, and landfill disposal without toxicity concerns. A detailed assessment of their environmental impact and sustainability will be provided in the Sustainability and Ethical Considerations section.

Cork fibers represent a promising alternative, offering moderate thermal insulation, good mechanical strength, and significant sustainability advantages. As a biodegradable material sourced from renewable cork oak trees, they provide an environmentally responsible option. While their thermal performance is lower than that of polyurethane foams, their minimal environmental footprint enhances their viability as an insulative core material.

Polyethylene foams also demonstrate potential due to their favorable thermal properties, mechanical strength, and flexibility. They offer moderate insulation efficiency while remaining lightweight and durable. Although their thermal performance is inferior to that of polyurethane foams, their balance of functionality and environmental benefits renders them a feasible alternative for the blanket design.

3.4.5 Protective Skin material Screening

This section analyzes the protective skin component, emphasizing strength and resilience to shield the insulative core from external elements. The material screening process follows the same methodology as Section 3.4.3.5, applying design constraints and screening criteria to identify materials with the required durability and flexibility.

GRANTA was used to refine material selection by imposing constraints on key properties such as maximum density, elongation and material family. This filtering process ensured that only materials meeting the necessary strength, resilience and flexibility requirements remained under consideration. The selected materials provide the durability and protection essential for the protective skin while maintaining balanced performance in density and flexibility.

The intermediate stages of material screening for the protective skin are detailed in Appendix C.5. This appendix illustrates the material filtering process using GRANTA-generated charts, systematically narrowing down the initial material pool to the most suitable candidates.

Figure 3.4.5-1 highlights materials with the highest tensile strength illustrating their performance in terms of resistance to mechanical stress. While tensile strength is weighted highly in the material selection process for the protective skin it will not be the only consideration. Other factors such as flexibility, weather resistance and overall durability will also play a significant role in determining the most suitable material for the protective skin, ensuring a balanced approach to material selection.

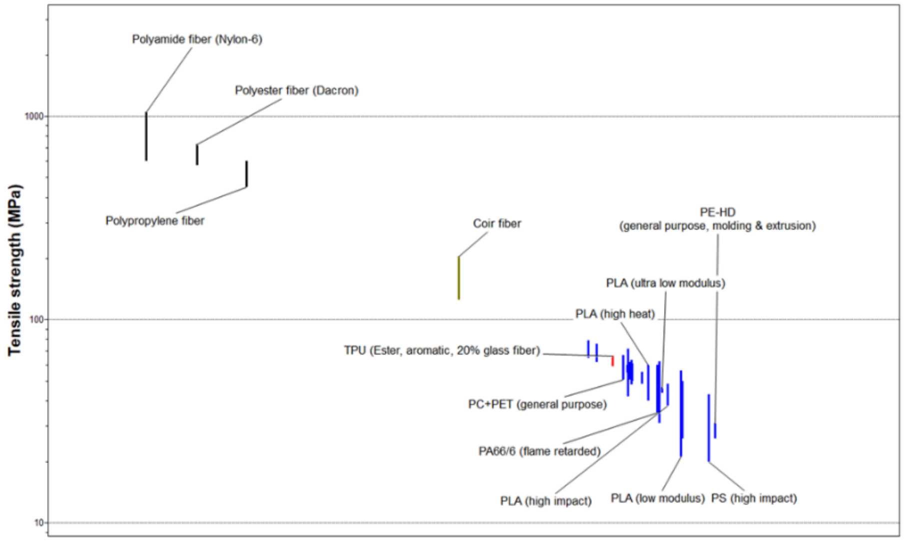

Figure 3.4.5-1: Bar chart displaying material with highest tensile strength. (GRANTA, 2023, Version 23.2.1)

3.4.5.1 Protective Skin Material Pool

Table 3.4.5.1-1: Pool of potential material candidates for protective skin	
• Polyamide (PA6, Nylon-6) • Polyester Fiber (Dacron) • Polypropylene Fiber • Celluloses fiber (Rayon)	• Acrylic Fiber (PAN) • Coir Fiber • PEEK

The GRANTA analysis generated a pool of potential material candidates by systematically applying constraints focused on mechanical attributes and sustainability. Using the software's material selection tools materials were evaluated based on key mechanical properties such as tensile strength and flexibility along with sustainability factors. Through an iterative process of refining these criteria GRANTA filtered out unsuitable materials, resulting in a smaller pool of candidates that best aligned with the design requirements for both performance and environmental considerations.

3.4.5.2 Decision Matrix for Protective Skin Materials

Similar to the previous section a decision matrix was created for the materials selected for the protective skin components. The matrix was divided into three main sections: thermal, mechanical and sustainable properties with each property normalized relative to each other. The weights applied to each category were not balanced. Mechanical and sustainable properties were given more weight than thermal properties to better achieve the protective skin's function. This approach allowed the materials to be ranked, identifying the best candidates based on a focused evaluation of mechanical performance and sustainability while still considering thermal properties.

Below in Figure 3.4.5.2-1, the results for the materials are displayed after the weights have been applied. This figure shows how the materials now rank based on a balanced evaluation of thermal, mechanical and sustainability properties with greater emphasis placed on mechanical and sustainable factors.

Figure 3.4.5.2-1 presents a bar chart of the decision matrix results for the protective skin, indicating nylon 6 and polyester as the top candidates. The scoring system used for this evaluation is detailed in Appendix C.6. The intermediate steps of the selection process are further expanded in Appendix C.8, which illustrates how mechanical, thermal, sustainability, and ethical properties were systematically considered.

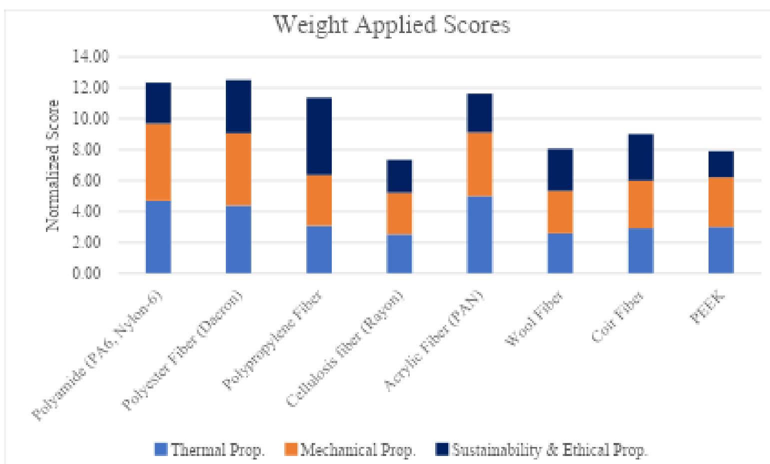

Figure 3.4.5.2-1: Bar chart of weighted and normalized properties in regards to the pool of materials.

3.4.5.3 Material Selection for the Protective Skin

Polyester fiber ranked number one after this analysis which aligns with the outcome presented in the research proposal report. Polyester excels in mechanical properties offering strong tensile strength and flexibility while also demonstrating relatively good sustainability and thermal properties. These characteristics make it an ideal candidate for the protective skin component where durability and resilience are crucial.

Coming in a close second is Nylon 6 which shares many of the same qualities as polyester in the key categories of mechanical, sustainable and thermal properties. Although slightly behind polyester in overall ranking Nylon 6 remains a strong contender due to its similar performance making it a viable alternative for the protective skin if needed. Both materials provide a solid balance of strength, flexibility and sustainability making them top choices for the protective skin component.

3.4.6 Material Selection Results Summary

The GRANTA analysis and decision matrix were instrumental in identifying the most suitable materials for both the insulative core and protective skin components. By applying design constraints and evaluating materials based on key properties, a more focused and informed selection was made ultimately ranking materials according to their performance in thermal, mechanical and sustainability categories.

For the insulative core, polyurethane foams emerged as the top choice due to their excellent thermal insulating properties and strong mechanical characteristics. While they have some environmental concerns regarding end-of-life disposal, polyurethane foams offer various disposal options such as downcycling or energy recovery with minimal toxicity risks. Cork fibers were also considered, offering moderate thermal properties, good mechanical strength and strong sustainability though their thermal insulation is vastly inferior to polyurethane foams. Polyethylene foams also proved to be a good option with favorable thermal properties, strength and flexibility, though they are slightly less thermally efficient than polyurethane foams.

For the protective skin, polyester fiber ranked number one offering excellent mechanical properties, good thermal characteristics and relatively strong sustainability features. Coming in second was Nylon 6 which shares similar attributes in terms of mechanical, sustainable and thermal properties making it a strong alternative. Both materials were recognized for their durability, flexibility and balance of performance, making them top candidates for the protective skin component.

3.5 Material Specifications

After the material selection process was completed and a pool of top material candidates were generated, a weight and cost analysis was conducted to estimate the approximate cost and weight of the insulative blanket. These numbers are theoretical and based on the material properties and assumptions made during the selection process. While the estimates are conservative, the actual values should likely be more favorable as factors such as material property errors, assumption variances and potential optimizations were not fully accounted for. This analysis provides a reasonable approximation for further design considerations though actual figures may differ upon implementation.

3.5.1 Insulative Core and Protective Skin

The insulative core materials were analyzed between thicknesses of ½” to ¾”, at 1/16” intervals, as outlined in Section 3.4. For the protective skin, thicknesses ranged from 2mm to 6mm, with 2mm intervals, keeping in mind that this is the overall thickness, and the outer and inner thicknesses on each side of the product will be half of the overall thickness. This approach ensured a thorough evaluation of material performance at different thicknesses to identify the optimal design.

After considering the two figures above (Figures 3.5.1-1 and 3.5.1-2) the cost per square foot for each material was examined over a range of thicknesses. It was determined that polyurethane foams would work best for the insulative core as outlined in Section 3.4 due to their superior thermal properties. Polyester and Nylon 6 emerged as the best candidates for the protective skin, offering a balance of mechanical strength and sustainability. More detailed information can be found in Appendix D. Additionally, the maximum masses at the maximum thickness for both components were calculated, resulting in a total weight of 31.5kg which ensures the design meets the maximum weight constraint.

It is worth considering two models of the product: one with a ⅝” and the other with a ¾” thickness of 0.024 elastomeric, open-cell polyurethane (PUR, 0.024). Both models can be paired with either a 4mm or 6mm protective skin made of polyester or Nylon 6. This design flexibility allows for balancing thermal insulation and mechanical properties while meeting performance and weight requirements. The total conservative mass for the two models would be 14.84 kg for the ⅝” model at a cost of $1.02 CAD/ft^2 and 21.83 kg for the ¾” model at a cost of $1.43 CAD/ft^2.

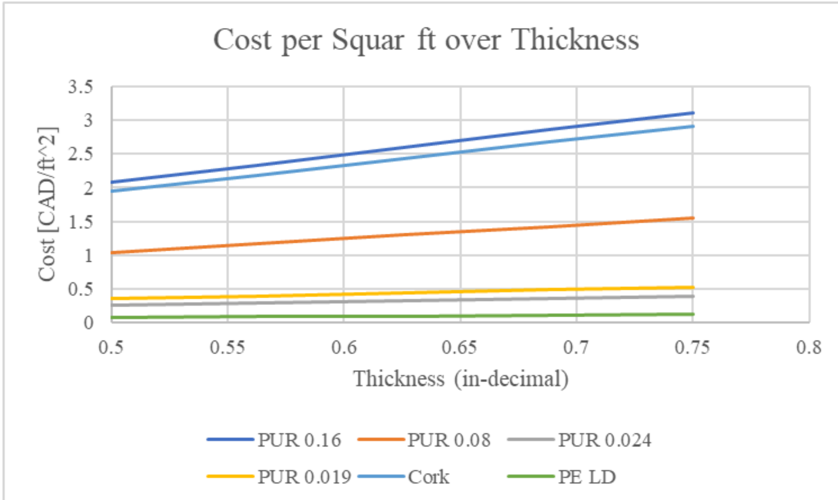

Figure 3.5.1-1: Cost per square foot of each material of interest for the insulative core.

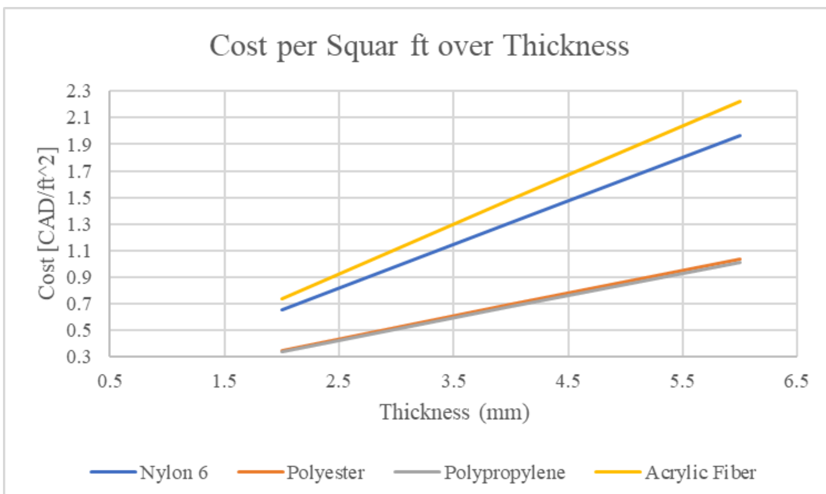

Figure 3.5.1-2: Cost per square foot of each material of interest for the Protective Skin.

3.5.2 Product R-Value

The analysis was also run to acquire the R-value for both product models which measures thermal resistance. For the ⅝” (insulative core) and 4mm (protective skin) model the R-value was calculated to be 3.55, while for the ¾” (insulative core) and 6mm (protective skin) model it was 4.31. These values represent the thermal resistance at the surface assuming no air gap is present. These R-values indicate the materials' effectiveness at resisting heat flow which is critical for ensuring the insulative blanket provides adequate thermal protection during the curing process.

This design should represent an improvement over current methods as the proposed insulative blanket offers higher thermal resistance values compared to traditional materials typically used for curing concrete in cold conditions.

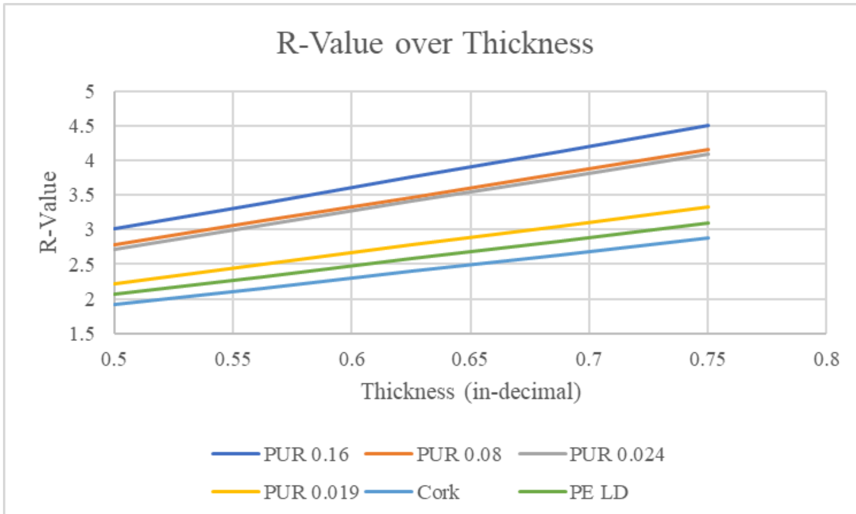

Figure 3.5.2-1: R-Value of each material of interest for the insulative core.

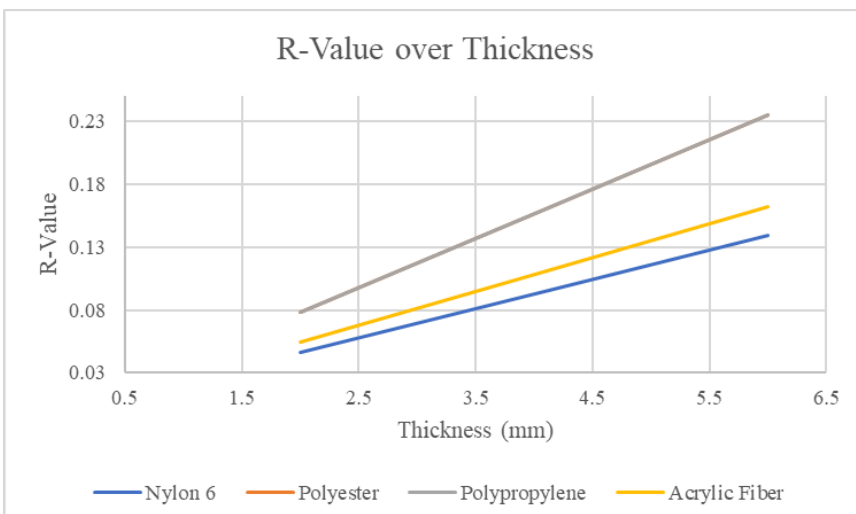

Figure 3.5.2-2: R-Value of each material of interest for the Protective Skin.

4.0 Sustainability and Ethical Considerations of Final Design

In this design report, sustainable and ethical practices were given high priority throughout the entire process. This section details the considerations made during the design process that pertained to health and safety, business and public welfare, sustainability and the environment.

4.1 Health and Safety Considerations

The safety of workers and end users was a critical factor in the design of the insulative blanket. To ensure safe handling, the blanket was engineered to be lightweight and ergonomically manageable, minimizing the risk of strain injuries during installation. Its thermal properties and flexibility were carefully evaluated to maintain ease of use while ensuring reliable performance and minimal electrical and burning hazards to workers. The power output of a single blanket reflects this.

Material selection also played a key role in mitigating potential health risks. All components were analyzed for chemical safety, eliminating the potential of toxic substances, volatile organic compounds (VOCs) and harmful particulates that could pose risks during manufacturing, installation, or prolonged use. Special attention was given to ensuring that no off-gassing or skin irritation would occur when handling the blanket in enclosed environments.

By choosing low risk materials, the blanket meets or exceeds occupational safety standards. This focus on safety and usability ensures that the product can be deployed across diverse job sites without introducing unnecessary hazards.

4.2 Business and Public Welfare Considerations

The insulative blanket was designed with economic viability and public welfare in mind, recognizing the broader impact that proper concrete curing has on construction quality, infrastructure longevity and safety. A failure in the curing process can lead to cracking, reduced compressive strength and structural weaknesses, resulting in expensive rework, construction delays and even legal liabilities. The financial burden of improper curing can quickly escalate into thousands or even millions of dollars in damage and lost productivity. Moreover, poorly cured concrete in buildings and other infrastructure can pose a risk to public welfare. Ensuring that concrete achieves its full strength and durability is essential for preventing failures that could endanger the public, which includes dwellers or workers at the buildings erected using our solution.

4.3 Environmental Considerations

Environmental concerns were a top priority in the material selection process. The materials used in the design were carefully chosen to ensure they were non-toxic to the environment. Alternative disposal options such as recyclability, downcycling, safe landfill disposal and energy recovery through combustion were explored to minimize the environmental impact. By considering these options the design seeks to balance high performance with sustainability ensuring that the insulative blanket is both effective and environmentally responsible.

Key factors such as embodied energy, CO2 footprint, water usage and end-of-life procedures were carefully evaluated to ensure that the chosen materials aligned with sustainable design principles.

Embodied energy, which refers to the amount of energy required to produce the material and CO2 footprint which measures carbon emissions per unit of material were assessed to understand the environmental impact of production. Water usage was also considered as materials with high water consumption could contribute to resource depletion, particularly in regions facing water scarcity.

End-of-life procedures were given significant attention. Materials were evaluated based on their potential for recycling, downcycling, biodegradability and safe landfill disposal. Preference was given to materials that could be easily recycled or downcycled or that biodegrade without causing harm to the environment. Safe landfill disposal was considered a last resort for materials that could not be recycled or biodegraded.

Combustion energy recovery was also considered as an end-of-life method, though it was viewed as the least optimal due to the potential emissions produced during combustion. The primary objective was to select materials that not only performed well during use but also had the least environmental impact throughout their life cycle from production to disposal. Considering the two figures above, the sustainable and ethical properties were carefully incorporated into the material selection process discussed in Section 3.2. Additional information and figures relating to this topic can be found in Appendix E.

For the insulative core the most beneficial material would be polyurethane foam. Despite its excellent thermal insulating properties, which are vital for the performance of the blanket, polyurethane foam poses challenges in terms of recyclability. The cross linked bonds in the polymer chain make it difficult to recycle which is a significant drawback from an environmental perspective. However, polyurethane foam's superior insulative properties cannot be overlooked, especially given the design's primary objective of maximizing thermal efficiency. It is essential for the success of the project that the material performs well in its intended function. Moreover, polyurethane foam has a lower embodied energy compared to other materials and it requires roughly half the amount of energy to produce compared to cork. As a result, despite its challenges in recyclability polyurethane foam emerges as the most desirable option for the insulative core in this design.

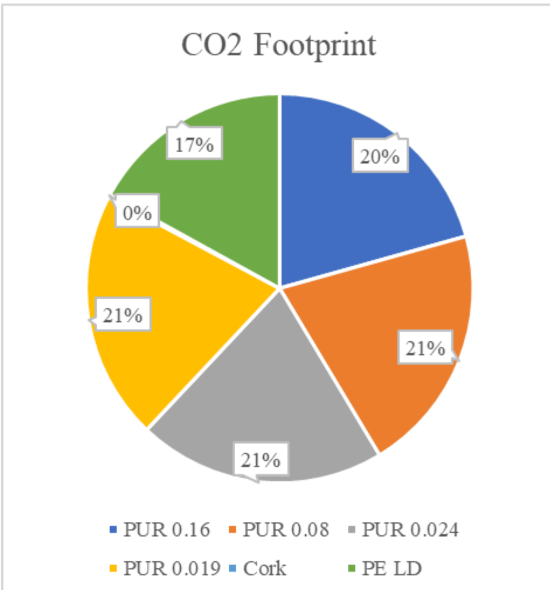

Figure 4.3-1: CO2 footprint produced from production. Quantity ratio is relative between materials examined for the insulating core.

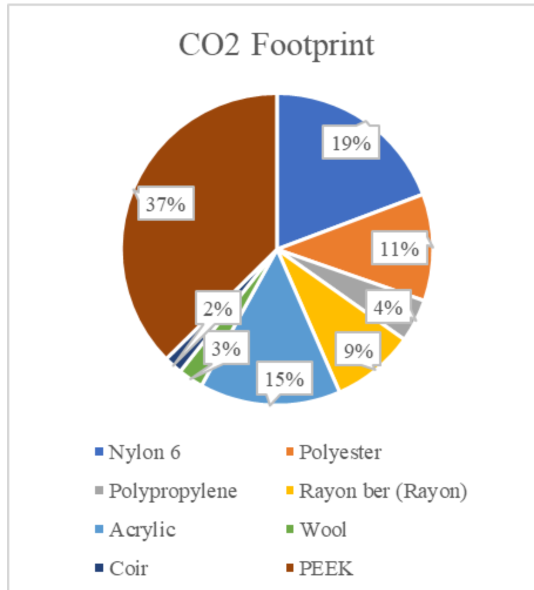

Figure 4.3-2: CO2 footprint produced from production. Quantity ratio is relative between materials examined for the protective skin.

Polyester and Nylon 6 are also excellent material choices for the protective skin component, given their relatively low embodied energy, water usage and CO2 footprint. Both materials are more sustainable compared to others as they require less energy to produce and have a smaller environmental impact during their manufacturing processes. In addition to their favorable environmental properties both polyester and Nylon 6 are recyclable, making them more sustainable options when considering their end-of-life impact. These materials meet the design requirements outlined above offering strong mechanical properties, flexibility and durability which are essential for the protective skin component. Their recyclability further supports the overall sustainability goals of the project as they can be reprocessed and reused, reducing waste and resource consumption. Given these advantages both polyester and Nylon 6 serve as highly viable materials for ensuring the design meets both performance and environmental objectives.

This solution also aligns with industry standards and building codes, ensuring compliance with safety regulations while minimizing waste and reducing environmental impact. The combination of affordable operation, reduced material waste and enhanced performance makes this approach a practical and responsible choice, reinforcing the project's commitment to sustainability and environmental conscientiousness.

5.0 Final Design Details and Performance Evaluation

This section details the electrical values, physical geometry and dimensions, materials and thermal properties of the final product design for curing concrete within Peri Gang forms in cold weather. In addition, the design of a scaled down prototype is fully detailed in Section 5.2 and contrasted against the proposed full-size product design. Finally, the prototype was tested to determine the efficacy of the proposed solution at a reduced scale. This was accomplished by constructing small wooden concrete forms (molds) and performing a series of temperature dependent tests to determine concrete strength as a function of curing conditions, which is described in detail in Section 5.2.2.

5.1 Final Product Design

5.1.1 Final Material Design

After evaluating the weights, R-values, and costs outlined in Section 3.5, the optimal material combination for the design consists of a ⅝” (15.875mm) elastomeric, open-cell polyurethane foam insulative core and a 6mm (15/64”) polyester fiber protective skin (3mm on each side). This selection was made based on a balance between insulation performance, cost efficiency, sustainability, and weight considerations. The slightly thinner foam core provides adequate thermal resistance while reducing overall weight and cost, whereas the thicker protective skin enhances structural integrity and durability.

The polyurethane foam core achieves a surface R-value of 3.40 $ft^2 \cdot °F \cdot hr/Btu$, with a total mass of 1.42 kg and a cost of \$0.33 CAD/ft^2. The polyester fiber protective skin contributes an additional R-value of 0.235 $ft^2 \cdot °F \cdot hr/Btu$, a mass of 20.125 kg, and a cost of \$1.04 CAD/ft^2. These values are based on square-foot R-values and costs, while the mass calculations are derived from a 13'-2" × 3'-2" product unit size.

When combined, the selected materials provide a total surface R-value of 3.63 $ft^2 \cdot °F \cdot hr/Btu$, a combined material cost of \$1.37 CAD/ft^2, and a total mass of 21.55 kg. This configuration ensures compliance with the weight constraints specified in Section 3.4, while maintaining cost-effectiveness and sufficient insulation performance.

5.1.2 Product Electrical Design

After evaluating both heating mats and heating cables for the concrete curing blanket, the heating cable solution was determined to be the most efficient, cost-effective and scalable. Heating cable offers particular advantages in large-scale applications ease of deployment becomes a key consideration. Table 5.1.2-1 shows the average parameters of heating cable that were utilized for the final design.

Since, on average, 10 blankets are required to cover a 16’ by 11’-6” Peri Gang form, the total current draw for one form shall be 30.6 A. Therefore, if standard 15A breakers are used in conjunction with 120 V outlets, the number of required circuit count is 3 per form. This may not be the case on work sites where generators with different specifications are used.

Table 5.1.2-1: Summary of the values (per blanket) for resistive heating cable utilized in the final design.

Parameter	Value
Cable Power Density	8 W/ft
Cable Length	45 ft
Power Consumption	360 W
Weight	2.02 lbs
Current (@ 120 V)	3.06 A

As earlier discussed, a popular heated blanket remedy for industrial use in cold weather concrete curing is the Powerblanket (Powerblanket, 2024). A similarly sized product from this supplier to that which we designed consumes approximately 655W. Therefore, the relative percent efficiency for our product compared to the leading market solution is 44%. This is a significant improvement in performance, partially due to the fact that we do not wish to provide power in excess to that which is needed for the specific application discussed in Section 3.3.2.

5.1.3 Product Geometry

5.1.3.1 Final Product Dimensions

The width was chosen to be the maximum allowable so as to fit an irreducible Peri Gang form section which was discussed in Section 3.2.2; this was 3'-2".

At the request of the client, the design for blanket height was adjusted to incorporate coverage over the top of the form rather than just the two faces. Typically, the thickness enclosed by the form structure is 8", yet this may vary in specialized applications; rarely does it ever exceed 12". In order to ensure full coverage with enough overlap to prevent significant heat leakage, the height was chosen to be 13'-2".

The approximate thickness was calculated using the insulative core and twice the thickness of the protective outer skim, since the heating cable is approximately fully embedded in the insulative core material (refer to Section 5.1.1 and Appendix F.1). The total thickness was therefore 0.988", or 253/256 inches.

5.1.3.2 Hook Design

It is important that our blanket can be installed to a Peri Gang form quickly. Specially designed metal hooks were used so that the blanket could be attached to the side of a Peri Gange form and bear the weight of the blanket. The mouth is large enough to fit over a 5" thick form. Our blanket design will have two hooks placed 11'-6" up from the bottom (heightwise) and 2" from either end (widthwise).

The material chosen for the hooks is Aluminum 356-T6. This was chosen for its strong combination of strength, corrosion resistance and castability. It has a yield strength of 22 Kpsi, which is adequate for the loads it will experience. Casting allows for a consistent quality and more cost-efficient manufacturing process. The T6 heat treatment enhances the mechanical properties, and the material's good heat conductivity will help to dissipate any localized heat.

A finite element analysis (FEA) was done in SolidWorks to test how much the hooks could hold. This is a static test, as the hooks will only be subject to a constant static force. The blanket weighs (ceiling value) 21 kg, and the load applied to the hook for this simulation was 25 kg. As each blanket will have two hooks, this means the simulation was done with a safety factor just over 2, which is good for static loads. It was found that the maximum displacement under load was 3.0×10^{-4} mm, and the max von Mises stress was 5.9×10^{5} N/m^2. Less than 1 mm displacement for a rigid part is usually acceptable, so this displacement is practically negligible. Converting the Von Mises stress to psi, we get approximately 86 psi. This is far below the yield strength of the material, which is 22 Kpsi. This simple FEA proves that our design and material selection will be able to hold our blanket. Refer to Appendix F.2 for the simulation results.

5.1.4 Final Design Drawings

The engineered drawings for the final blanket design and the hook design are appended to this report in the Appendices for maximum resolution and clarity. Refer to Appendix F.

5.2 Final Design Performance Evaluation

5.2.1 Prototype Design

To test the effects of the designed blanket solution a works-like prototype was constructed to apply during the testing phase. The concrete form that was constructed of ½” plywood and 2” * ⅝” planks with use of the UBC okanagan woodshop lab (refer to Appendix G for mold dimensions and relevant drawings). The prototype heating apparatus was designed around the dimensions of the constructed form. The following materials were used in the construction of the prototype blanket.

Materials And Equipment:

Nylon (40D 60” x 39”) fabric shell; polyethylene 4 mm sheet; TOPDURE JHSD 9’ pipe heating cable; plastic zip ties; gorilla tape; red HD nylon thread; construction blade & knife; sewing machine; HD polyurethane foam insulation

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The prototype construction began with the shaping of the moisture barrier polyurethane sheet. The sheet was cut to the dimensions given in Appendix G and used as the main mounting point for the remaining materials. Next, the foam insulation was wrapped with aluminum foil to increase heat radiation towards the testing mold sample. Cables were laid and temporarily held in place with Gorilla Tape before each section was also secured using zip ties through the foam and poly-sheet material. Finally, the external shell was measured and sewn together with a high durability thread via the sewing machine. One end was left open to slide the internals of the blanket into the shell. Minor aesthetic changes and sealing was performed with Gorilla Tape to improve final prototype visuals.

5.2.2 Prototype Testing

The testing procedure was created to evaluate the effects of a formwork heating apparatus on concrete curing in suboptimal winter conditions, to verify the need for an industry solution.

Materials and Equipment:

Three concrete samples (same mix design and batch); temperature and moisture-controlled curing room; winter simulated environment; heating apparatus for one cold temperature sample; wood molds for concrete samples; data recording sheet or software; Instron compressive strength testing machine; PPE (gloves, safety goggles, lab coat)

Procedure:

1. Sample Preparation:

   1. Prepare and mix the concrete according to standard guidelines.
   2. Pour the concrete into three identical molds, ensuring uniformity in sample size and compaction.
      - Testing Mold Design: 3x molds using 2x 0.5” planks
   3. Label the samples as follows:
      - Control Sample: Cured in a temperature and moisture-controlled room
      - Winter Sample: Cured in a controlled cold environment
      - Heated Winter Sample: Cured in a controlled cold environment with the prototype heating blanket
   4. Set concrete samples to allow for transportation to the cold simulated environment (Kelowna Curling Club).

2. Curing Process:

   1. Place the control sample in a temperature and moisture-controlled room at 21°C.
   2. Position the two cold samples in Kelowna Curling club rink exposed to low-temperature conditions (~4°C).
   3. Set up and activate the heating blanket for the heated winter sample, ensuring it operates consistently.

4. Record temperature of the environment.

3. Sample Removal and Testing:
   1. After three days, remove all samples from their molds carefully.
   2. Visually inspect the samples for surface irregularities, cracks, or other curing-related effects.
   3. Record final temperature data.
   4. Conduct a compressive strength test on each sample using a compressive testing machine, following standard testing procedures.
   5. Record the compressive strength results for each sample.

4. Data Analysis and Conclusion:
   1. Compare the compressive strength results of the three samples.
   2. Analyze the impact of temperature fluctuations and heating on curing and final concrete strength.

5.2.3 Prototype and Mold Documentation

For the purpose of resolution preservation and clarity the engineered drawings for the mold and the prototype designs are appended to this report in Appendix G.

5.2.4 Testing Results

Testing the concrete samples was performed post-curing with all of the samples being tested within an hour of removal from their respective environments. The apparatus used for compressive strength testing was an Instron compressive test apparatus. Each sample was mounted with the exact same protective rubber (to prevent force concentration on high points) and a metal plate to distribute the load evenly. Compressive increase was set to 2 KN/m and the test was run to a 22% decrease limit for stopping criteria. The curing time was divided into two stages, and tracked by the hour as shown in Table 5.2.4-1. The results of the compressive strength tests are shown in Table 5.2.4-2 and Figure 5.2.4-1 (also see Appendix H for individual stress test plots).

Table 5.2.4-1: Curing Time Tracking	
Curing Stage	Time (hours)
Setting	23.8
Cold Curing	66.53
Total Time	90.33

Table 5.2.4-2: Final Concrete Testing Results			
	Baseline Cure (21°C ambient temperature)	Cold Cure (4°C ambient temperature)	Blanket Cure (4°C ambient temperature)
Surface Area (m)	0.029715	0.029988	0.029715
Peak Load (KN)	233.012	197.213	313.704
Peak MPa Rating	7.841	6.576	10.55709
Relative Compressive Strength	0%	**-15.36%**	**34.63%**

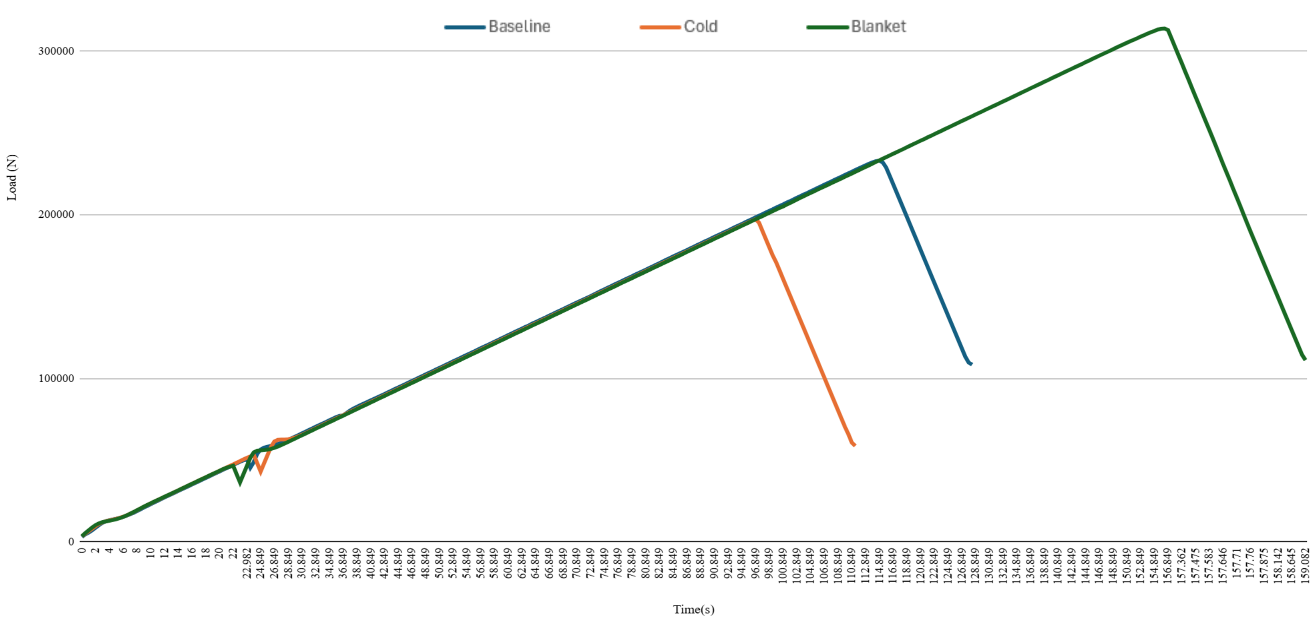

Figure 5.2.4-1 Compressive Testing Plot (load in Newtons versus time in seconds). The vertices at the apex of each line represent the failing point.

5.2.5 Results Discussion

This project aimed to prevent the loss of structural strength in concrete cured below CSA A23.1 temperature standards. We compared optimal curing (21°C) to cold conditions (4°C) with and without a heated blanket. The goal was for the blanket-supported sample to achieve compressive strength close to the ideally cured sample.

As shown in Table 5.2.4-2 and Figure 5.2.4-1, the heated blanket not only counteracted cold temperature weakening but also increased structural integrity beyond the ideally cured sample. Compressive strength improved by nearly 35% over the baseline (Table 5.2.4-2, column 2) and 37.7% over the cold condition sample. The test sample's post-cure temperature (Table 5.2.4-2, column 4) accelerated the curing process to approximately one week of standard conditions.

Cold curing effects were evident (Table 5.2.4-2, column 3), with a ~15% strength reduction at $T = 4$°C. Literature (Husem, 2005) aligns with our findings, indicating curing disruption below 10°C.

A minor anomaly in Figure 5.2.4-1 shows a load drop around 50kN, consistent across tests. This resulted from a 4mm rubber pad used to prevent stress concentrations, with failure occurring at that point. Since it appeared in all tests, it was attributed to the setup and disregarded.

6.0 Risk Assessment and Risk Mitigation

This section addresses the risks of curing concrete formwork in the winter. The local work environment was analyzed, focusing on high-frequency and high-impact risks, as identifying *all* associated direct/indirect risks is a large task and outside the scope of the project.

6.1 Risk Associated With the Problem

Inadequate curing in cold conditions can weaken structures, posing physical hazards (collapses, falling objects) and financial risks (demolition, delays) as discussed in Section 4.

6.2 Risks Associated With Failing to Deliver a Final Product

Since solutions already exist, risks mainly affect direct stakeholders. Financial risks include wasted consulting time, potential loss of the $500 CAD project fund, and possible grade penalties for an incomplete design. Exceeding the $1000 CAD budget was also a concern.

6.3 Risks Associated With Our Solution

Workers carry the risk of injury during installation. Installation hazards include overexertion, slips, trips and confined space risks (see Appendix *I*). Improper labor conditions can reduce productivity and extend timelines, leading to financial loss. The solution's weight may affect formwork stability and design aspects, such as the removable inlet, introduce failure points.

6.4 Ethical Risks

Building occupants rely on the solution's success to avoid harm. Environmental/societal concerns include material sourcing, durability, and disposal (see Section 4). A successful implementation could reduce construction costs and timelines. However, if successful, the solution could reduce construction costs and timelines, benefiting all stakeholders involved.

6.5 Risk Mitigation

Concrete strength testing ensures proper curing, while PPE, training, and site regulations minimize worker risks. Regular communication with Traine and faculty advisors helped ensure project success. Sustainable materials and a structured design process reduced environmental and financial waste.

Risks associated with not solving the problem were mitigated through ensuring the success of the project. To achieve this, the group participated in regular communication regarding project progress and bolstered such communication through close collaboration with the client and the faculty advisors. To mitigate societal risk/damage in the event of wide-scale use, efforts were made to ensure the product was made of sustainable and environmentally safe materials with a realistic lifespan and end-of-life disposal plan. Finally, care was made to fully conceptualize the design before generating the prototype to minimize budget waste on material procurement and fabrication. See Appendix *I* for the risk matrix and further information on risk assessment.

7.0 Overall Project Success

7.1 Alignment Between Initial Goals and Final Outcomes

The primary goal of this project was to develop a modular heating solution that maintains the temperature of freshly poured concrete within the CSA A23.1 standard range for winter curing conditions in Kelowna, BC. Additionally, the solution had to be cost-effective, energy-efficient, compatible with Peri gang formwork and easy to maintain.

Final outcomes:

- **Concrete strength improvement:** The developed prototype blanket exceeded expectations, increasing compressive strength by 35% over ideal curing conditions and 37.7% over cold conditions. Originally intended as a mitigation tool, the solution enhanced concrete performance, transforming it into an improvement technology rather than just a preventative measure.
- **Energy efficiency:** The heating system reduced power consumption by 44% per unit area compared to similar market products, aligning with stakeholder needs for cost-effectiveness and sustainability.
- **Compatibility and modularity:** The modular hooking system integrates with Peri gang forms, allowing scalability for larger curing areas without requiring costly solutions.
- **Cost effectiveness:** The entire project was completed for under $500 (see Appendix K.2), staying well below the $1000 CAD budget constraint while meeting all functional requirements and successfully conducting our prototype testing.
- **Field testing success:** The prototype was successfully tested at the Kelowna Curling Club (4°C environment), validating real-world effectiveness.
- The results of field testing indicate strong alignment with the initial goals, exceeding expectations in performance, efficiency, and affordability.

In particular, considering the product design of Section 5, it is estimated that one blanket will cost $133.50 CAD in materials. Adding 50% to this for production and overhead gives a rough pessimistic estimate of **$200 CAD per blanket**, which is 86.44% less expensive than a Powerblanket of similar size. This represents a considerable improvement in cost effectiveness.

7.2 Key Challenges, Obstacles, and Lessons Learned

Several challenges arose during the project, each requiring a targeted solution. Ensuring proper thermal behavior was the largest design challenge. It was addressed through an in depth material analysis and thermal simulation, ensuring proper heat retention and avoiding an overuse of electrical power. An increase of efficiency over competitor solutions was also a primary challenge; and achieved by tailoring the solution to Peri gang forms, which improved energy conservation over existing technologies like Powerblanket, reducing power consumption by 44% per unit area without compromising thermal effectiveness. Integration with Peri gang formwork required custom modifications compared to existing blanket technologies. A modular hooking system was developed to enable effective integration without altering the formwork, which is unique to the design team's product.

Experimental setup limitations became evident with a 50kN force dip anomaly in compression test data. This was traced to the failure of 4mm rubber pads used in testing, highlighting the need for future setups to use materials that isolate concrete performance from experimental setup artifacts.

Strict project deadlines necessitated efficient scheduling of material procurement, prototyping, and testing. Rigorous project management, including regular meetings, ensured all deliverables were completed on time. Key lessons learned included recognizing that temperature control could enhance concrete strength beyond expectations, suggesting new opportunities for curing improvements. Additionally, early collaboration with stakeholders like Traine Construction ensured practical real-world applicability, emphasizing the importance of stakeholder engagement in the development of our design.

8.0 Conclusion

This capstone project applied multidisciplinary engineering knowledge to develop an effective and economical solution for low-temperature concrete curing. The project successfully met all objectives, requirements, and constraints, with testing results surpassing expectations. The final heating blanket prototype enhanced concrete strength, reduced energy consumption, and remained cost-effective while integrating seamlessly with simulated formwork. Compared to a commercially available Powerblanket of similar size, the developed design was 86.44% less expensive and consumed 44% less power. Performance tests showed a nearly 35% increase in strength over the ideal baseline and a 37.7% increase over concrete cured in cold conditions, confirming its effectiveness. The selected materials provided a total surface R-value of 3.63 $ft^2 \cdot °F \cdot hr/Btu$, further improving insulation and thermal efficiency.

Collaboration with Traine Construction & Development played a key role in refining the design and validating performance criteria, ensuring industry relevance. Their involvement and feedback demonstrated satisfaction with the team's efforts (Appendix J). The challenges encountered offered valuable learning experiences, highlighting the importance of multidisciplinary engineering approaches.

Beyond ensuring compliance with CSA A23.1 standards, the project demonstrated that thermal control can actively enhance concrete properties. While further refinements are possible (see Appendix J), the current prototype highlights the impact of student-driven engineering design on real-world applications.

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Appendix A - CSA A23.1 Relevant Standards

Traine Construction adheres to the requirements set out by CSA A23.1, and specifies the following requirements for curing concrete in cold weather (as per Section 1.1):

1. Forecasted Air Temperature at or below 5 degrees Celsius

    A) The aggregate or mixing water shall be heated to maintain a minimum concrete temperature of 10 degrees Celsius at point of pour.
    B) Concrete shall not be placed on or against any surface
    C) Contractor shall be prepared to cover slabs if an unexpected drop in air temperature should occur.
    D) Concrete exposure classes requiring curing type 1 (basic) in accordance with CSA A23.1 shall have the concrete temperature maintained above 10 degrees Celsius for at least 7 days or until the concrete reaches 70% of specified strength.

2. Forecasted Air Temperature below 2 but not below -4 degrees Celsius

    A) Forms and steel shall be free from ice and snow.
    B) The aggregate or mixing water shall be heated to give a minimum concrete temperature of 10 degrees Celsius at point of pour.
    C) Concrete shall not be placed on or against any surface which is at a temperature of less than 5 degrees Celsius.
    D) Slabs shall be covered with canvas or similar, kept a few inches clear of surface.
    E) In windy weather, the storey below the slab shall be enclosed.
    F) Protection shall be maintained for at least the specified curing period.
    G) Concrete temperature shall be maintained above 10 degrees Celsius for the specified curing period.

3. Forecasted Air Temperature below -4 degrees Celsius

    A) The Story below shall be enclosed and artificial heat provided. Heating to be started at least one hour ahead of pouring and maintained for a minimum of the specified curing period.
    B) Temperature of the concrete at all surfaces shall be kept at a minimum of 20 degrees Celsius for 3 days or 10 degrees for 7 days. Concrete shall be kept above freezing temperatures until it reaches 70% of its specified strength.
    C) An enclosure must be constructed so that air can circulate outside the outer edges and members.
    D) Reinforcing to be covered and warmed to maintain its temperature at 0 degrees Celsius or higher at the time of concrete placement.

Appendix B - Peri Gang Form Volume

Figure B-1 shows an example of a Peri gang form. It illustrates the complexity that is possible using such structures. This is considered in Section 3.2.

Figure B-1: An example of gang forms taken from the Peri website (Wall Formwork, 2024).

Traine construction and the present researchers have agreed that the scope must be limited to the gang forms they use in practice. Sheets 2 and 3 in Appendix F.1 show dimensions of a typical form. The depth dimension is not shown but assumed typical: 8”. Therefore, the volume of concrete contained by a single 16’ gang form is:

$$V_{form} = 16' \bullet 11' - 6" \bullet 8" = 4.88m \bullet 3.51m \bullet 0.20m = 3.474\, m^3$$

Appendix C - Additional Material Selection Analysis Information

Appendix C includes the intermediate steps of the material selection process from Section 3.4, providing a detailed breakdown of the approach taken. The process begins with an analysis of the current market to determine approximate prices, weights and available materials. Following this, material property definitions are established and an analysis of free volume and density is conducted to assess mass factors. The selection process then progresses through insulative and protective skin material screening with each material being evaluated based on its performance. The materials are ranked according to key properties which are then used in the decision matrices for both the insulative core and protective skin. These decision matrices are essential tools for systematically comparing the materials and identifying the most suitable candidates.

Appendix C.1 - Current Market Examples

Examples of current insulating blanket providers and their products' material components and properties (from Section 3.4.2). It is to be noted that not all researched providers were listed so as to conserve space, but the top few will be provided below.

Norseman solutions provide two sets of insulating blankets. The difference between the two are their thicknesses. The thinner blanket 3/8" has a corresponding R-value of 2.8 and the thicker blanket 1/2" has a corresponding R-value of 4.0, both with air spaces. Both blankets are made from PE foam cores; the protective skin was not provided (Norseman Solutions, 2024).

Steel Safety Guard provides a blanket that is approximately ½" thick and produces an R-value of 5.7. The protective skin is made from Polyethylene and has a PE microcell foam core (Steel Safety Guard, 2024).

FM Industrial offers a wide range of insulating blankets with thicknesses ranging from 4 mm to 12 mm and corresponding R-values from 0.62 to 1.82. The protective skin is made of polyethylene while the insulating core consists of closed-cell insulation (FlexiMake Industrial, 2024).

ALCO offers two types of insulating blankets, differentiated by thickness. The thinner blanket, measuring ⅜", has a surface R-value of 1.35 which increases to 3.3 when combined with an air space. The thicker blanket, measuring ½", has a surface R-value of 1.5 rising to 3.43 with an air space. Both blankets feature a protective skin made of woven polyethylene and an insulating core composed of closed-cell polyethylene foam (ALCO Construction Covers, n.d.).

Appendix C.2 - Material Property Definitions

Thermal Properties (Section 3.4.3.2):

- Thermal Conductivity: is a measure of how well a material transfers heat (GRANTA, 2023, Version 23.2.1).
- Glass Transition Temperature: is a property of non-crystalline solids, which do not have a sharp melting point. It characterizes the transition from true solid to viscous liquid in these materials (GRANTA, 2023, Version 23.2.1).
- Maximum Service Temperature: highest temperature at which material can be used for an extended period without significant problems, such as oxidation, chemical change, excessive creep, loss of strength, or other primary property for which the material is normally used (GRANTA, 2023, Version 23.2.1).
- Minimum Service Temperature: at which a material can be used without becoming too brittle. 'Too brittle' means 'too brittle in comparison to its brittleness at room temperature' i.e. relative brittleness rather than an absolute measure (GRANTA, 2023, Version 23.2.1).
- Flammability: rating on a four-point scale. These are the approximate correspondences to LOI and UL-94 at 1.6 mm thickness (GRANTA, 2023, Version 23.2.1).

Mechanical Properties:

- Tensile Strength: stress required to break the material (GRANTA, 2023, Version 23.2.1).
- Shear Strength: strength of a material loaded in shear (GRANTA, 2023, Version 23.2.1).
- Shear Modulus: initial, linear elastic slope of the stress-strain curve in shear. (GRANTA, 2023, Version 23.2.1).
- Specific Strength: a measure of the resistance to elastic deformation (Young's modulus) per unit of mass, or density (GRANTA, 2023, Version 23.2.1).
- Elongation: extension in length of tensile specimen at break as (%) of original length (GRANTA, 2023, Version 23.2.1).

- Densification Strength: nominal compressive strain at which cell walls are forced into contact with each other, when the stress-strain curve rises steeply (GRANTA, 2023, Version 23.2.1).
- Fatigue Strength: maximum cyclic stress for which the material survives 107 (10 million) cycles. For some classes of materials this is regarded as the 'endurance limit', the stress at which the material has infinite fatigue life (GRANTA, 2023, Version 23.2.1).
- Vickers Hardness: is measured using a square based, diamond pyramid. The load is increased from 1 kg to 100 kg and then held for 10–15 seconds. The hardness is derived from the force applied and the area of the indentation. It can be used to test soft to very hard materials. (GRANTA, 2023, Version 23.2.1).
- Toughness: a measure of a material's ability to absorb energy during fracture (GRANTA, 2023, Version 23.2.1).

Sustainability and Ethical Properties:

- Density: mass per unit volume (GRANTA, 2023, Version 23.2.1).
- Cost: The monetary cost of a product with given mass or volume.
- Durability: a materials resilience to acids, oxidation and UV radiation (GRANTA, 2023, Version 23.2.1).
- Embodied Energy: energy required to make 1 kg of the material from its ores, feedstocks, or recycled materials (GRANTA, 2023, Version 23.2.1).
- CO2 Footprint: the CO2-equivalent mass of greenhouse gases (kg CO2e), in kg, produced and released into the atmosphere as a consequence of the production of 1 kg of the material (GRANTA, 2023, Version 23.2.1).
- Water Usage: fresh water required to make 1 kg of the material (GRANTA, 2023, Version 23.2.1).
- End of Life: Considers different methods on how to deal with the product at the end-of-life stage.
    - Recyclability: indicates whether a material can be recycled into a grade of similar quality (GRANTA, 2023, Version 23.2.1).
    - Down-cyclability: indicates whether a material can be reprocessed into material of lower quality or performance (GRANTA, 2023, Version 23.2.1).

- Combustion Recovery: the amount of carbon dioxide released (in kg) when one kilogram of material is fully combusted (GRANTA, 2023, Version 23.2.1).
- Biodegradability: indicates whether a material is biodegradable (GRANTA, 2023, Version 23.2.1).
- Landfill: indicates whether a material can be safely deposited in landfill sites (GRANTA, 2023, Version 23.2.1).

Appendix C.3 - Free Volume and Density Analysis

Using the data from Table 3, described in the Rout and Singh study (Section 3.4.3.3), an average porosity percentage was found to be 39.19% which can be used as a free volume factor, thus density for bulk materials can be accounted for. However, to ensure the product adheres to the design constraints the porosity percentage was reduced to 35%. The percentage was implemented in the equation below to correct for effective density.

$$\rho_{effective} = \rho_{bulk}\, x\, (1 - Porosity) \quad (Eq.\ 3.2.1)$$

Regarding the mass and geometry consideration, area is a fixed constraint because the product must fit the Peri gang forms, as detailed in Appendix B. However, GRANTA does not account for geometry so area cannot be treated as a variable. To calculate the insulating blanket's overall mass, which is the product of density and volume, the total surface area (SA) must be determined. The blanket must cover the curing concrete and Peri gang forms, with the area divided into two sections each with a surface area of 13’-2”x3’-2”.

The constraints state the product must be lightweight and easy to handle. According to Occupational Health and Safety Regulations of Canada, Section 14.49, if an employee is to lift more than 45 kg the employer must train the employee in safe lifting methods and in a work procedure suitable to the employee’s bodily condition and the workplace conditions (Legislative Services Branch, 2024). Considering this information, the maximum mass the product can be is 45 kg so long as the employee’s chief position is not office work.

Assuming the overall product thickness (*t*) range of the blanket section (13’-2”x3’-2”) is to be approximately ½” to 1” thick, the volume range of the product units would be:

$$V = SA(t) = 0.047m^3\ to\ 0.095m^3$$

Finally, by considering mass and geometry, a density range for the material can be determined. The mass of the material limitations combined with its geometry allows for the calculation of its density. Once the appropriate density range is identified it can be input into GRANTA for further material screening, helping to narrow down suitable materials that meet the required specifications. Therefore, the approximate overall product density range is assumed to be:

$$\rho_{mean\ range} = \frac{m}{V} = 475.5\frac{kg}{m^3}\ to\ 951.0\frac{kg}{m^3}$$

However, the two product components must be categorized with separate density ranges as the protective skin and insulative core serve distinct functions, as outlined in Section 3.4.3.1. It can be assumed that the protective skin will have a higher density, as materials with higher strength typically exhibit higher densities whereas insulating materials generally have lower densities.

Based on the research in Appendix C.1, similar products typically have an overall thickness of just over ½ inch, with a protective skin thickness of 6 mm (~15/64 inch) or 3 mm per side (~7/64 inch) and an insulative thickness of ½ inch (12.7 mm). From these values the approximate maximum densities can be determined. To account for design flexibility and ensure the maximum weight limit is not exceeded a more conservative approach was taken, assuming a protective skin thickness of 8 mm (5/16 inch) and an insulative core thickness of 19.1 mm (¾ inch). This extra thickness was incorporated to provide additional room for adjustments while reducing the maximum density.

$$\rho_{overall}^{eff.} = \frac{m}{V} = 446.5\frac{kg}{m^3}$$

$$\rho_{overall}^{max,\ bulk} = \frac{\rho_{overall}^{eff.}}{(1-Porosity)} = 686.9\ kg/m^3$$

Since the densities of the protective skin and insulative core were not yet determined, a range of densities was established for input into GRANTA to ensure the product adheres to mass restrictions and is proportional to the assumed volumes. The density distribution range was determined using the following formulae:

$$m_{total} = m_{prot.\ skin} + m_{insl.\ core} \quad (Eq.\ 3.4.2)$$

$$(\rho V)_{total} = (\rho V)_{prot.\ skin} + (\rho V)_{insl.core} \quad (Eq.\ 3.4.3)$$

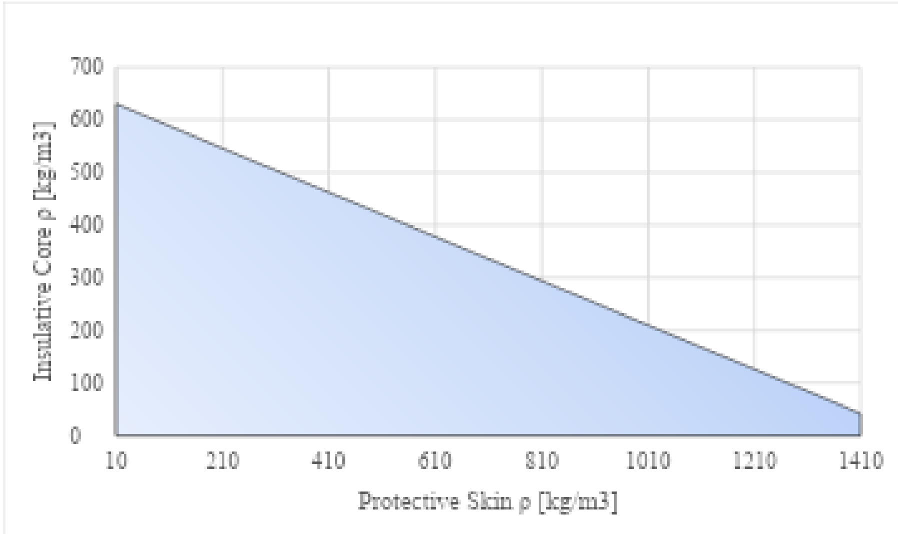

Figure C.3-1: Density distribution of the protective skin and insulative core where the shaded area indicates potential density combinations to meet design weight constraints.

Appendix C.4 - Insulative Core Material Screening

The figures below illustrate how GRANTA filters out materials for the insulative core that do not meet the specified criteria (Section 3.4.3.5). Initially, materials that failed to meet basic thermal and mechanical performance standards or cost constraints were eliminated. As the analysis progressed, more stringent requirements were applied in stages. This step-by-step filtering process ensured that only the most suitable materials remained for further consideration.

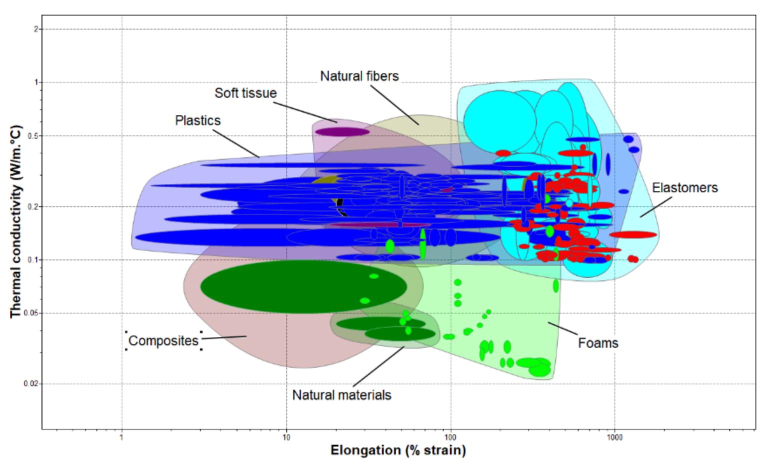

Figure C.4-1: Thermal conductivity vs elongation with moderate applied material contains. (GRANTA, 2023, Version 23.2.1)

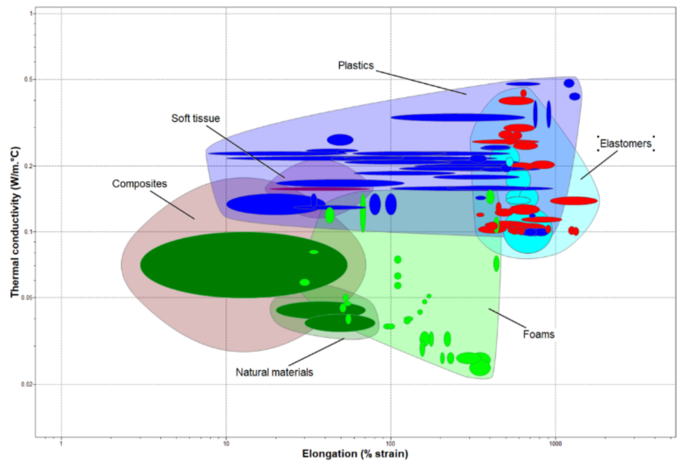

Figure C.4-2: Thermal conductivity vs elongation with high applied material contains. (GRANTA, 2023, Version 23.2.1)

Appendix C.5 - Protective Skin Material Screening

Similarly to Appendix C.4, the figures below for the protective skins demonstrate the gradual elimination of materials that did not satisfy the required criteria (Section 3.4.5). The filtering process began with broad constraints, such as cost and mechanical properties, and then became more refined, considering factors like sustainability and ethical considerations. Through each stage, materials were progressively removed, leaving only those that met all necessary performance standards for the protective skin.

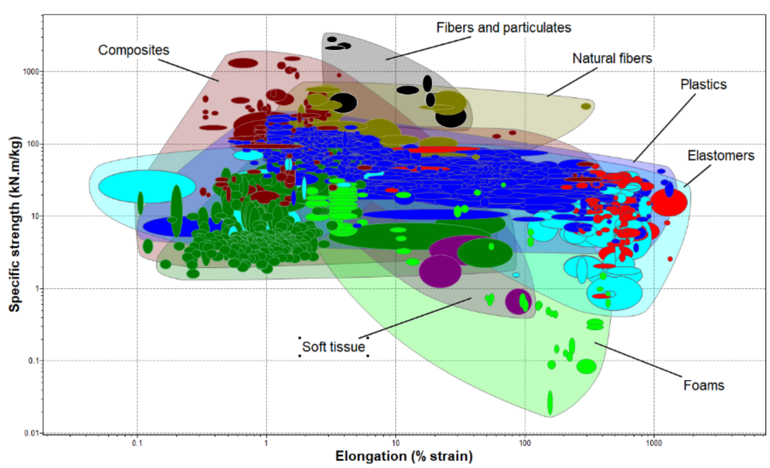

Figure C.5-1: Specific strength vs elongation with material families labeled. (GRANTA, 2023, Version 23.2.1).

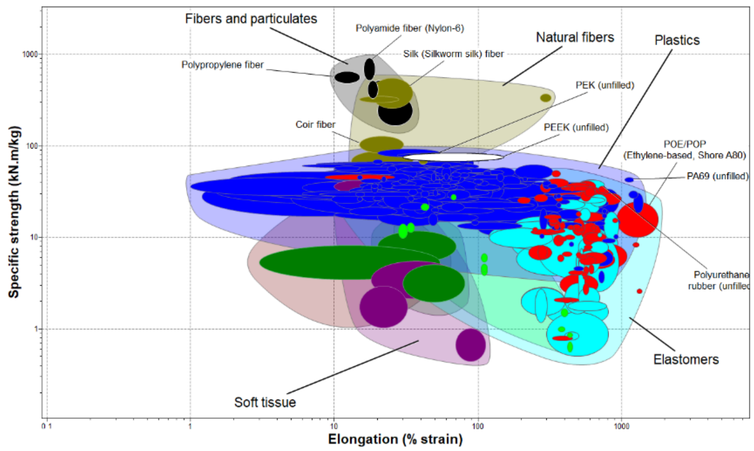

Figure C.5-2: Specific strength vs elongation with additional constraints. Material families and some materials labeled. (GRANTA, 2023, Version 23.2.1)

Appendix C.6 - Property Ranking

The next step involves setting appropriate constraint limits and incorporating them into GRANTA to refine material selection by eliminating non-compliant options (see Section 3.4.4.2). While the constraints in Table 3.4.3.1-1 are identical for both layers, the imposed limits vary based on their specific objectives. The protective skin prioritizes strength and is expected to use a stronger, thinner material, whereas the insulating core emphasizes thermal resistance and consists of thicker, more thermally resistant materials. Additionally, the properties in Table 3.4.3.4-1 were considered but ranked separately based on their relevance to each layer.

Table C.6-1: Property Ranking for weighted Distribution			
Insulative Core		Protective Skin	
Property	Weight	Property	Weight
Thermal Conductivity	1	Tensile Strength	1
Cost	.85	Shear Modulus	.9
Elongation	.75	Specific Strength	.9
Density	.75	Elongation	.9
CO2 Footprint	.63	Density	.75
Embodied Energy	.63	Cost	.75
End-of-Life	.63	Thermal Conductivity	.7

Flammability	.6	CO2 Footprint	.7
Tensile Strength	.6	Embodied Energy	.7
Shear Strength	.5	End-of-Life	.7
Specific Strength	.5	Abrasion Resistance	.6
Densification Strength	.5	Flammability	.5
Toughness	.4	Durability	.4
Glass Trans Temp	.35	Glass Trans Temp	.3
Max/Min Op Temp	Pass/Fail	Max/Min Op Temp	Pass/Fail

It should be noted that some ranked properties may be equivalent, and any properties found to be significantly detrimental or below the design requirements will be considered and discussed in Section 3.4, Section 4.3, Appendix C.7 and Appendix C.8.

Appendix C.7 - Insulative Core Material Pool and Decision Matrix

Materials within the same family typically exhibit similar properties due to their molecular similarities though they may vary in density (Section 3.4.4.2). Therefore, the materials listed in Table 3.4.4.1-1 were selected from polymer foams, elastomers, thermoplastics, fiber and natural fiber families focusing on those with the most favorable thermal conductivity characteristics to meet the design objectives.

For properties where a minimum value was desirable such as thermal conductivity, the normalization method involved dividing the minimum value by each material's thermal conductivity and then multiplying the resulting ratio by 5, with 5 representing the highest ranking. The rankings from 0 to 5 are colour coded for visual ease as can be seen below in Table C.7-1. For properties where a maximum value was desirable such as tensile strength, the corresponding material's tensile strength was divided by the total population's tensile strength value and then multiplied by 5. Lastly, for properties with an optimal value (often referred to as the "Goldilocks" zone) the absolute ratio difference from the ideal value was calculated and normalized to determine how closely the material approached the optimal performance range.

In cases where specific physical properties were not provided in GRANTA those missing material properties were excluded from the weighted calculations. This ensured that only materials with complete data were considered, maintaining the integrity of the analysis and the final material selection process.

Table C.7-1: Ranking Colour Code			
Excellent	5	Poor	2
Good	4	Sub-poor	1
Moderate	3	Terrible	0

Table C.7-2: Insulating Core Weighted Thermal Properties Decision Matrix					
Materials	Thermal Conductivity	Glass Transition Temp.	Max/Min Serv. Temp.	Flammability	Overall
PUR Foam (flex., CC, 0.16)	5	4.9	PASS	3	5
PUR Foam (flex., CC, 0.08)	4.62	4.9	PASS	3	4.78
PUR Foam (elast, OC, 0.024)	4.53	4.4	PASS	3	4.62
PUR Filter Foam (OC, 0.019)	3.69	4.9	PASS	3	4.25
Cork (Low Density)	3.19	1.02	PASS	5	3.77
PE LD (C-L, CC, 0.018)	3.43	2.42	PASS	1	2.85
Tissue Paper (cellulose)	1.6	2.1	PASS	1	1.74
Butyl (IIR, unreinforced)	1.14	3.73	PASS	1	1.85
SBS (Shore A50)	1.19	3.985	FAIL	1	0
PC+PL T-A	1.17	0.3	PASS	3	1.76
Leather	0.76	0	PASS	3	1.46
Acrylic Fiber	0.57	0.83	PASS	1	0.86
Wool	0.48	0.93	NA	3	1.51

Table C.7-3: Insulating Core Weighted Mechanical Properties Decision Matrix								
Materials	Tensile Str.	Shear Str.	Spec. Str.	Elong.	Densif. Str.	Fatigue Str.	Though.	Overall
PUR Foam (flex., CC, 0.16)	1.35	2.4	3	5	3.76	1.8	4.29	3.81
PUR Foam (flex., CC, 0.08)	0.71	1.38	3.4	5	4.27	0.9	1.56	3.25
PUR Foam (elast.c, OC, 0.024)	0.75	0.2	1.8	3.29	5	1.2	1.21	2.55
PUR Filter Foam (OC, 0.019)	0.44	0.11	1.2	3.14	4.92	0.6	0.33	2.14

Cork (Low Density)	4.25	5	5	0.79	4.15	4.5	2.94	3.76
PE LD (C-L, CC, 0.018)	1.4	0.63	5	1.36	4.92	1.75	2.69	2.72
Tissue Paper (cellulose)	5	NA	5	0.35	NA	5	5	2.70
Butyl (IIR, unreinforced)	5	NA	0.01	5	NA	5	5	3.65
SBS (Shore A50)	5	5	5	5	NA	5	5	5
PC+PL T-A	5	5	5	5	NA	5	5	5
Leather	5	NA	5	0.66	NA	5	5	2.88
Acrylic Fiber	5	NA	NA	0.39	NA	NA	NA	1.12
Wool	5	NA	NA	0.34	NA	NA	5	1.55

Table C.7-4: Insulating Core Weighted Sustainability Properties Decision Matrix

Materials	Density	Cost	Embod. Energy	CO2 Footpr.	Water Usage	End-of-Life	Comb. Recov.	Overall
PUR Foam (flex., CC, 0.16)	0.56	0.74	3.94	2.33	2.12	3	2.44	2.52
PUR Foam (flex., CC, 0.08)	1.13	1.5	3.94	2.33	2.12	3	2.44	2.82
PUR Foam (elast.c, OC, 0.024)	3.75	1.78	3.94	2.33	2.12	3	2.44	3.44
PUR Filter Foam (OC, 0.019)	4.74	1.05	3.94	2.33	2.12	3	2.56	3.48
Cork (Low Density)	0.60	1.50	2.97	5	0.89	4	2.22	2.95
PE LD (C-L, CC, 0.018)	5	4.39	3.76	2.83	2.74	3	5	4.71
Tissue Paper (cellulose)	0.33	5	5	5	5	5	2.28	5
Butyl (IIR, unreinforced)	0.10	5	3.68	2.35	4.90	3	4.89	4.10
SBS (Shore A50)	0.10	4.02	4.17	2.63	2.51	4	4.67	3.73
PC+PL T-A	0.08	2.68	2.99	1.74	3.65	4	3.22	3.12
Leather	0.10	0.65	3.27	2.35	0.54	4	2.22	2.16
Acrylic Fiber	0.12	3.17	2.97	1.54	5.43	4	1.91	3.41
Wool	0.11	3.87	5	5	0.37	4	2.28	3.69

The tables above (Tables C.7-2 to C.7-4) illustrate the normalized values for mechanical, thermal and sustainability properties. This standardization enabled a direct comparison between materials, allowing the selection process to focus on the top-performing candidates based on critical attributes.

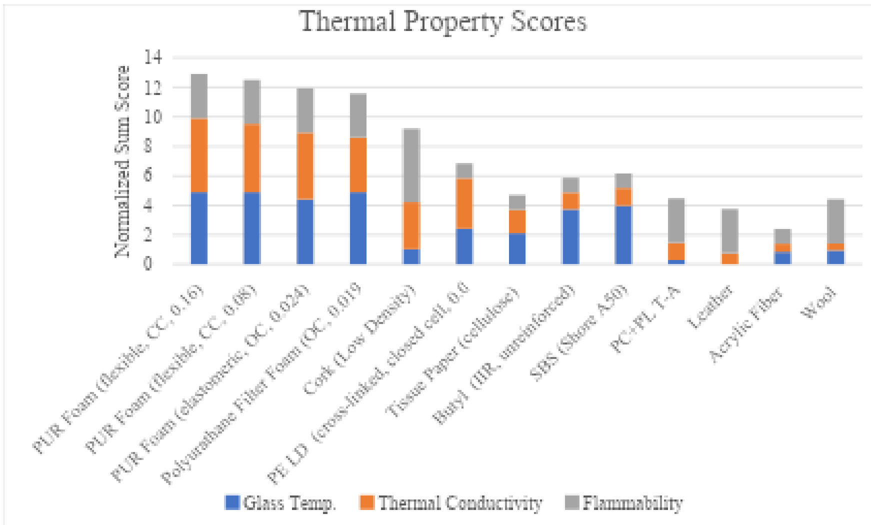

Figure C.7-1: Normalized thermal properties on a 0 to 5 scale summed together for overall score.

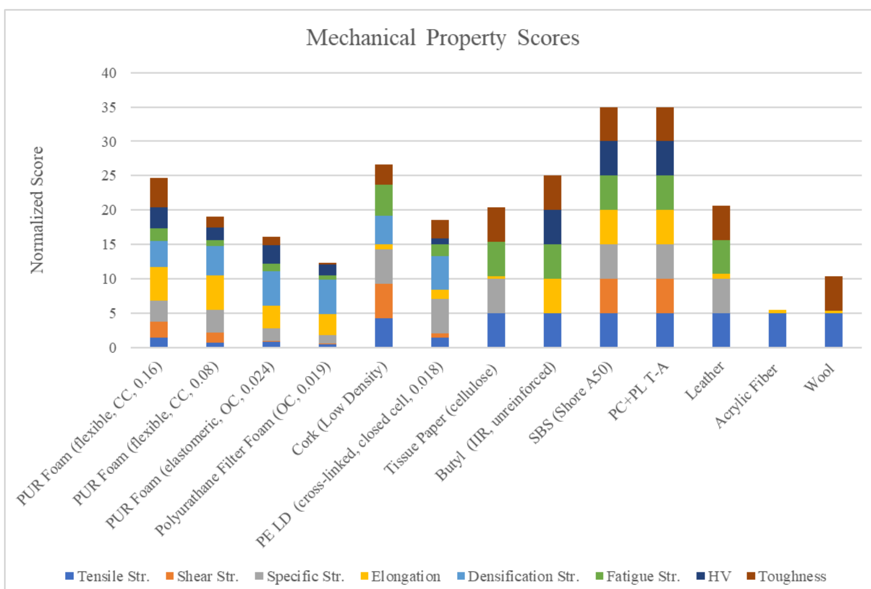

Figure C.7-2: Normalized Mechanical properties on a 0 to 5 scale summed together for overall score.

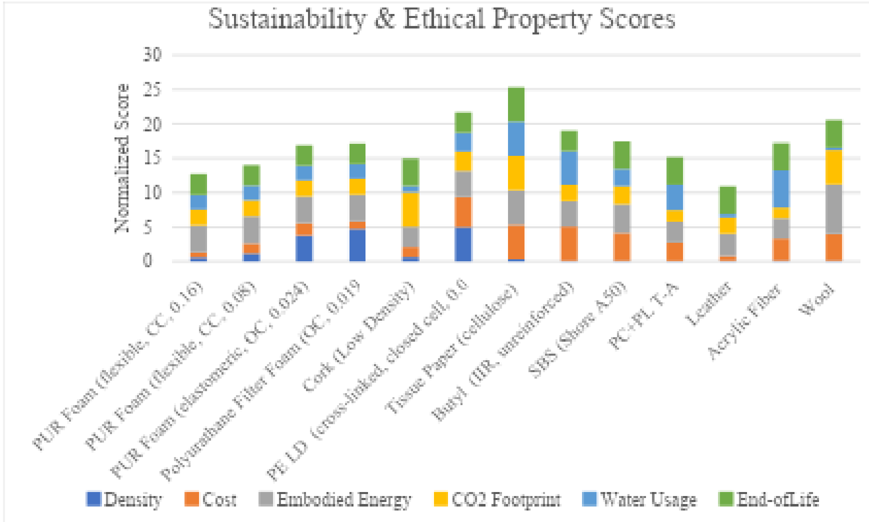

Figure C.7-3: Normalized sustainable and properties on a 0 to 5 scale summed together for overall score.

Figures C.7-1 to C.7-3 illustrate the different material properties relative to each other, providing a visual representation of how each material performs across various attributes such as thermal conductivity, tensile strength, flexibility, density, cost and end of life procedures. These graphs allow for easy comparison of the materials based on their individual properties.

Table C.7-5: Considering All Insulating Core Weighted Property Values Decision Matrix

Materials	Thermal Properties	Mechanical Properties	Sustainability	Overall	Rank
PUR Foam (flex., CC, 0.16)	5	3.81	2.52	5	**1**
PUR Foam (flex., CC, 0.08)	4.78	3.25	2.82	4.79	**2**
PUR Foam (elast, OC, 0.024)	4.62	2.55	3.44	4.68	**3**
PUR Filter Foam (OC, 0.019)	4.25	2.14	3.48	4.36	7
Cork (Low Density)	3.77	3.76	2.95	4.62	4
PE LD (C-L, CC, 0.018)	2.85	2.72	4.71	4.54	5
Tissue Paper (cellulose)	1.74	2.70	5	4.16	9
Butyl (IIR, unreinforced)	1.85	3.65	4.10	4.23	8
SBS (Shore A50)	0	5	3.73	3.85	10
PC+PL T-A	1.76	5	3.12	4.36	6
Leather	1.46	2.88	2.16	2.87	12

Acrylic Fiber	0.86	1.12	3.41	2.38	13
Wool	1.51	1.55	4.08	3.15	11

Table C.7-5 showcases the combined normalized values of all considered properties, serving as the basis for Figure 3.4.4.2-1 which visually represents the top-performing materials for the insulating core. The table also ranks the top three materials, highlighting those that best satisfy the selection criteria. This comprehensive assessment enables a clear comparison of candidates by integrating mechanical, thermal, sustainability and ethical properties.

Appendix C.8 - Protective Skin Material Pool and Decision Matrix

The same procedures outlined in Appendix C.7 were followed, with the primary difference being the adjustment of the decision matrices' weighted values to align with the functionality requirements of the protective skin as specified in Table C.6-1 (Section 3.4.5.2). Additionally, the same ranking and color-coding procedure illustrated in Table C.7-1 was applied to ensure consistency in evaluating and visualizing the results.

Table C.8-1: Protective Skin Weighted Thermal Properties Decision Matrix

Materials	Thermal Conductivity	Glass Transition Temp.	Max/Min Serv. Temp.	Flammability	Overall
Polyamide (PA6, Nylon-6)	2.96	2.5	PASS	4	3.95
Polyester Fiber (Dacron)	5	2	PASS	4	5
Polypropylene Fiber	5	4	PASS	1.5	4.47
Cellulose fiber (Rayon)	5	NA	PASS	1.5	3.48
Acrylic Fiber (PAN)	3.45	1.1	FAIL	1.5	2.87
Wool Fiber	2.9	1.2	PASS	4	3.60
Coir Fiber	0	0	PASS	1.5	0.61
PEEK	2.9	0.1	PASS	5	3.74

Table C.8-2: Protective Skin Weighted Mechanical Properties Decision Matrix

Materials	Tensile Str.	Shear Mod.	Specific Str.	Elongation	Abras. Resist.	Durab.	Overall
Polyamide (PA6, Nylon-6)	5	4.41	5	3.18	4	3.13	5
Polyester Fiber (Dacron)	3.96	4.41	3.25	4.18	4	4.17	4.68

Polypropylene Fiber	3.18	1.18	3.96	2.27	2.50	4.43	3.28
Cellulose fiber (Rayon)	2.55	1.79	2.90	3.36	1	0.83	2.68
Acrylic Fiber (PAN)	1.88	5	1.81	5	4	3.91	4.12
Wool Fiber	1.03	3.38	0.49	4.36	2.50	2.60	2.75
Coir Fiber	1	5	0.73	4.09	2.50	2.60	3.10
PEEK	0.64	4.09	0.52	5	2.50	5	3.20

Table C.8-3: Protective Skin Weighted Sustainability Properties Decision Matrix

Materials	Density	Cost	Embod. Energy	CO2 Footpr.	Water Usage	End-of-Life	Comb. Recov.	Overall
Polyamide (PA6, Nylon-6)	4.01	3.22	1.83	0.68	1.12	4	4.57	2.64
Polyester Fiber (Dacron)	3.30	5	2.71	1.18	1.56	4	3.35	3.43
Polypropylene Fiber	5	5	3.35	2.92	5	4	5	5
Cellulose fiber (Rayon)	4.01	2.83	2.69	1.51	0.88	2	0	2.13
Acrylic Fiber (PAN)	3.88	2.94	2.03	0.89	1.80	4	2.01	2.52
Wool Fiber	3.49	3.59	5	5	0	3	2.40	2.73
Coir Fiber	3.86	5	5	5	0	3	1.71	3.00
PEEK	3.49	0.13	0.81	0.35	0.21	4	3.65	1.69

The following three figures (Figures C.8-1 to C.8-3) show the property distribution for each property category before the weights were applied. These figures illustrate how each material performs relative to the thermal, mechanical and sustainable properties providing a clear overview of their distribution prior to the weighting process.

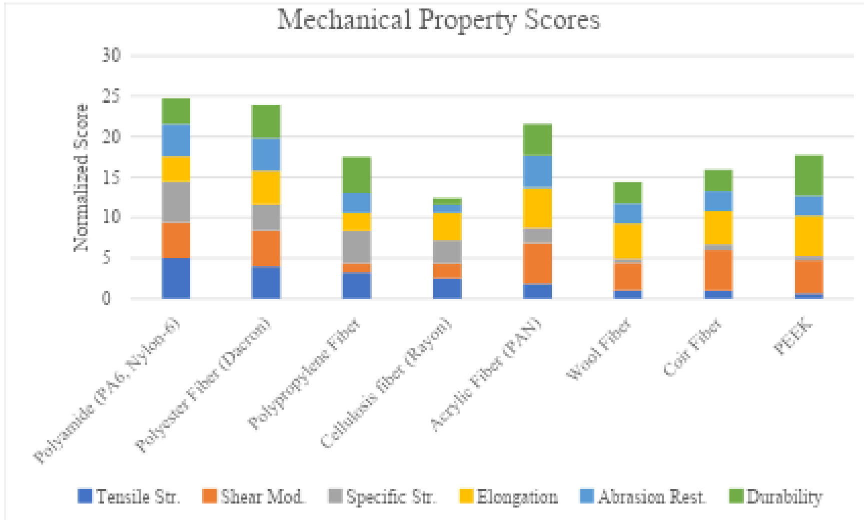

Figure C.8-1: Normalized Mechanical properties on a 0 to 5 scale summed together for overall score.

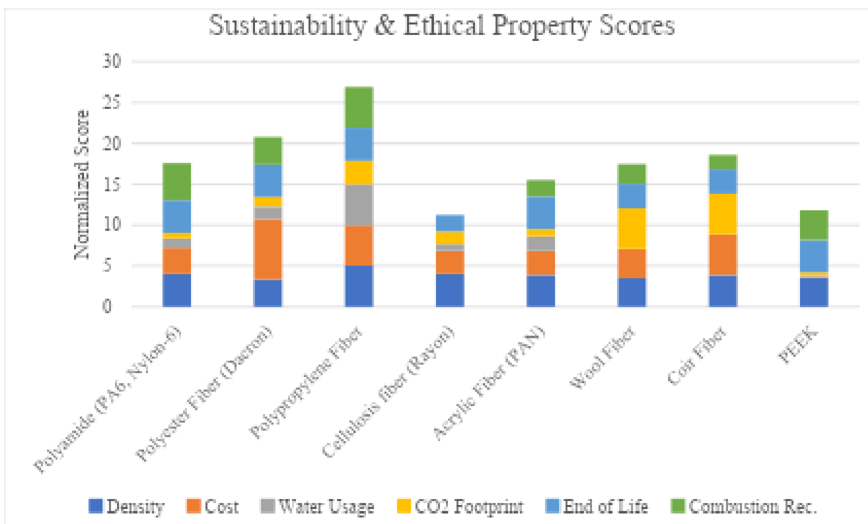

Figure C.8-2: Normalized Sustainable & Ethical properties on a 0 to 5 scale summed together for overall score.

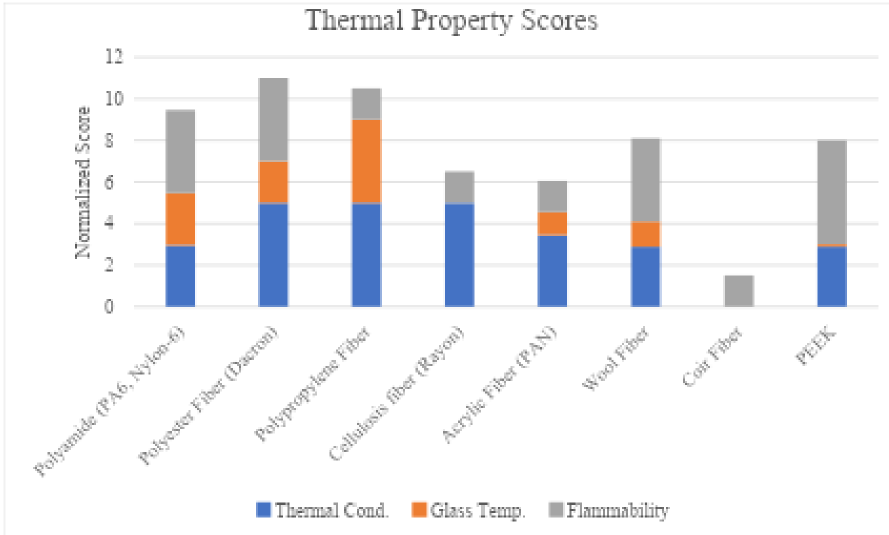

Figure C.8-3: Normalized Thermal properties on a 0 to 5 scale summed together for overall score.

Table C.8-4: Considering All Protective Skin Weighted Property Values Decision Matrix

Materials	Thermal Properties	Mechanical Properties	Sustainability	Overall	Rank
Polyamide (PA6, Nylon-6)	4.71	5	2.64	4.94	**2**
Polyester Fiber (Dacron)	4.40	4.68	3.43	5	**1**
Polypropylene Fiber	3.09	3.28	5	4.55	4
Cellulose fiber (Rayon)	2.53	2.68	2.13	2.93	8
Acrylic Fiber (PAN)	5	4.12	2.52	4.65	**3**
Wool Fiber	2.59	2.75	2.73	3.22	6
Coir Fiber	2.92	3.10	3.00	3.60	5
PEEK	3.01	3.20	1.69	3.16	7

Table C.8-4 showcases the combined normalized values of all considered properties, serving as the basis for Figure 3.4.5.2-1 which visually represents the top-performing materials for the protective skin. The table also ranks the top three materials, highlighting those that best satisfy the selection criteria. This comprehensive assessment enables a clear comparison of candidates by integrating mechanical, thermal, sustainability and ethical properties.

Appendix D - Parameter Variations with Respect to Thickness

The following section presents additional figures pertaining to Section 3.5, which examined the top material candidates through an analysis of mass, cost and R-value. These figures illustrate the variation of these parameters as the thickness of each material is increased. The data presented in these figures facilitated the determination of an optimal combination of insulative core thickness, protective skin thickness and the corresponding materials utilized. The analysis enabled the selection of configurations that maximize performance while minimizing both weight and cost.

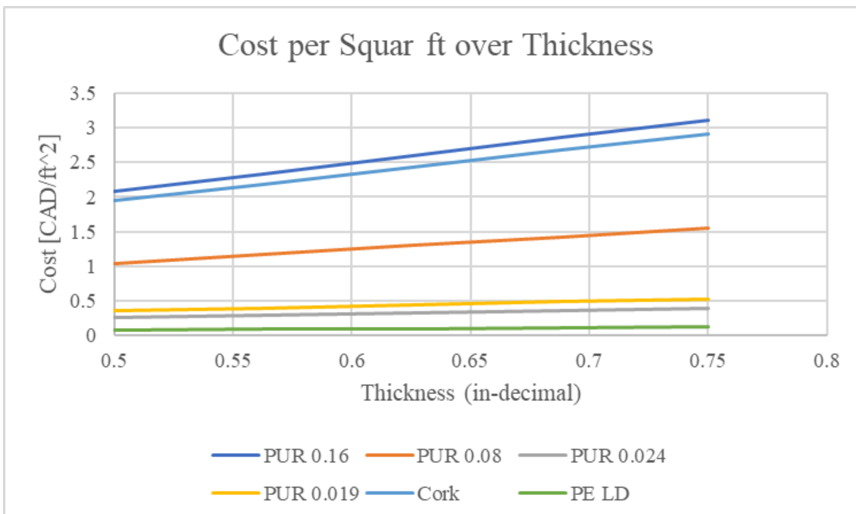

Figure D-1: Cost per square foot of each material of interest for the insulative core.

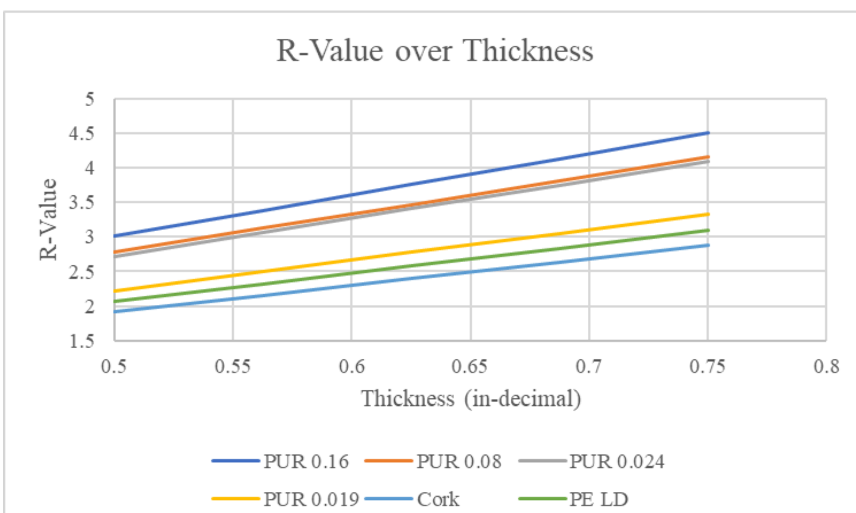

Figure D-2: R-Value of each material of interest for the insulative core.

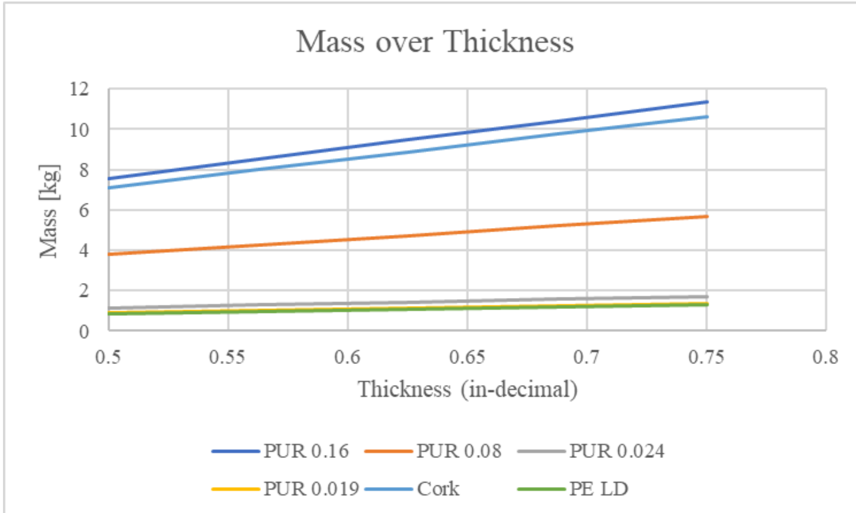

Figure D-3: Mass of each material of interest for the insulative core.

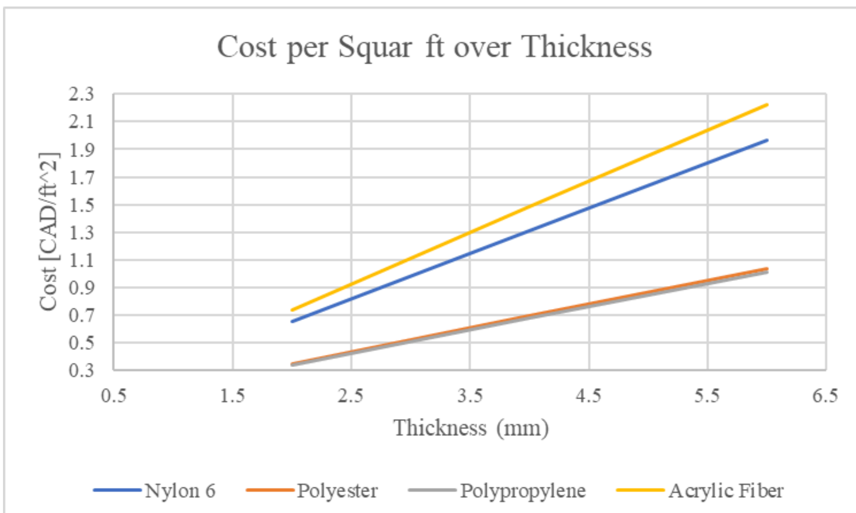

Figure D-4: Cost per square foot of each material of interest for the protective skin.

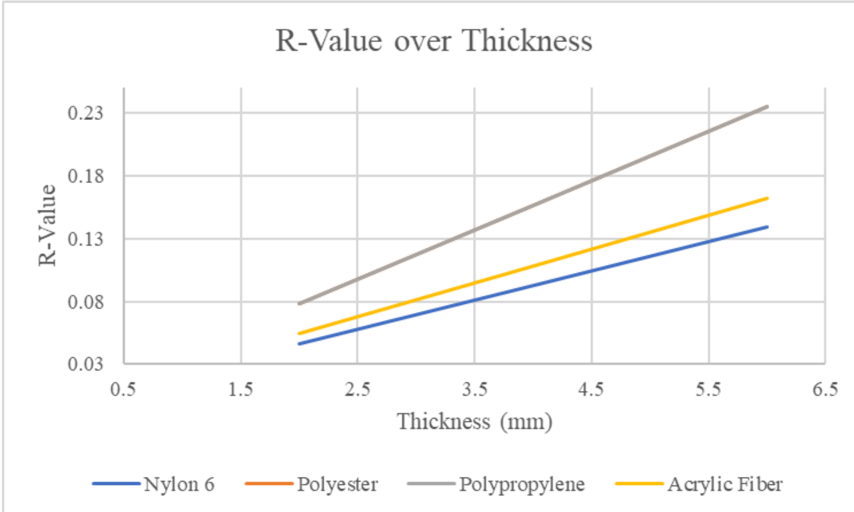

Figure D-5: R-Value of each material of interest for the protective skin.

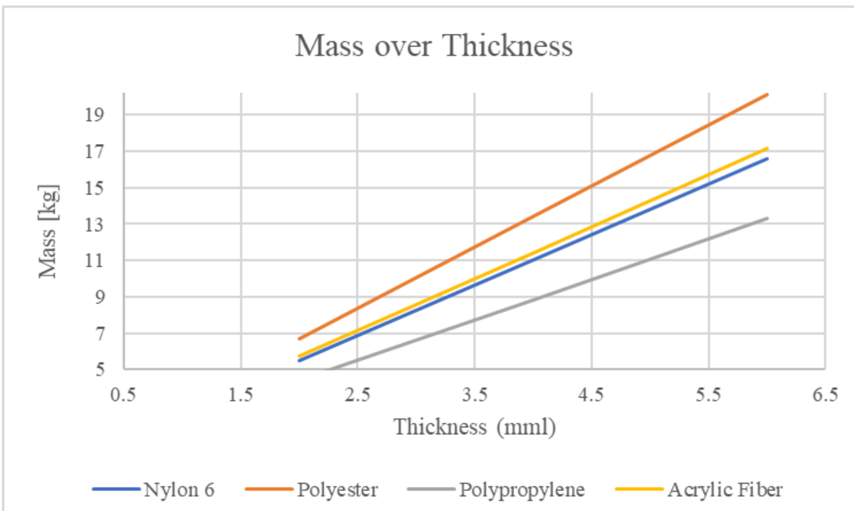

Figure D-6: Mass of each material of interest for the protective skin.

Appendix E - Sustainability Analysis

The following Appendix presents the expanded results of Section 4.3 for the ethical and sustainability analysis conducted for both the insulative core and protective skin materials. Key environmental impact metrics, including embodied energy, CO_2 footprint, water usage and combustion energy recovery were evaluated to determine the relative effects of each material. Additionally, end-of-life procedures were assessed to establish whether materials could be recycled, down-cycled or required disposal in a landfill. Biodegradability and toxicity were also analyzed to quantify additional environmental impacts. The charts presented below illustrate the relative percentages of each metric, allowing for straightforward comparison between materials.

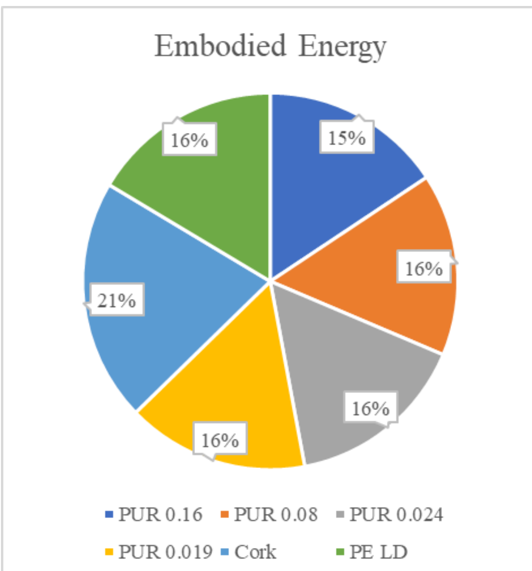

Figure E-1: Embodied energy consumption of producing materials. Quantity ratio is relative between materials examined for the insulating core.

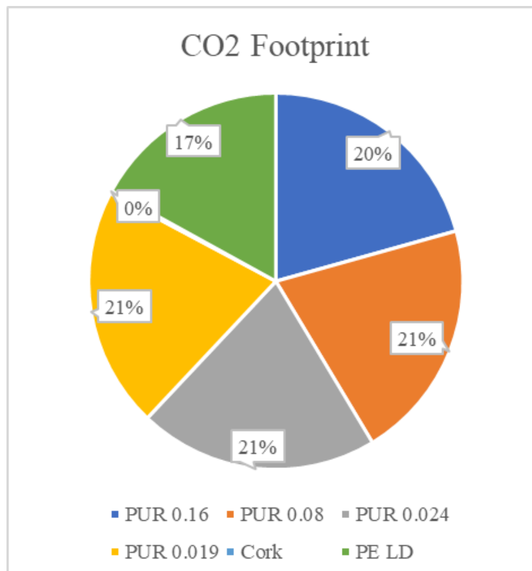

Figure E-2: CO2 footprint produced from production. Quantity ratio is relative between materials examined for the insulating core.

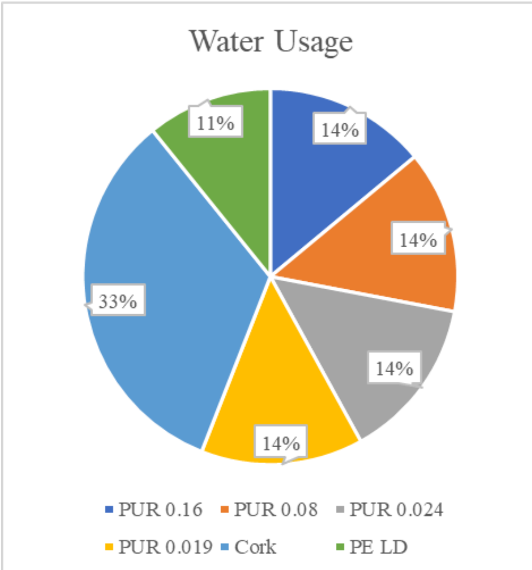

Figure E-3: Fresh water consumption used in material production. Quantity ratio is relative between materials examined for the insulating core.

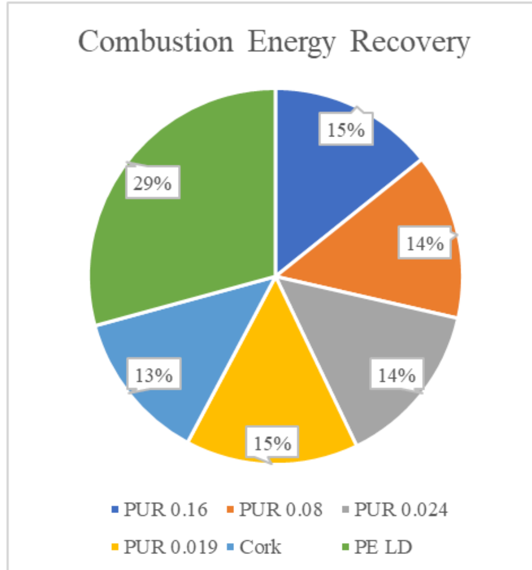

Figure E-4: Combustion energy recovery produced if material is combusted for energy rather than disposing in landfill. Quantity ratio is relative between materials examined for the insulating core.

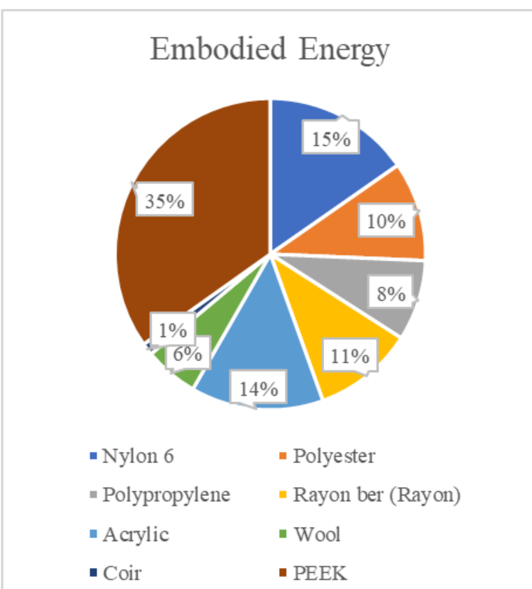

Figure E-5: Embodied energy consumption of producing materials. Quantity ratio is relative between materials examined for the protective skin.

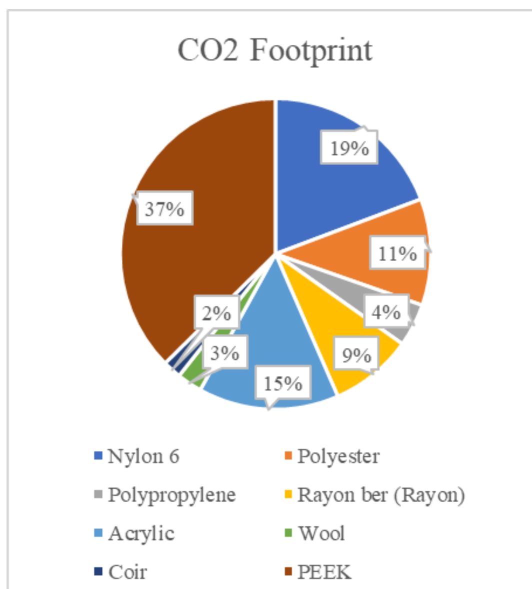

Figure E-6: CO2 footprint produced from production. Quantity ratio is relative between materials examined for the protective skin.

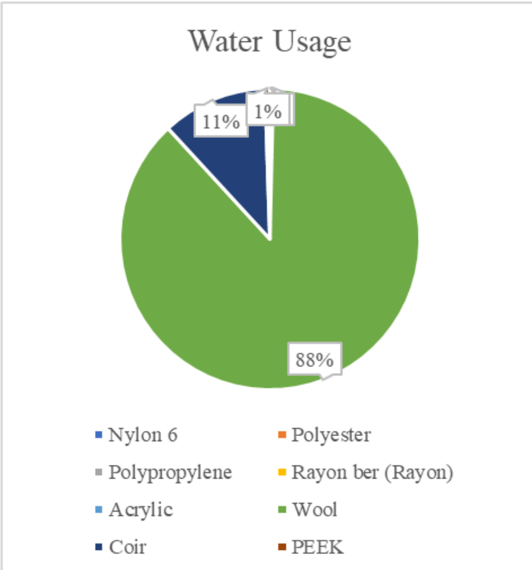

Figure E-7: Fresh water consumption used in material production. Quantity ratio is relative between materials examined for the protective skin.

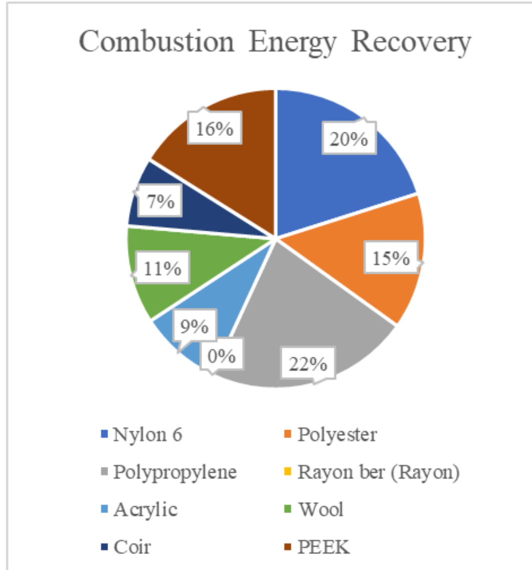

Figure E-8: Combustion energy recovery produced if material is combusted for energy rather than disposing in landfill. Quantity ratio is relative between materials examined for the protective skin.

Table E-1: End-of-Life Potential Procedures

Materials	Recyclability	Down-cyclability	Biodegradability	Landfill
Polyurethane Foam (flexible, closed cell, 0.16)	NO	YES	NO	YES
Polyurethane Foam (flexible, closed cell, 0.08)	NO	YES	NO	YES
Polyurethane Foam (elastomeric, open cell, 0.024)	NO	YES	NO	YES
Polyurethane Filter Foam (open cell, 0.019)	NO	YES	NO	YES
Cork (Low Density)	NO	YES	YES	YES
PE Low Density (cross-linked, closed cell, 0.018)	NO	YES	NO	YES

Polyamide (PA6, Nylon-6)	YES	YES	NO	YES
Polyester Fiber (Dacron)	YES	YES	NO	YES
Polypropylene Fiber	YES	YES	NO	YES
Celluloses fiber (Rayon)	NO	YES	NO	YES
Acrylic Fiber (PAN)	YES	YES	NO	YES
Wool Fiber	NO	YES	YES	YES
Coir Fiber	NO	YES	YES	YES
PEEK	YES	YES	NO	YES

Appendix F - Final Design Specifications

The following pages include both the engineered drawings for the final design of a heated blanket for cold weather concrete curing that was detailed in Section 5.1 and the hook force simulation conducted in SolidWorks.

Appendix F.1 - Final Design Engineering Drawings

This Appendix details the blanket design and analysis discussed in Section 5.1.4. The remainder of this page is left intentionally blank.

PROPOSED INSULATED BLANKET/TARP DESIGN PLANS

PREPARED FOR:

TRAINE

PREPARED ON:
March 29, 2025

Sheet Number	Sheet Name
1	Cover Page
2	ROV General Form Layout
3	Peri Gang Forms
4	Insulating Blanket Cross-Section & Materials
5	Hook Design
6	Insulating Blanket Layout
7	Launching Insulated Blanket onto Peri Gang Forms
8	Notes

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SHEET 1 OF 8

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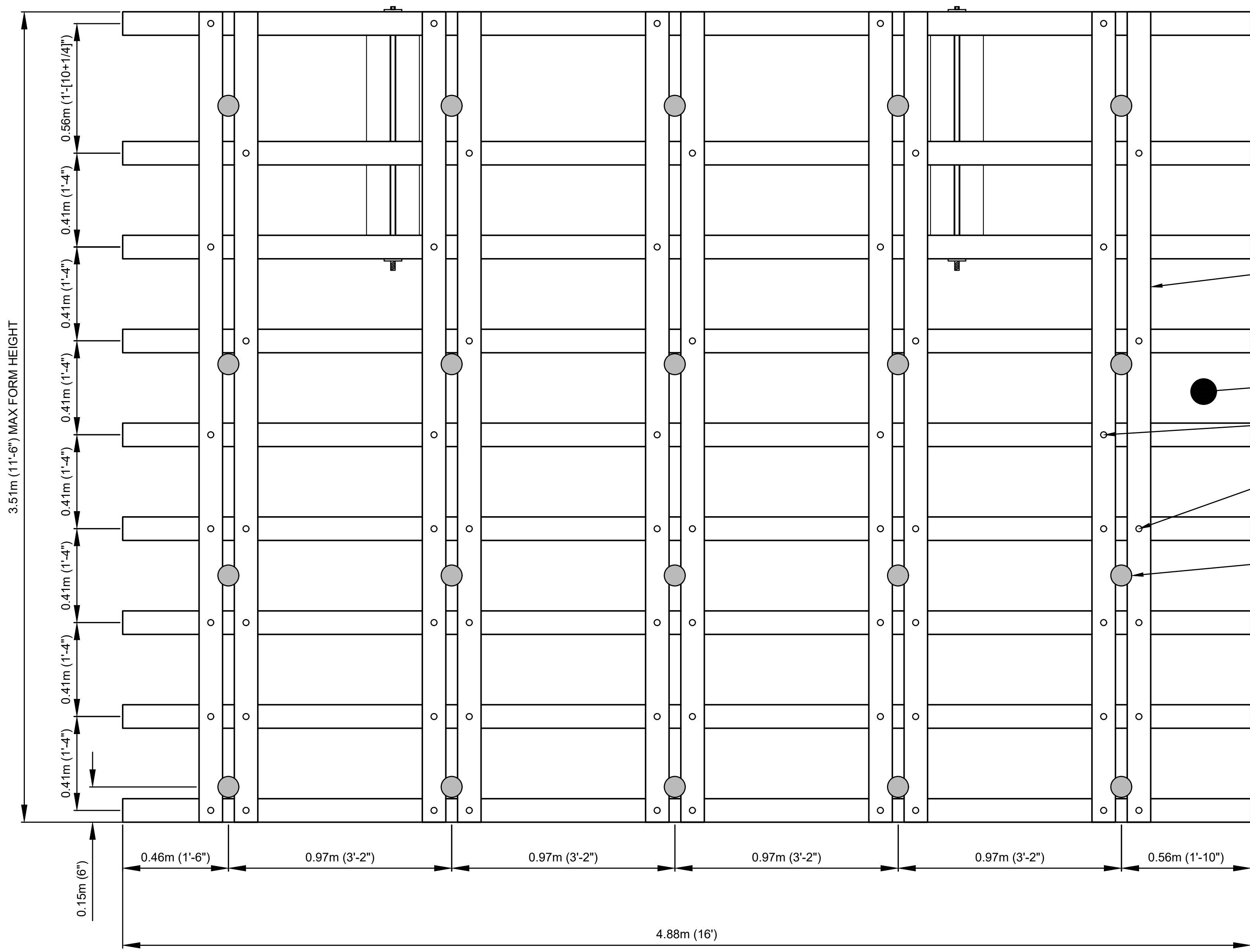
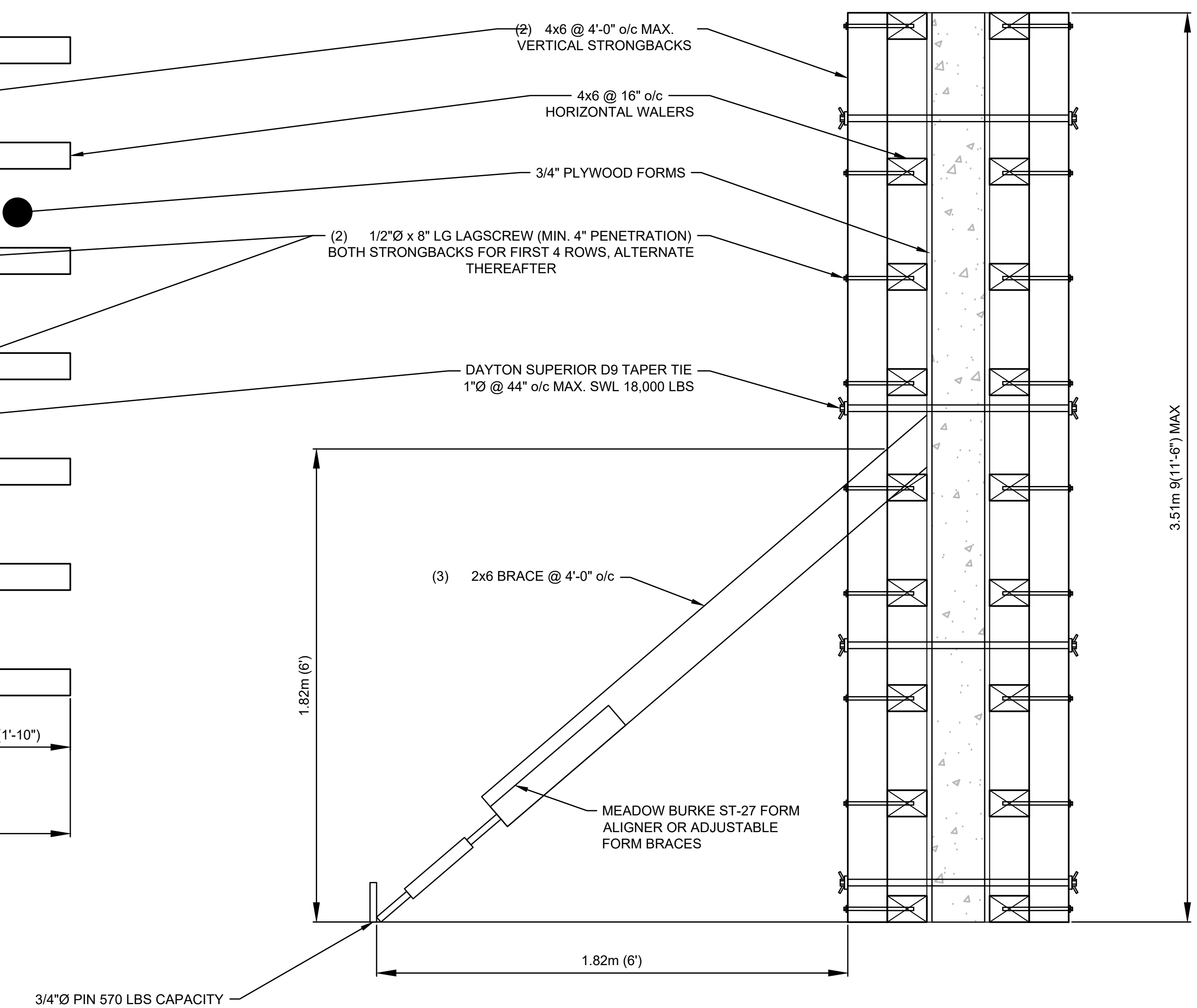


ROV FORM PROFILE VIEW
SCALE 1:25



IT IS TO BE NOTED THAT THE DRAWINGS ON SHEET 2 (THIS SHEET) WERE MADE AND PROVIDED BY ROV - ENGINEERING CONSULTANTS. THESE DRAWINGS PROVIDE THE NECESSARY DIMENSIONS THAT THE INSULATION BLANKET/TARP IS TO BE DESIGNED TO.

ROV FORM SECTIONAL VIEW
SCALE 1:25

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	DESIGN BY: Infrastructure Group A	DRAWING DATE: March 29, 2025
	DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
SHEET NAME: ROV GENERAL FORM LAYOUT	REVIEWED BY: To Be Determined	REVISION DATE:-
	CONCEPT DATE: JAN, 21, 2025	DWG#: 001

SHEET 2 OF 8

SINGLE PERI PANEL SIDE (3.3m x 1.2m):

SCALE 1:25

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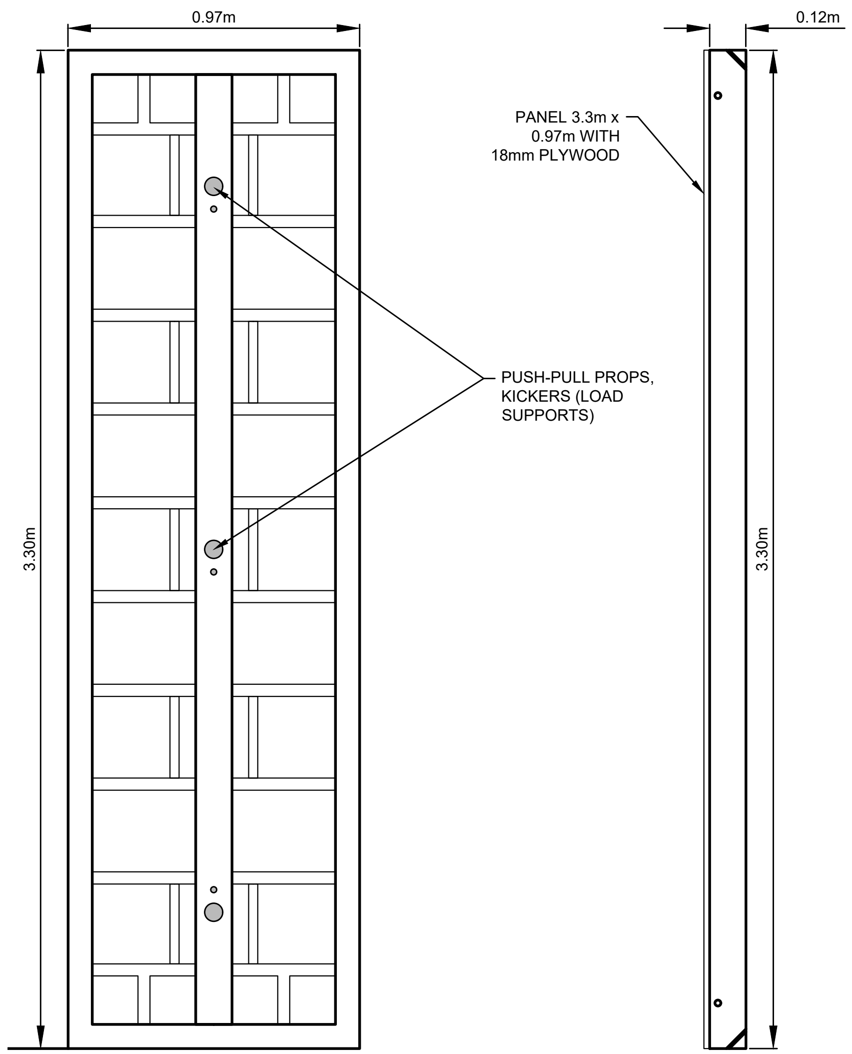

SINGLE PERI PANEL FRONT (3.3m x 1.2m):

SCALE 1:25

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LINKED PERI GANG FORMS FRONT VIEW:

SCALE 1:25

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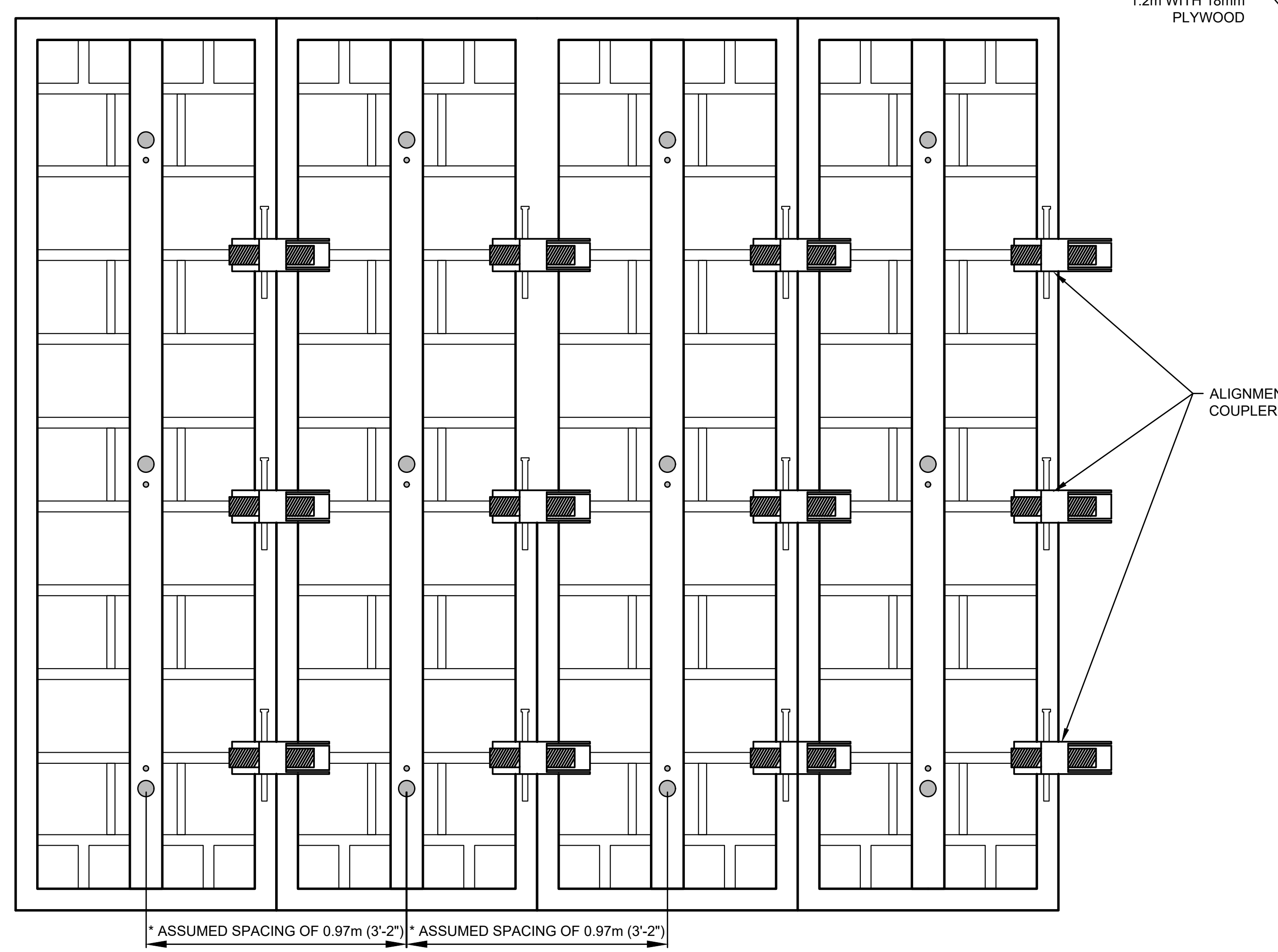

LINKED PERI GANG FORMS SIDE VIEW:

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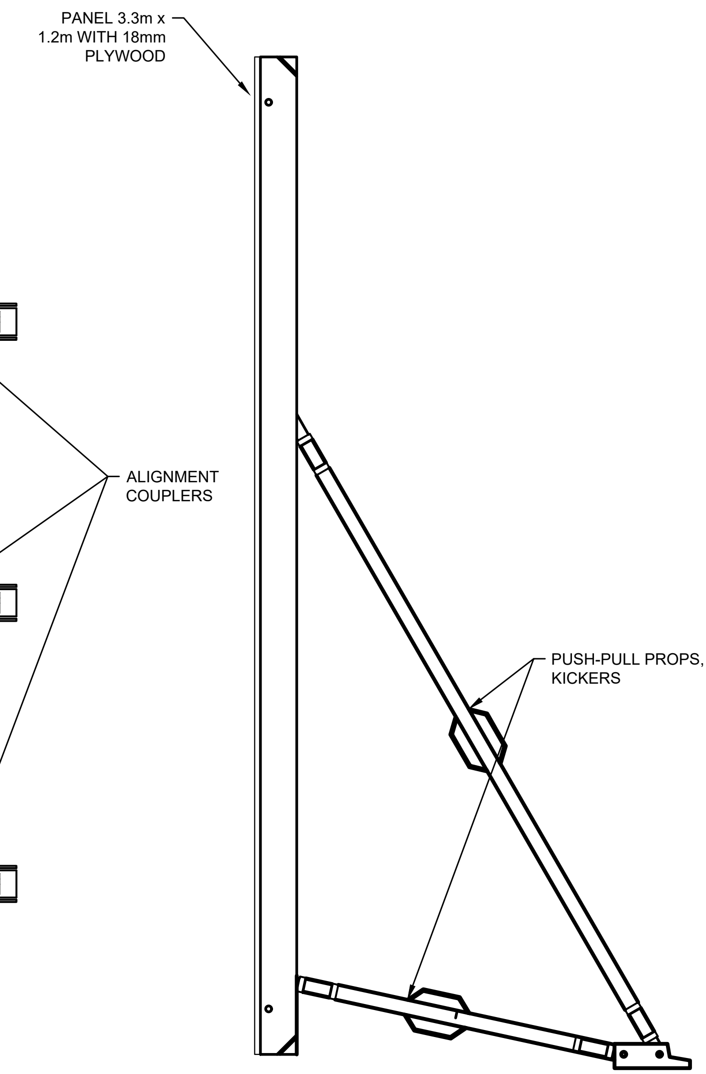

EXACT PERI GANG FORM DIMENSIONS COULD NOT BE FOUND ON THE ASSEMBLY INSTRUCTIONS; THEREFORE, ESTIMATIONS WERE USED IN ORDER TO COMPLETE THE PRELIMINARY DESIGNS. IT IS TO BE NOTED THAT SOME DIMENSIONS ON THIS SHEET MAY VARY.

FOR THE PURPOSES OF THIS DRAFT, THE LARGEST MAXIMO PERI FORM HEIGHT OF 3.3m (10'- 10") WILL BE ASSUMED BECAUSE THIS BEST COMPLIES WITH THE GENERAL DRAWING ON SHEET 2, AND THE FORM SIZES LISTED ON THE PERI WEBSITE. TO AGAIN COMPLY WITH THE DRAWING ON SHEET 2, THE LENGTH WILL BE ASSUMED TO BE 0.97m (3'-2").

*SINCE THE EXACT DIMENSIONS OF PERI GANG WERE NOT ABLE TO BE FOUND, THE SPACING BETWEEN PUSH-PULL KICKERS (FORM SUPPORTS) WILL BE ASSUMED AS 0.97m (3'-2") AS IN THE "ROV GENERAL FORM LAYOUT" ON SHEET 2.

REFERENCE:

PERI. (2018). MAXIMO MX 15, Panel Formwork 270 | 330. Instructions for Assembly and Use – Standard Configuration – Issue 04. https://www.peri.ca/en

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SHEET NAME: PERI GANG FORMS

SCALE: As Indicated	REFERENCE DRAWING: ROV Engineering Consultants
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DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
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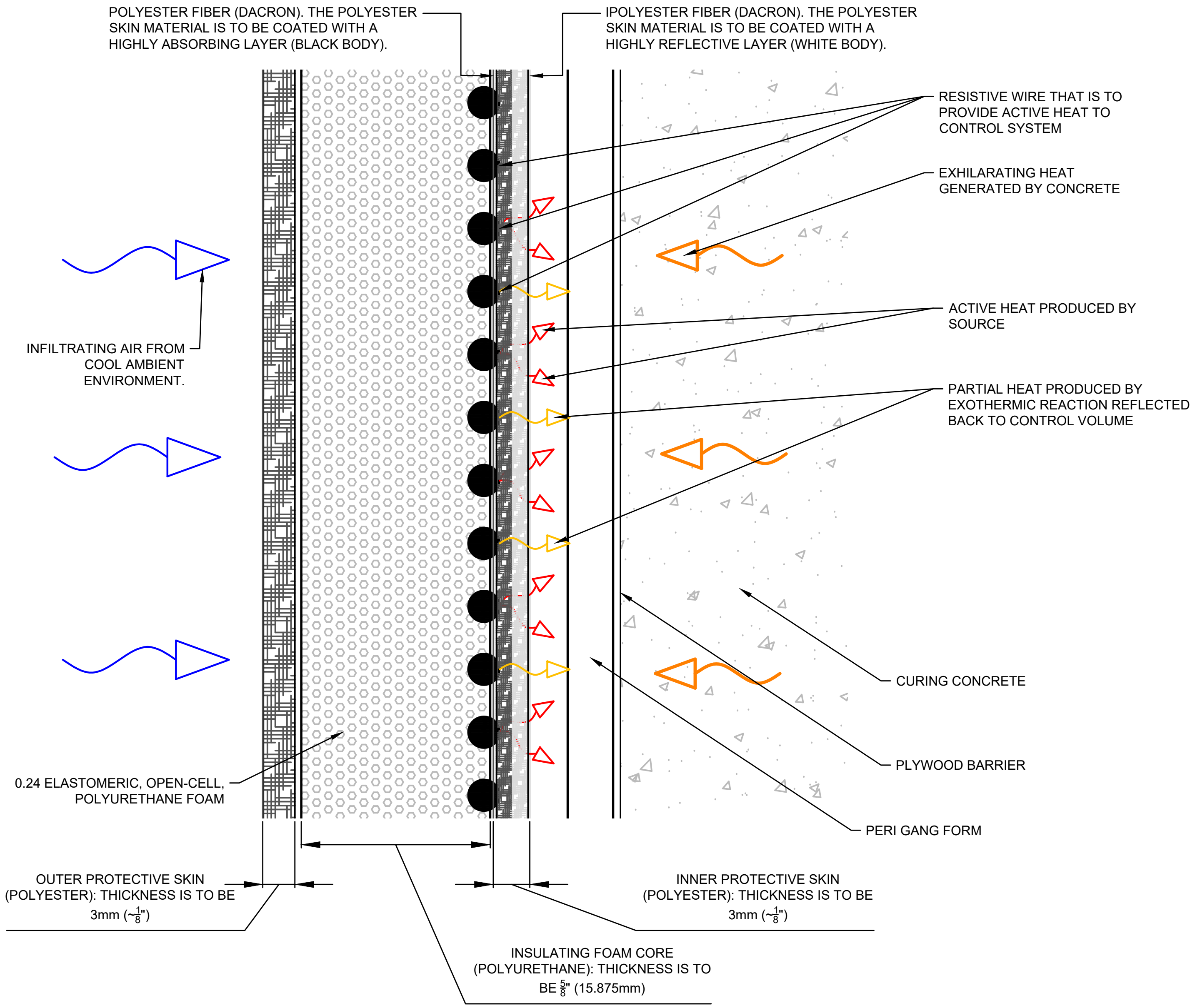
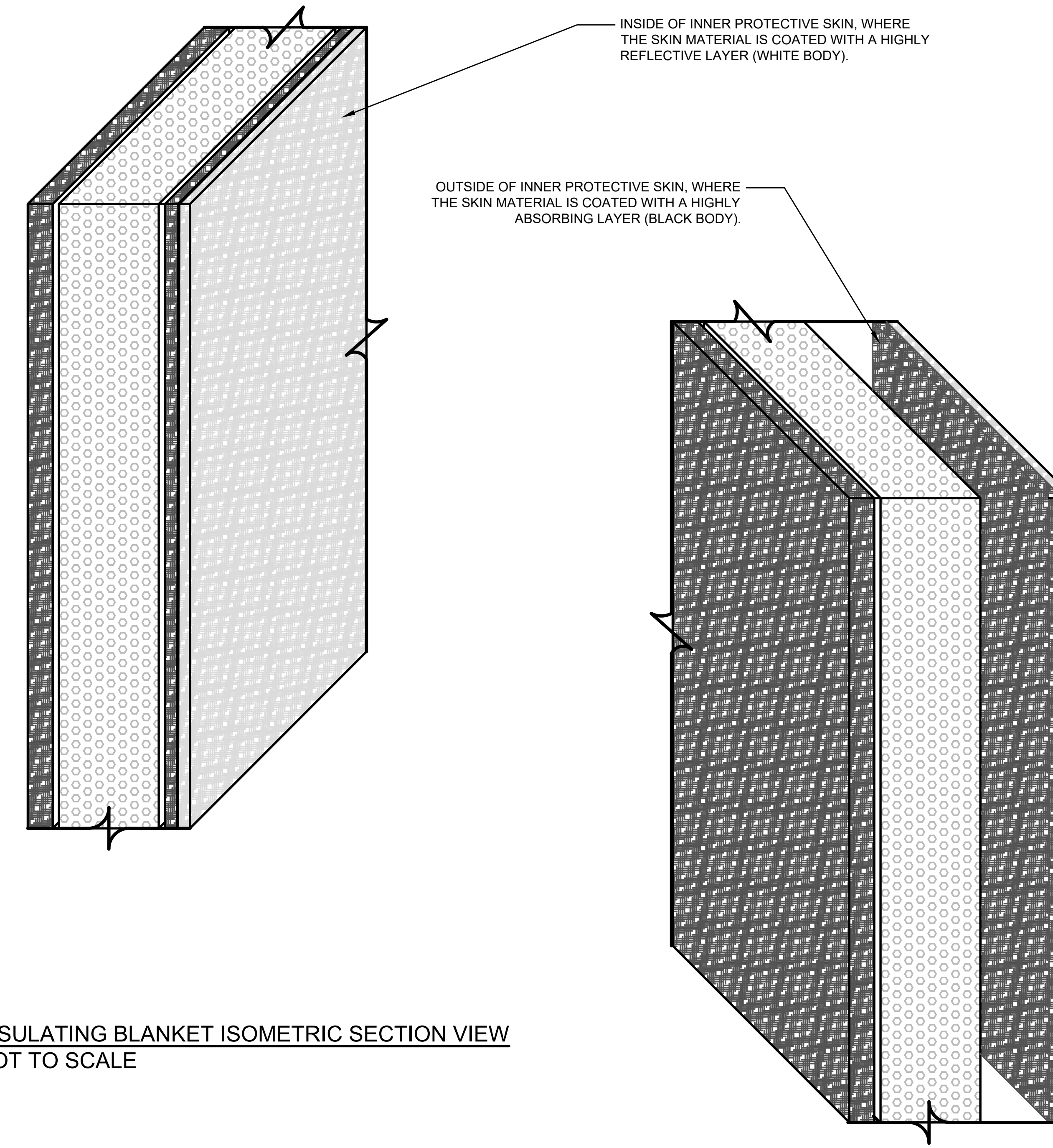


INSULATING BLANKET SECTIONAL VIEW
NOT TO SCALE



INSULATING BLANKET ISOMETRIC SECTION VIEW
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PROPOSED INSULATED BLANKET/TARP DESIGN PLANS

SHEET NAME:
INSULATING BLANKET CROSS-SECTION & MATERIALS

SCALE: As Indicated	REFERENCE DRAWING: ROV Engineering Consultants
DESIGN BY: Infrastructure Group A	DRAWING DATE: March 29, 2025
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REVIEWED BY: To Be Determined	REVISION DATE:-
CONCEPT DATE: JAN, 21, 2025	DWG#: 001

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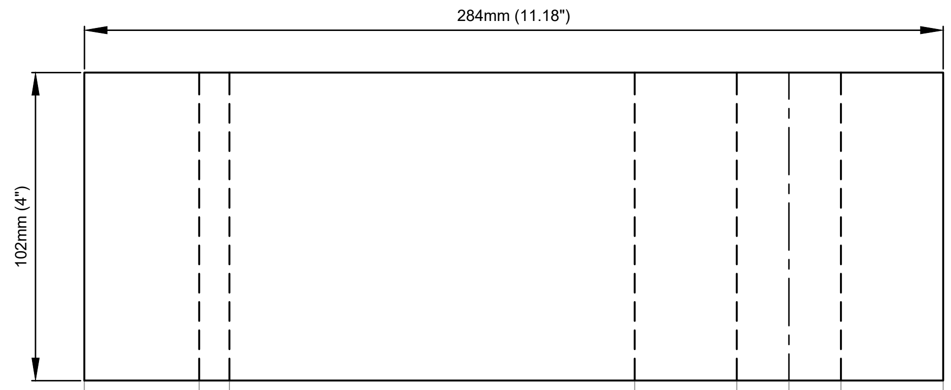
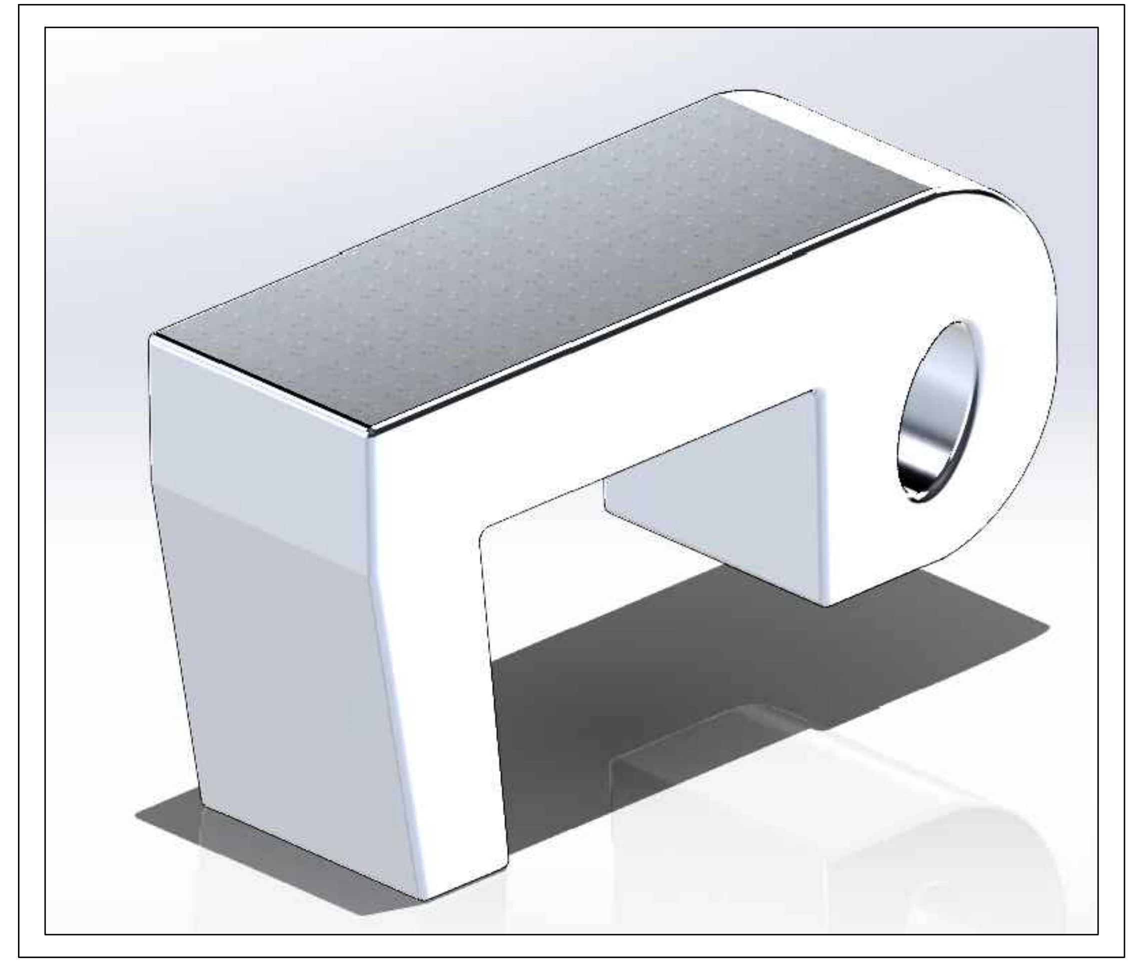
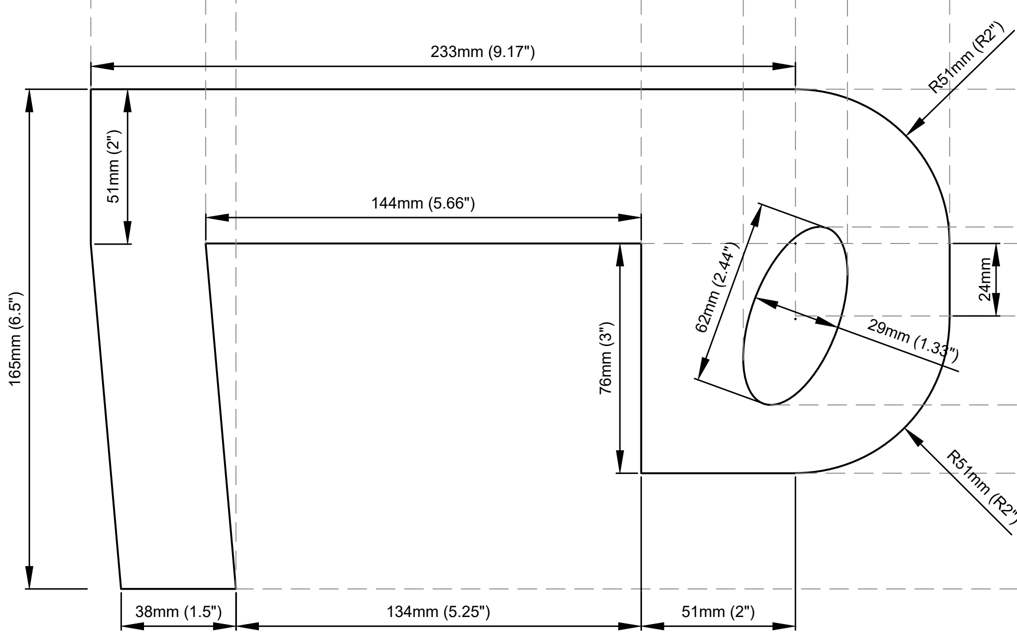
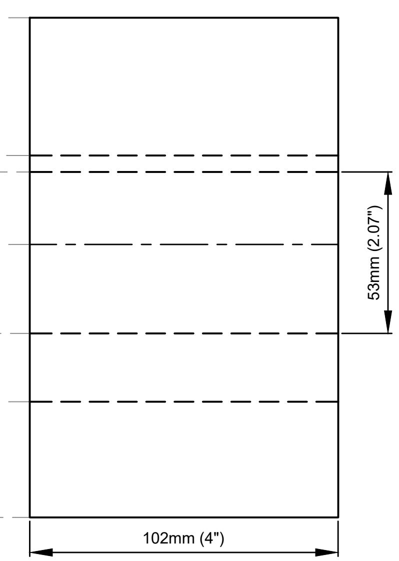
HOOK DESIGN - TOP VIEW:
SCALE 1:2.5

-2.5cm 0cm 2.5cm 5cm 7.5cm 10cm 1.25cm









HOOK DESIGN ORIGIN AND REPRODUCTION

THE HOOK DESIGN PRESENTED IN THIS DOCUMENT WAS ORIGINALLY DRAFTED USING AN ALTERNATIVE CAD SOFTWARE, SOLIDWORKS. TO ENSURE CONSISTENCY AND EASE OF REFERENCE, THE DRAWING HAS BEEN REPRODUCED WITHIN THIS DOCUMENT USING THE CURRENT CAD PLATFORM.

THE ORIGINAL IMAGE DESIGN WAS PRODUCED BY SEBASTIAN SCHMIDT.

HOOK DESIGN - SIDE VIEW:
SCALE 1:2.5

-2.5cm 0cm 2.5cm 5cm 7.5cm 10cm 1.25cm

HOOK DESIGN - FRONT VIEW:
SCALE 1:2.5

-2.5cm 0cm 2.5cm 5cm 7.5cm 10cm 1.25cm

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	DESIGN BY: Infrastructure Group A	DRAWING DATE: March 29, 2025	
	DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0	
SHEET NAME: HOOK DESIGN	REVIEWED BY: To Be Determined	REVISION DATE:-	
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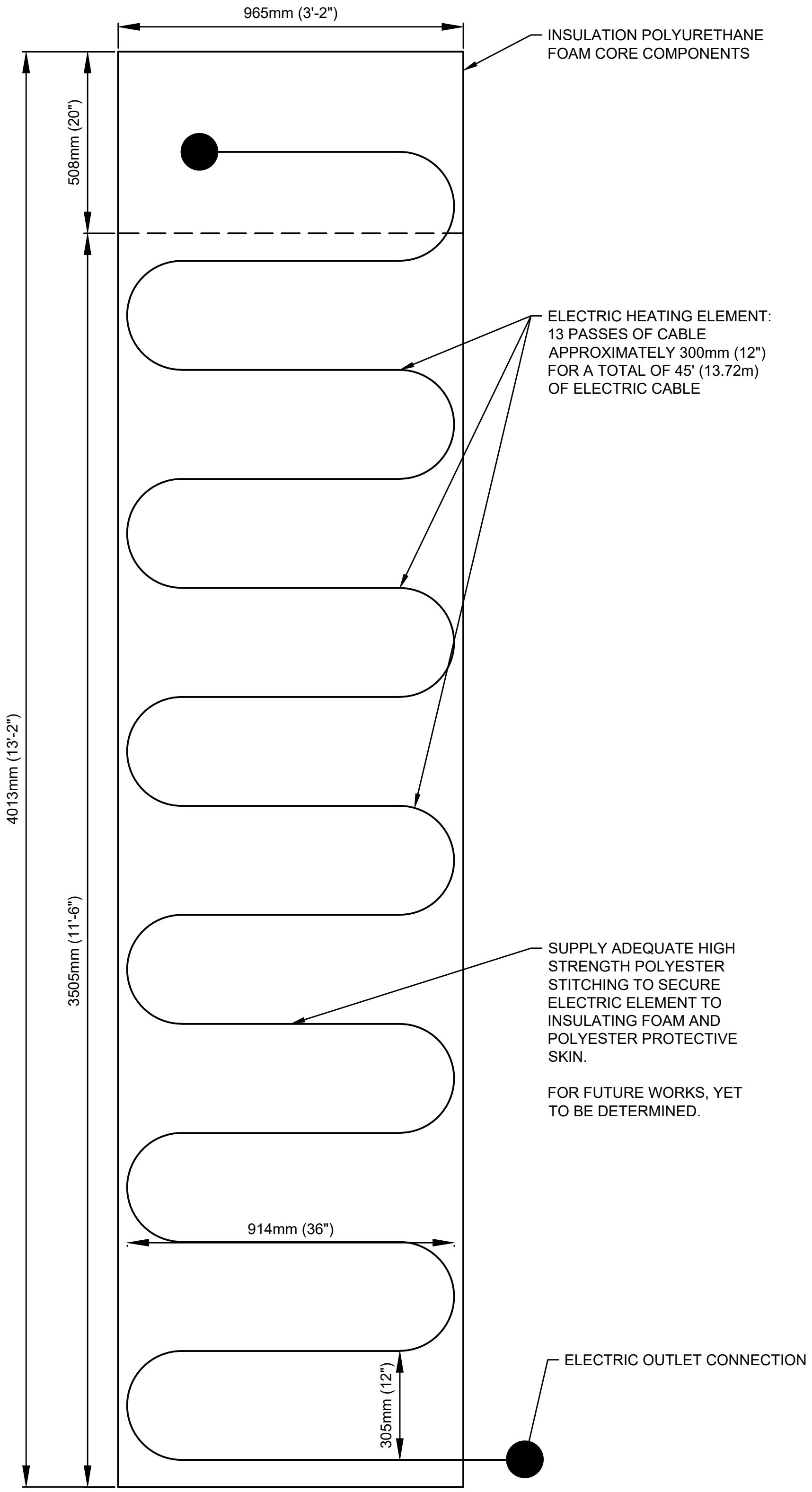

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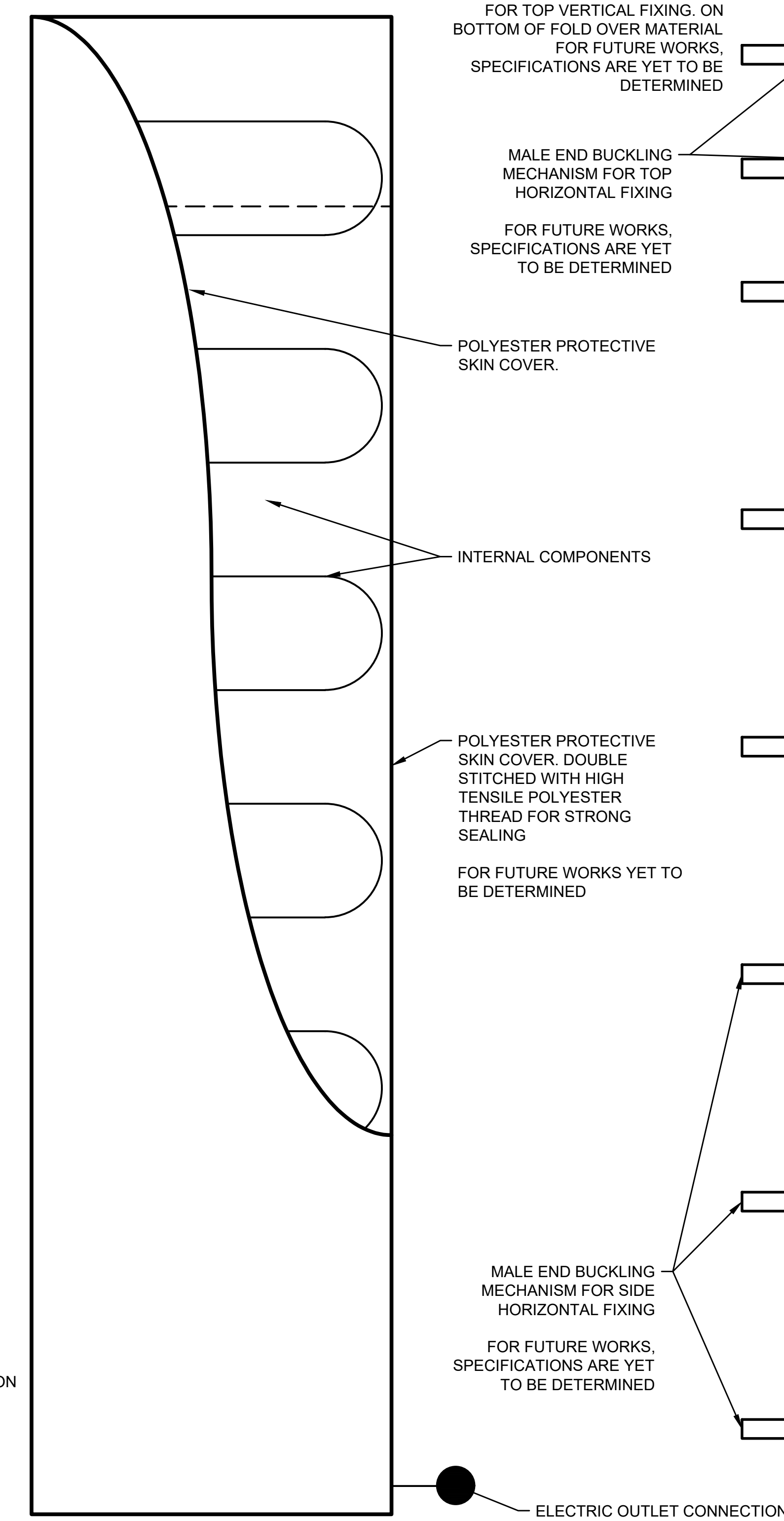

SECTIONAL INSULATING BLANET COMPONENTS:

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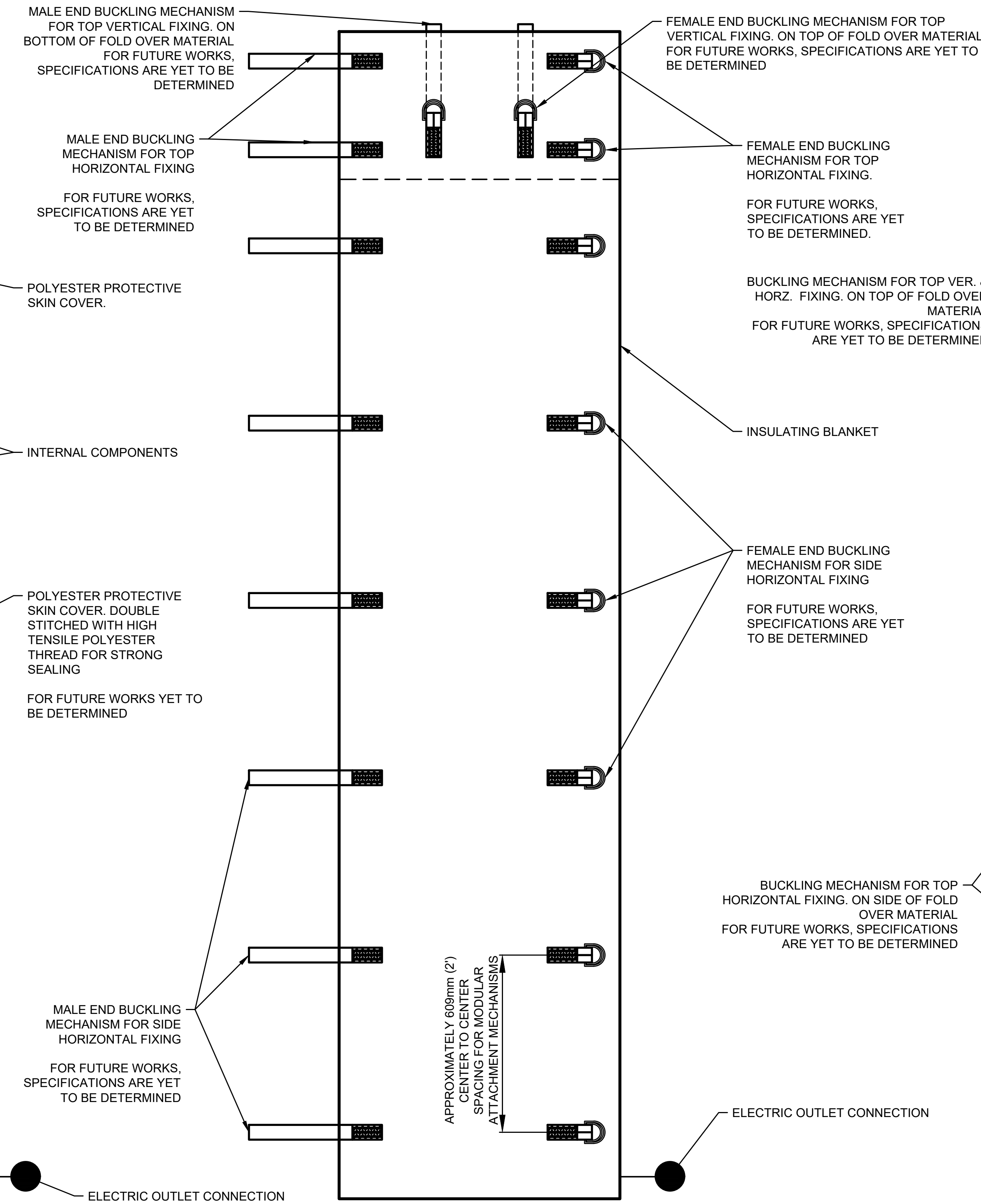

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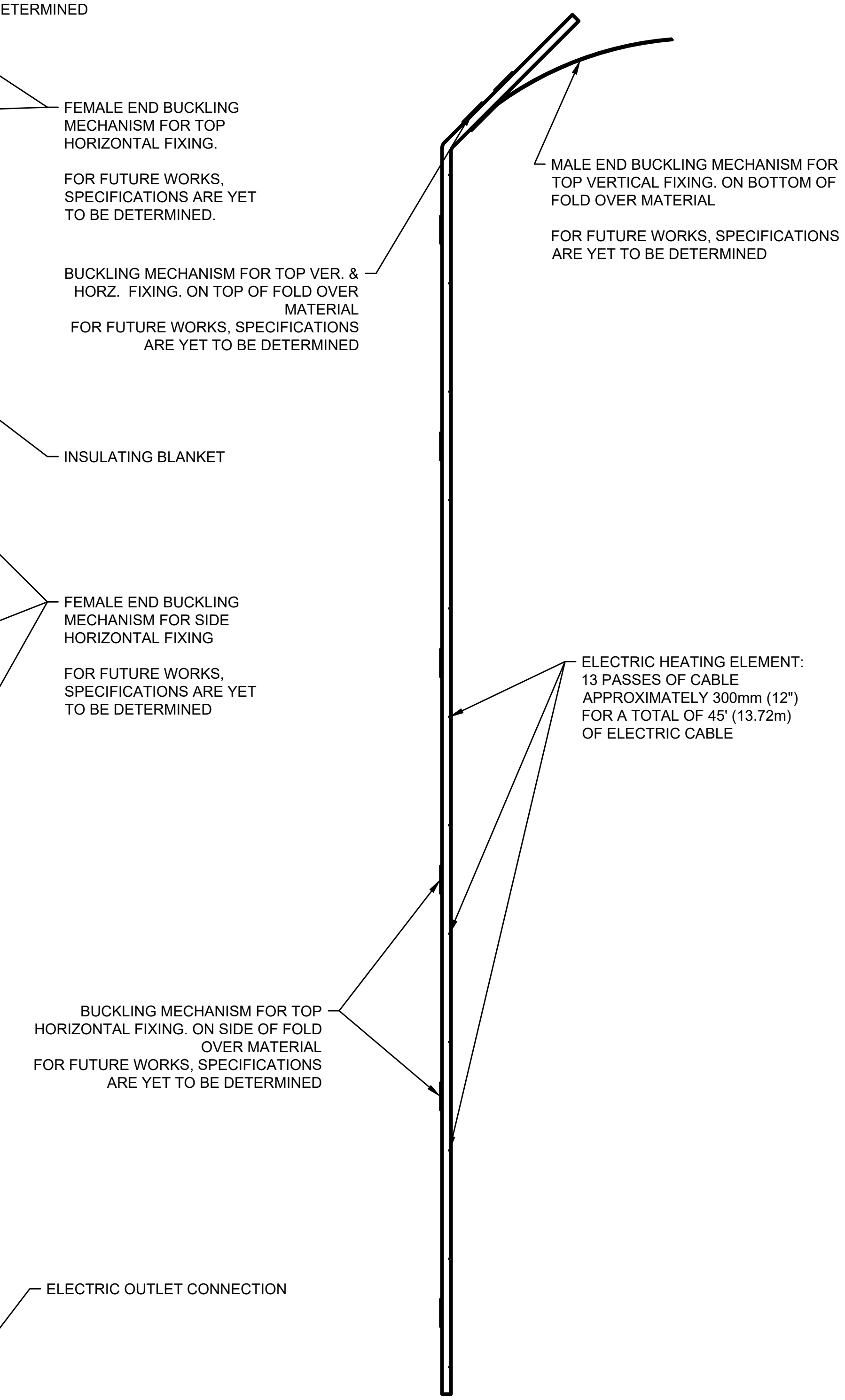

SIDE VIEW INSULATING BLANKET:

SCALE 1:25

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SCALE: As Indicated	REFERENCE DRAWING: ROV Engineering Consultants
DESIGN BY: Infrastructure Group A	DRAWING DATE: March 29, 2025
DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
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CONCEPT DATE: JAN, 21, 2025	DWG#: 001

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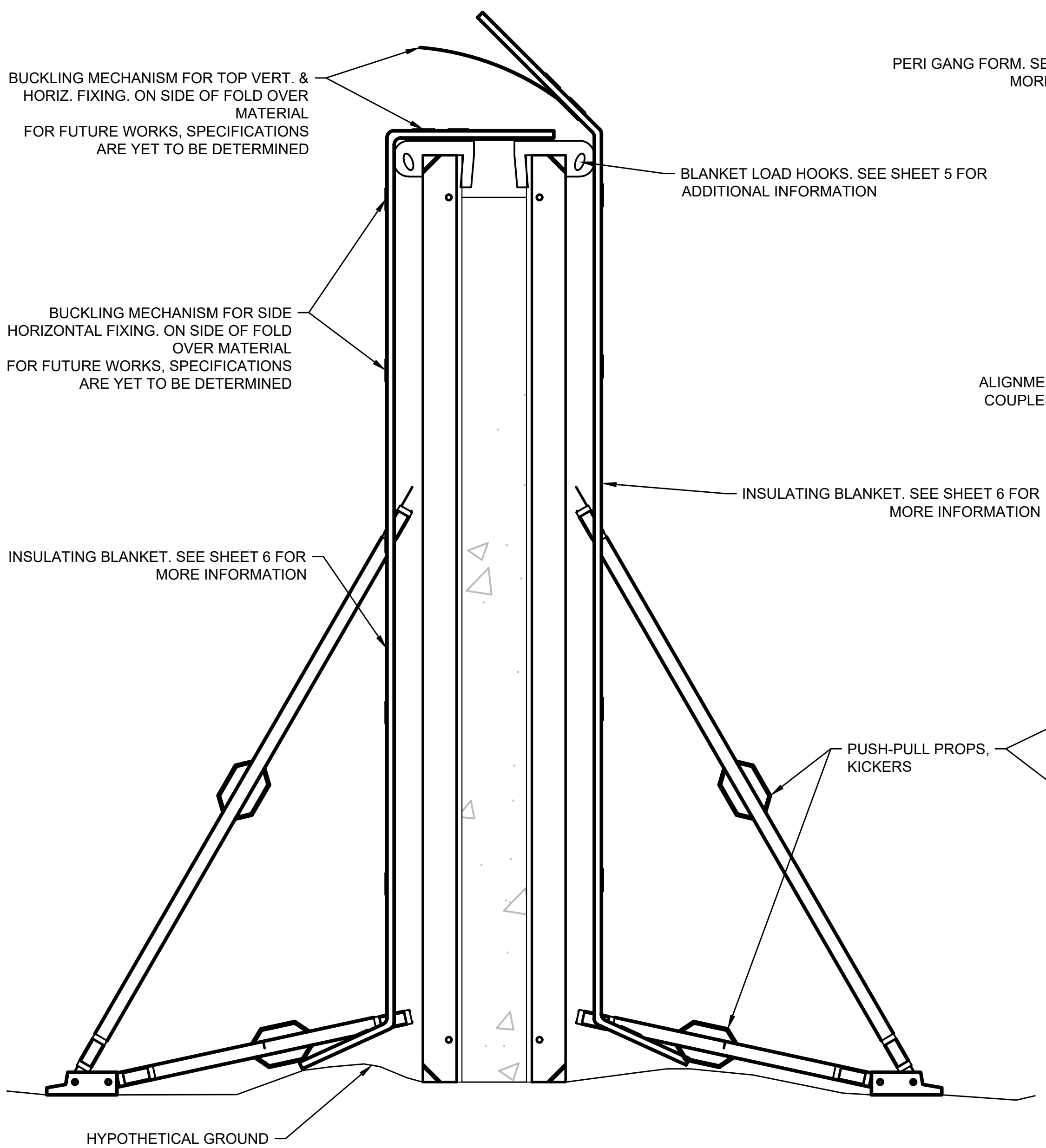

SIDE VIEW INSULATING BLANKET WITH PERI FORMS:

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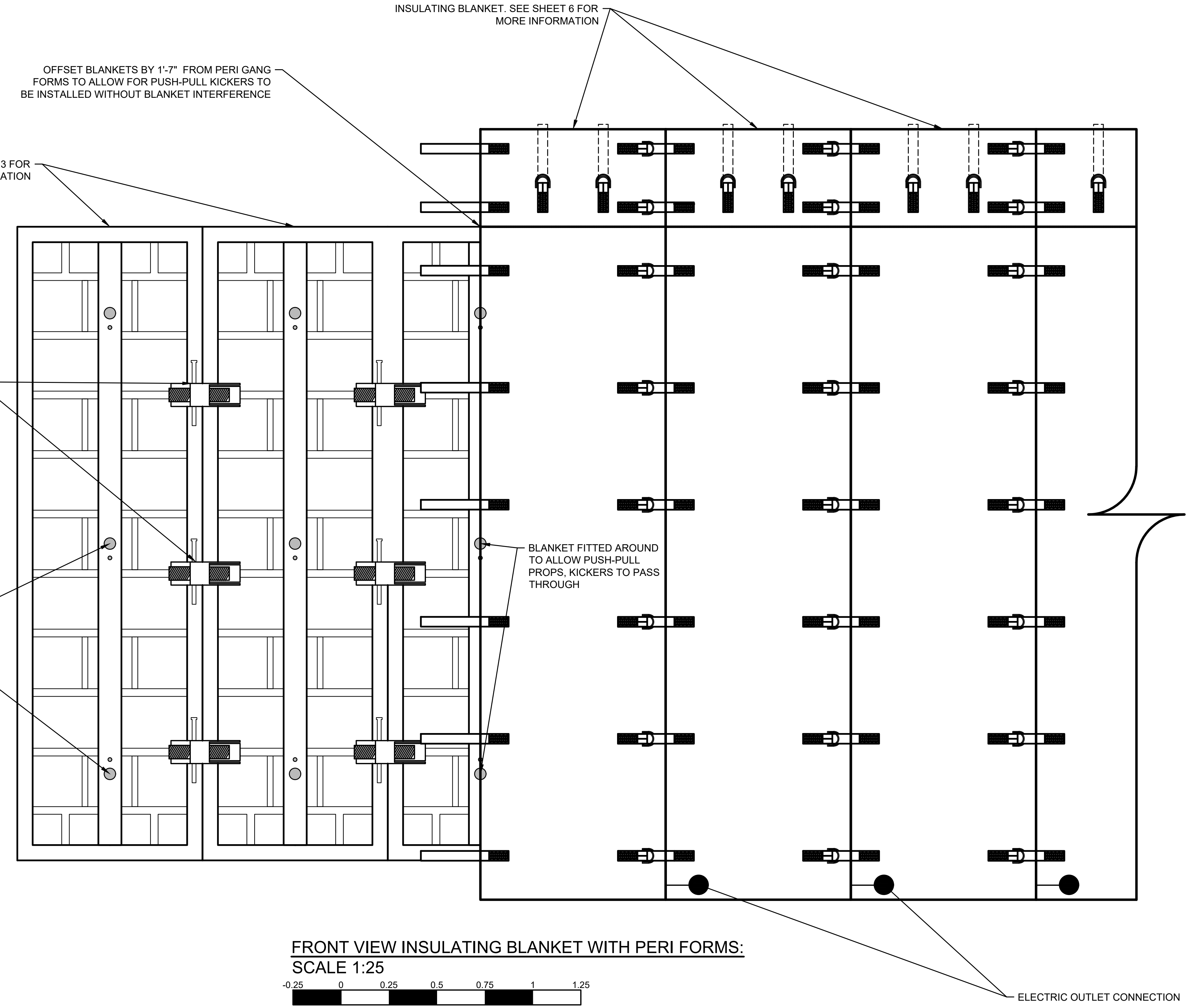

FRONT VIEW INSULATING BLANKET WITH PERI FORMS:

SCALE 1:25

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PROPOSED INSULATED BLANKET/TARP DESIGN PLANS

SHEET NAME:
LAUNCHING INSULATED BLANKET ONTO PERI GANG FORMS

SCALE: As Indicated	REFERENCE DRAWING: ROV Engineering Consultants
DESIGN BY: Infrastructure Group A	DRAWING DATE: March 29, 2025
DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
REVIEWED BY: To Be Determined	REVISION DATE:-
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SHEET
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OF 8

1 - PURPOSE AND SCOPE

THIS CAD DRAWING IS INTENDED TO PROVIDE A COMPREHENSIVE AND ACCURATE REPRESENTATION OF THE DESIGN SOLUTION DEVELOPED TO ADDRESS THE CHALLENGE OF CONCRETE CURING IN COLD WEATHER CONDITIONS, SPECIFICALLY IN THE OKANAGAN AREA. THE PRIMARY OBJECTIVE OF THIS DESIGN IS TO FACILITATE CONCRETE POURS AT AMBIENT TEMPERATURES AS LOW AS -15°C.

THE MODULAR INSULATED BLANKET DESIGN PRESENTED HEREIN IS ENGINEERED TO MAINTAIN A CONTROLLED INTERNAL ENVIRONMENT, ENSURING THAT THE TEMPERATURE WITHIN THE INSULATED SPACE REMAINS AT OR ABOVE +10°C. THIS DESIGN ENABLES CONCRETE CURING TO PROCEED EFFECTIVELY UNDER THE SPECIFIED CONDITIONS, PROVIDED THAT THE AMBIENT TEMPERATURE DOES NOT FALL BELOW -25°C.

BY ADHERING TO THE SPECIFICATIONS OUTLINED IN THIS DRAWING, TRAINE CAN CONFIDENTLY PERFORM CONCRETE POURS DURING COLD WEATHER, MITIGATING THE RISKS ASSOCIATED WITH INADEQUATE CURING AND ENSURING STRUCTURAL INTEGRITY.

2 - SCOPE LIMITATIONS

THIS CAD DRAWING REPRESENTS A NEAR-COMPLETE DESIGN SOLUTION AIMED AT ADDRESSING THE PRIMARY CHALLENGE OF CONCRETE CURING IN COLD WEATHER CONDITIONS IN THE OKANAGAN AREA. WHILE THE MODULAR INSULATED BLANKET DESIGN HAS BEEN THOROUGHLY DEVELOPED TO MEET THE SPECIFIED PERFORMANCE CRITERIA, IT IS ACKNOWLEDGED THAT CERTAIN CHALLENGES REMAIN UNRESOLVED.

THESE OUTSTANDING ISSUES FALL OUTSIDE THE SCOPE OF THIS ENGR 499 CAPSTONE PROJECT AND WILL REQUIRE FURTHER INVESTIGATION AND DEVELOPMENT TO ENHANCE THE OVERALL EFFECTIVENESS AND PRACTICALITY OF THE SOLUTION. FUTURE WORK MAY INCLUDE OPTIMIZATION OF THERMAL EFFICIENCY, ADAPTATION TO VARYING SITE CONDITIONS, AND IMPROVEMENTS IN MODULARITY AND EASE OF DEPLOYMENT.

ANY NOTES LABELED AS "FOR FUTURE WORKS" PERTAIN TO OUT-OF-SCOPE CRITERIA THAT WILL OR WOULD BE PURSUED IN THE EVENT THAT TRAINE DECIDES TO MANUFACTURE THIS PRODUCT. THESE ITEMS REPRESENT AREAS OF FURTHER DEVELOPMENT AND OPTIMIZATION THAT EXTEND BEYOND THE SCOPE OF THIS ENGR 499 CAPSTONE PROJECT BUT MAY BE ESSENTIAL FOR COMMERCIAL VIABILITY AND LONG-TERM PERFORMANCE.

3 - CONCRETE GUIDE LINES

THE USE OF THIS PRODUCT REQUIRES OVERSIGHT BY AN ENGINEER OR EQUIVALENT QUALIFIED PERSON(S) DURING CONCRETE POURING OPERATIONS. ALL ACTIVITIES MUST STRICTLY ADHERE TO THE GUIDELINES SET FORTH BY THE CSA A23.1 STANDARDS FOR CURING CONCRETE.

THE ENGINEER OR EQUIVALENT QUALIFIED PERSON(S) IS RESPONSIBLE FOR MAINTAINING A CONTINUOUS TEMPERATURE AS SPECIFIED BY THE CONCRETE MANUFACTURER OR CSA A23.1 THROUGHOUT THE CURING PROCESS. UPON COMPLETION OF CURING, QUALIFIED PERSON(S) MUST INSPECT THE CONCRETE TO VERIFY COMPLIANCE WITH ALL RELEVANT SPECIFICATIONS AND STANDARDS.

CSA A23.1 RELEVANT STANDARDS:

1.1. FORECASTED AIR TEMPERATURE AT OR BELOW 5 DEGREES CELSIUS
THE AGGREGATE OR MIXING WATER SHALL BE HEATED TO MAINTAIN A MINIMUM CONCRETE TEMPERATURE OF 10 DEGREES CELSIUS AT POINT OF POUR.
CONCRETE SHALL NOT BE PLACED ON OR AGAINST ANY SURFACE.
CONTRACTOR SHALL BE PREPARED TO COVER SLABS IF AN UNEXPECTED DROP IN AIR TEMPERATURE SHOULD OCCUR.
CONCRETE EXPOSURE CLASSES REQUIRING CURING TYPE 1 (BASIC) IN ACCORDANCE WITH CSA A23.1 SHALL HAVE THE CONCRETE TEMPERATURE MAINTAINED ABOVE 10 DEGREES CELSIUS FOR AT LEAST 7 DAYS OR UNTIL THE CONCRETE REACHES 70% OF SPECIFIED STRENGTH.

FORECASTED AIR TEMPERATURE BELOW 2 BUT NOT BELOW -4 DEGREES CELSIUS
FORMS AND STEEL SHALL BE FREE FROM ICE AND SNOW.
THE AGGREGATE OR MIXING WATER SHALL BE HEATED TO GIVE A MINIMUM CONCRETE TEMPERATURE OF 10 DEGREES CELSIUS AT POINT OF POUR.
CONCRETE SHALL NOT BE PLACED ON OR AGAINST ANY SURFACE WHICH IS AT A TEMPERATURE OF LESS THAN 5 DEGREES CELSIUS.
SLABS SHALL BE COVERED WITH CANVAS OR SIMILAR, KEPT A FEW INCHES CLEAR OF SURFACE.
IN WINDY WEATHER, THE STOREY BELOW THE SLAB SHALL BE ENCLOSED.
PROTECTION SHALL BE MAINTAINED FOR AT LEAST THE SPECIFIED CURING PERIOD.
CONCRETE TEMPERATURE SHALL BE MAINTAINED ABOVE 10 DEGREES CELSIUS FOR THE SPECIFIED CURING PERIOD.

FORECASTED AIR TEMPERATURE BELOW -4 DEGREES CELSIUS
THE STOREY BELOW SHALL BE ENCLOSED AND ARTIFICIAL HEAT PROVIDED. HEATING TO BE STARTED AT LEAST ONE HOUR AHEAD OF POURING AND MAINTAINED FOR A MINIMUM OF THE SPECIFIED CURING PERIOD.
TEMPERATURE OF THE CONCRETE AT ALL SURFACES SHALL BE KEPT AT A MINIMUM OF 20 DEGREES CELSIUS FOR 3 DAYS OR 10 DEGREES FOR 7 DAYS. CONCRETE SHALL BE KEPT ABOVE FREEZING TEMPERATURES UNTIL IT REACHES 70% OF ITS SPECIFIED STRENGTH.
AN ENCLOSURE MUST BE CONSTRUCTED SO THAT AIR CAN CIRCULATE OUTSIDE THE OUTER EDGES AND MEMBERS.
REINFORCING TO BE COVERED AND WARMED TO MAINTAIN ITS TEMPERATURE AT 0 DEGREES CELSIUS OR HIGHER AT THE TIME OF CONCRETE PLACEMENT.

4 - WARNINGS

THE INSULATED BLANKET MUST BE INSPECTED PRIOR TO EACH USE TO ENSURE SAFE AND EFFECTIVE OPERATION. ALL ELECTRICAL CORDS MUST BE EXAMINED FOR FAULTS, CUTS, OR OTHER DAMAGE TO MINIMIZE THE RISK OF ELECTROCUTION. ANY SHARP EDGES OR DAMAGED SECTIONS OF THE BLANKET MUST BE IDENTIFIED AND REPAIRED TO REDUCE THE RISK OF CUTS AND SCRAPES.

ALL PERSONNEL USING THIS PRODUCT MUST BE PROPERLY TRAINED IN ITS OPERATION AND SAFETY PROCEDURES. UNDER NO CIRCUMSTANCES SHOULD WORN OR DEFECTIVE MATERIALS BE UTILIZED. SUCH MATERIALS MUST BE EITHER RETURNED TO THE MANUFACTURER FOR REPAIR OR DISPOSED OF IN ACCORDANCE WITH SAFETY STANDARDS.

4 - END-OF-LIFE

AT THE END OF THE PRODUCT'S SERVICE LIFE, COMPONENTS SHALL BE DISASSEMBLED AND PROPERLY DISPOSED OF ACCORDING TO THE FOLLOWING GUIDELINES:

1. POLYESTER PROTECTIVE SKIN: THE POLYESTER PROTECTIVE SKIN SHALL BE STRIPPED FROM OTHER COMPONENTS AND SENT TO A FABRIC RECYCLING CENTER.

2. POLYURETHANE FOAM: POLYURETHANE FOAM SHALL BE SENT TO A DOWN-CYCLING CENTER. IF A SUITABLE DOWN-CYCLING FACILITY CANNOT BE LOCATED, THE FOAM SHALL BE DISPOSED OF IN A LANDFILL OR SENT TO A COMBUSTION ENERGY RECOVERY CENTER.

3. ELECTRICAL HEATING ELEMENT: THE ELECTRICAL HEATING ELEMENT SHALL BE SENT TO AN ELECTRONIC RECYCLING CENTER TO ENSURE PROPER HANDLING AND RECYCLING OF ELECTRICAL COMPONENTS.

4. BUCKLING AND FABRIC MECHANISMS: ANY BUCKLING AND FABRIC MECHANISMS SHALL BE COLLECTED AND SENT TO AN APPROPRIATE RECYCLING CENTER.

PROPER ADHERENCE TO THESE DISPOSAL GUIDELINES WILL MINIMIZE ENVIRONMENTAL IMPACT AND COMPLY WITH APPLICABLE WASTE MANAGEMENT REGULATIONS.

Appendix F.2 - SolidWorks Hook Finite Element Analysis

This Appendix details the Solidworks force analysis discussed in Section 5.1.3.2.

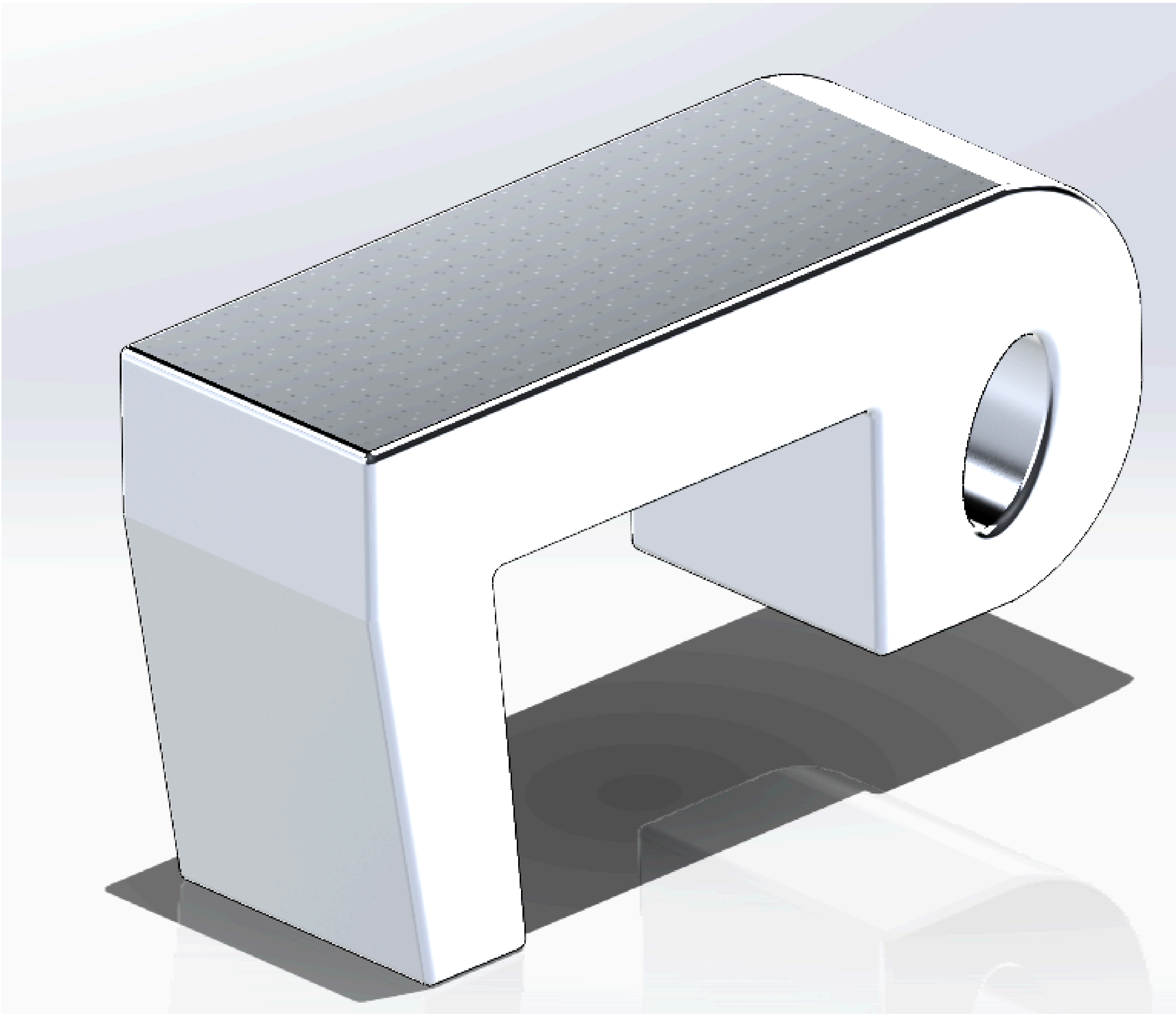


Figure F.2-1: Hook design 3D SolidWorks depiction.

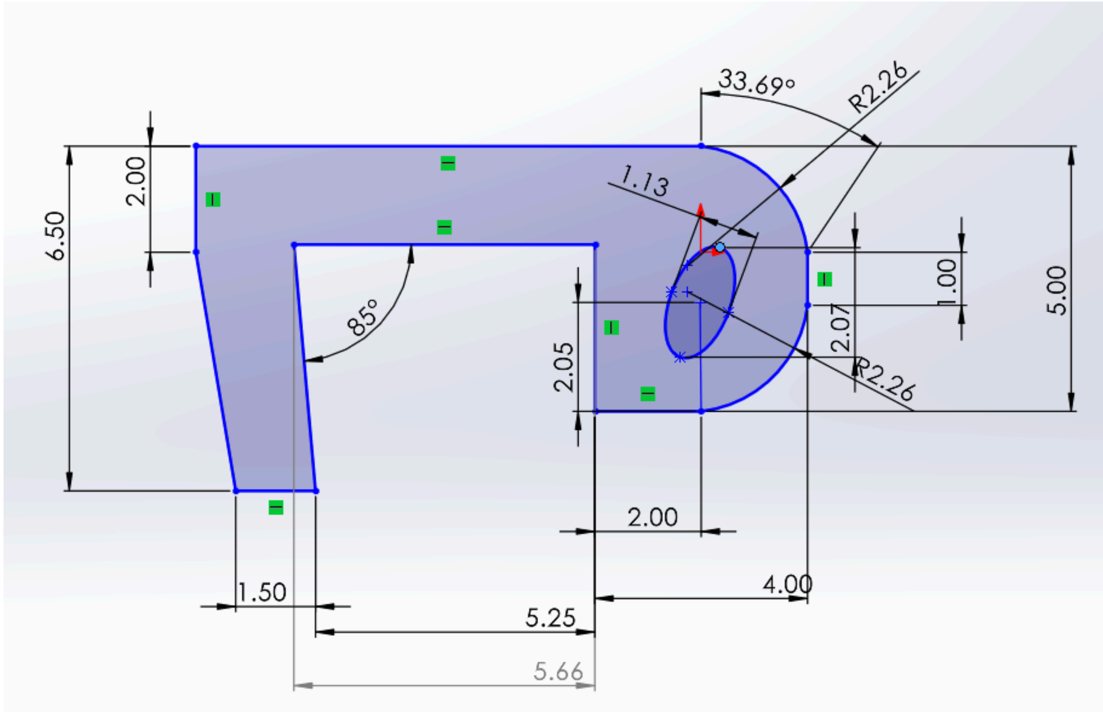


Figure F.2-2: Hook dimensions.

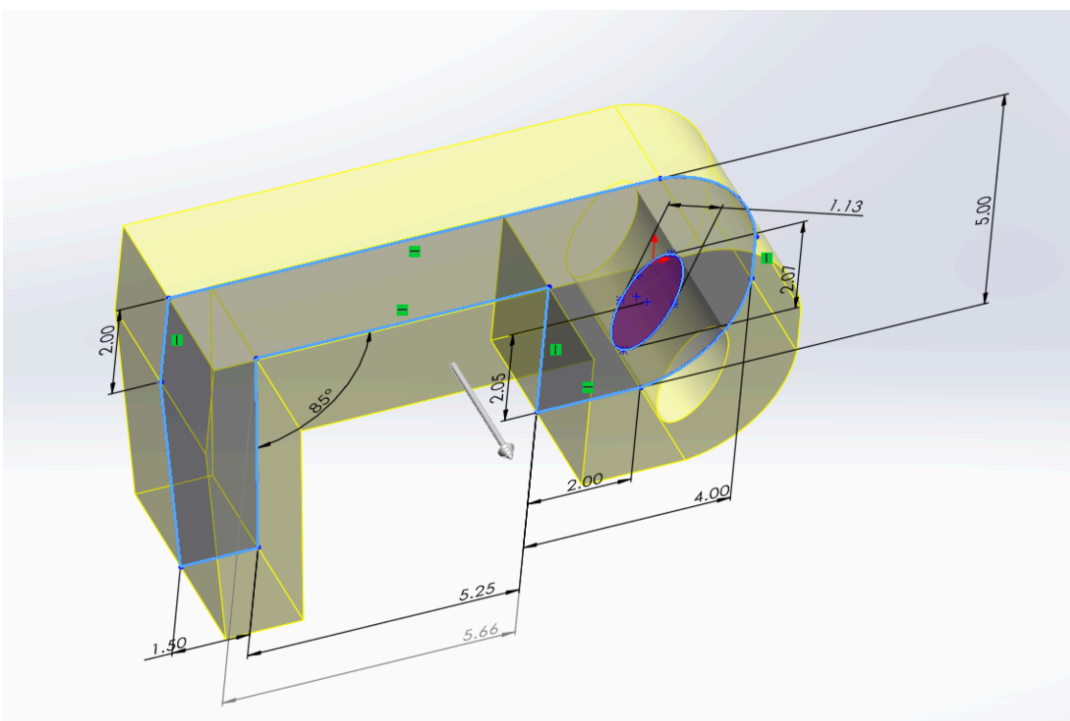


Figure F.2-3: Hook dimensions, depth of 4”.

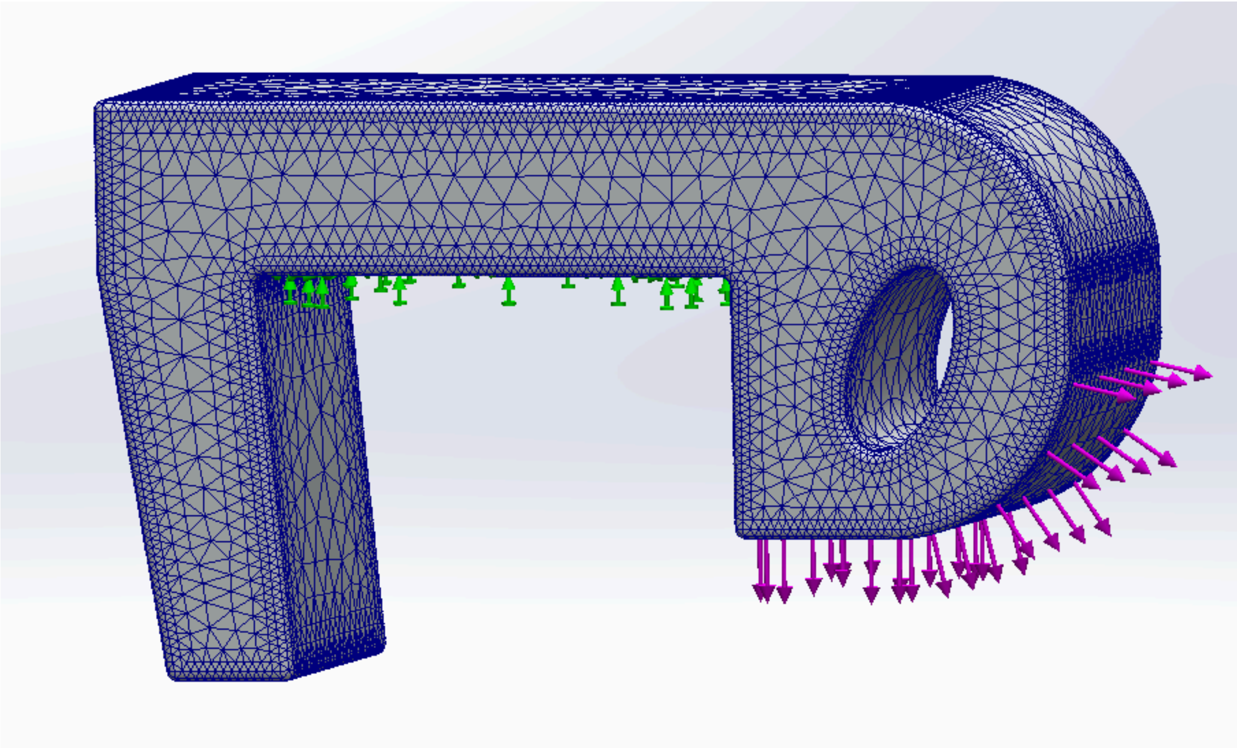


Figure F.2-4: Mesh.

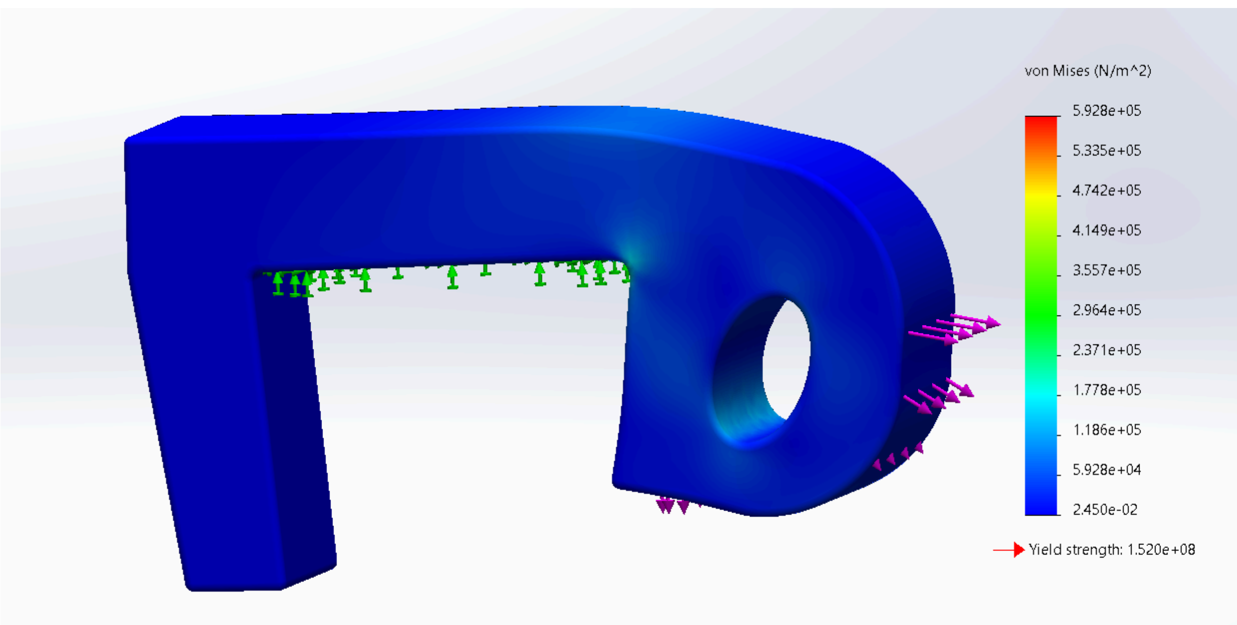


Figure F.2-5: Von Mises stress.

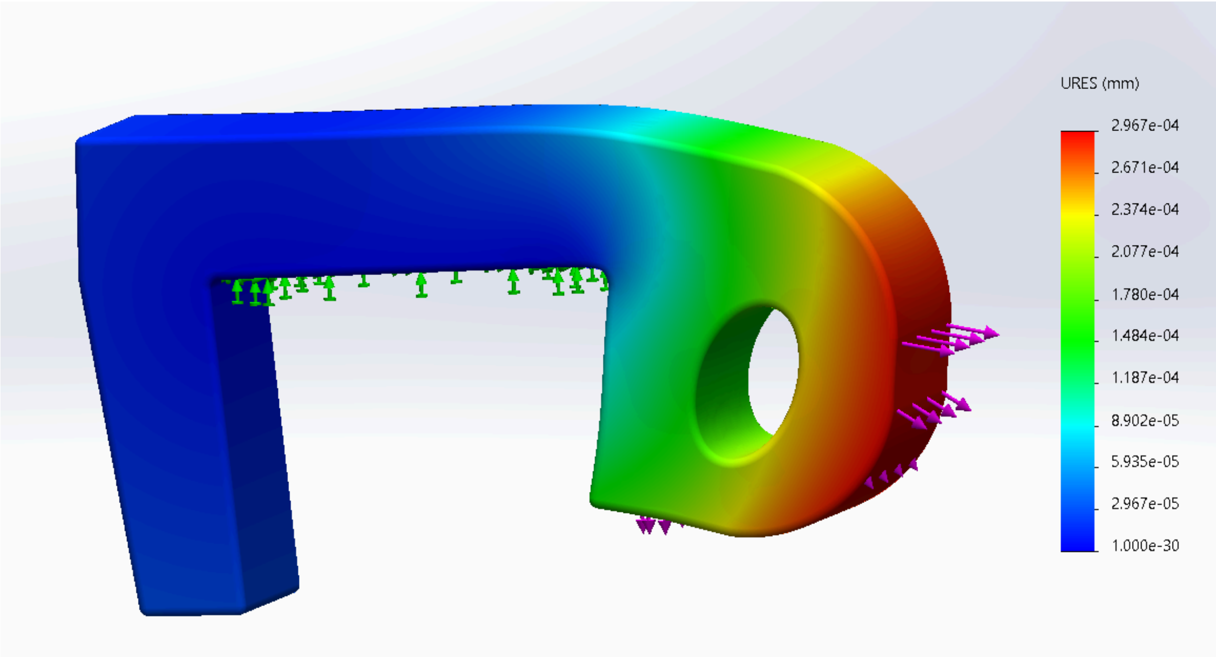
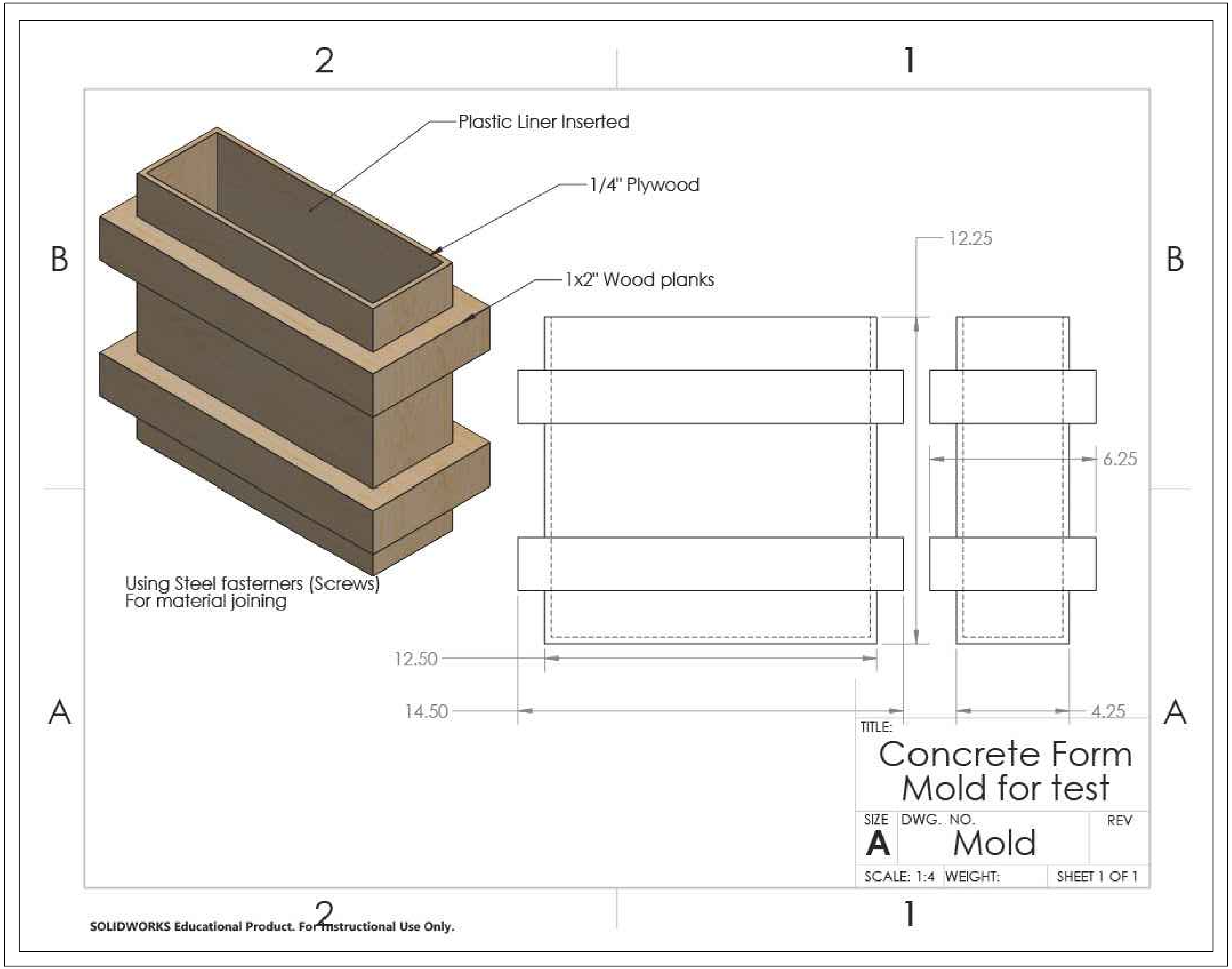


Figure F.2-6: Displacement

Appendix G - Prototype and Mold Engineering Drawings

The following pages include both the mold and prototype engineered drawings that were followed in the prototype design and mold design processes detailed in Section 5.2.1 and 5.2.2. The remainder of this page is left intentionally blank.



PROPOSED PROTO-TYPE

PREPARED FOR:

TRAINE

PREPARED ON:
March 28, 2025

Sheet Number	Sheet Name
1	Cover Page
2	Proto-type Formwork
3	Insulating Proto-type Blanket Components
4	Insulating Proto-type Blanket Assembly
5	Prototype Hook Design
6	Prototype Assembly Photos
7	Finished Prototype Photos
8	Prototype Concrete Testing Photos

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SHEET
1
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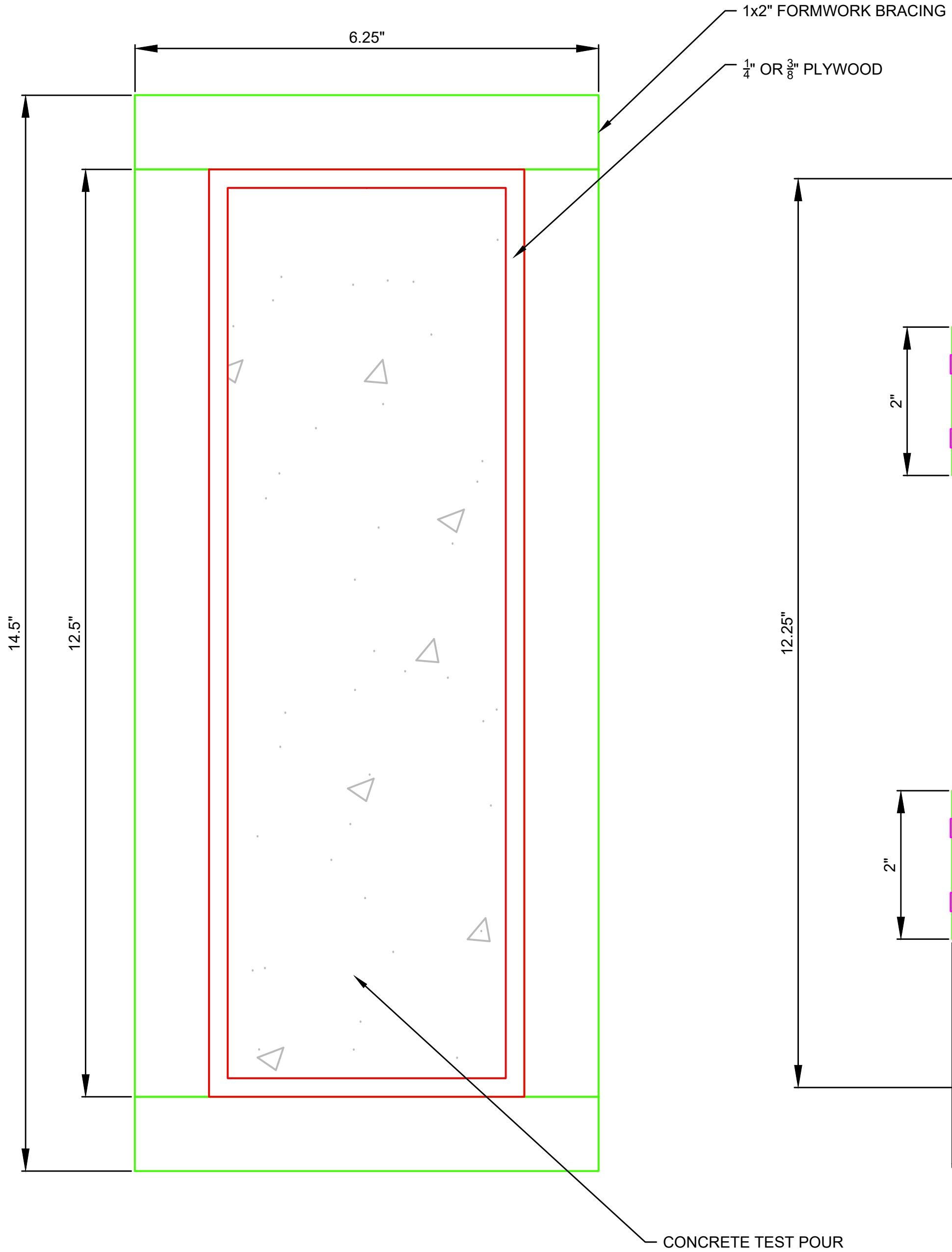
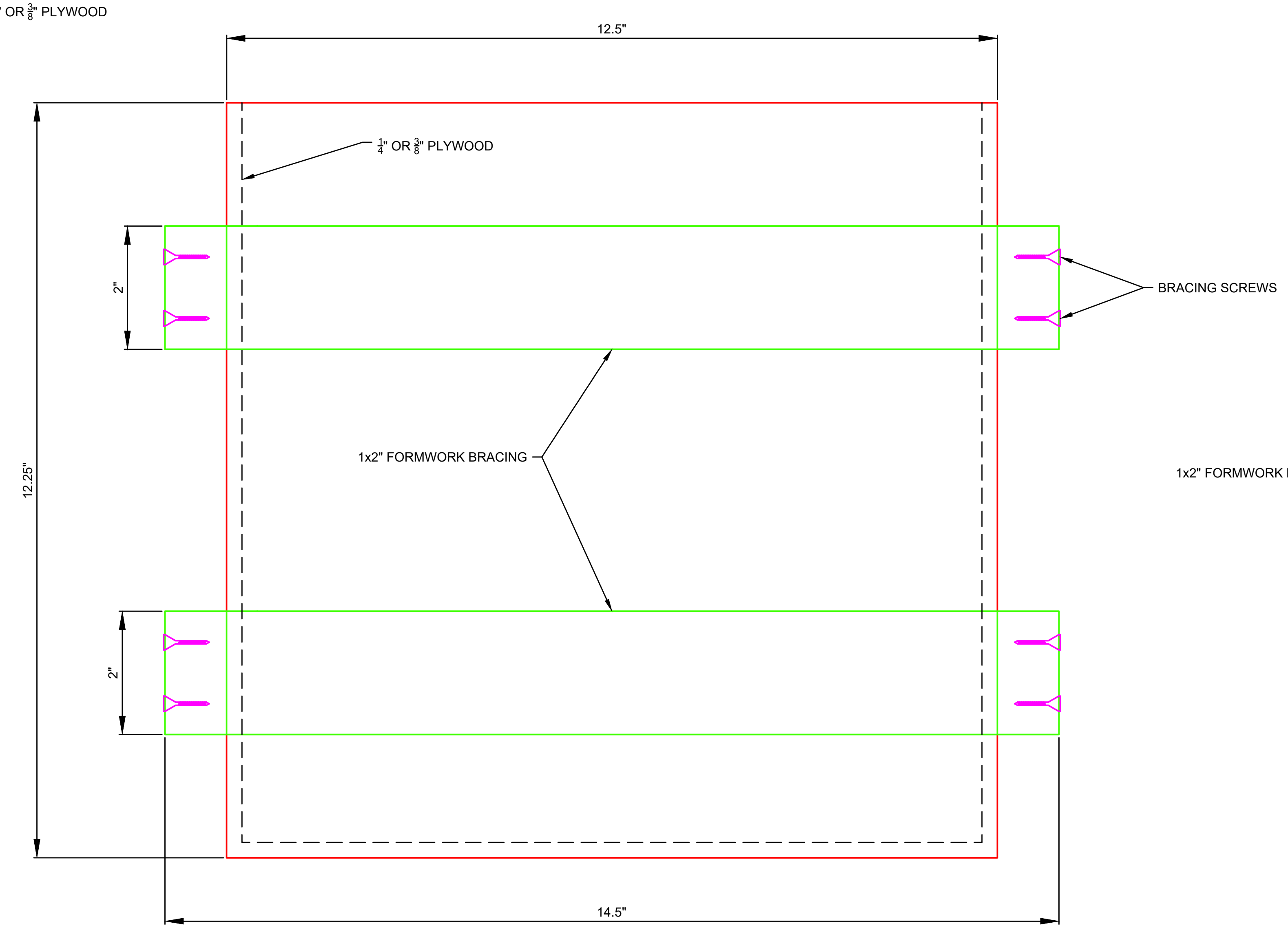
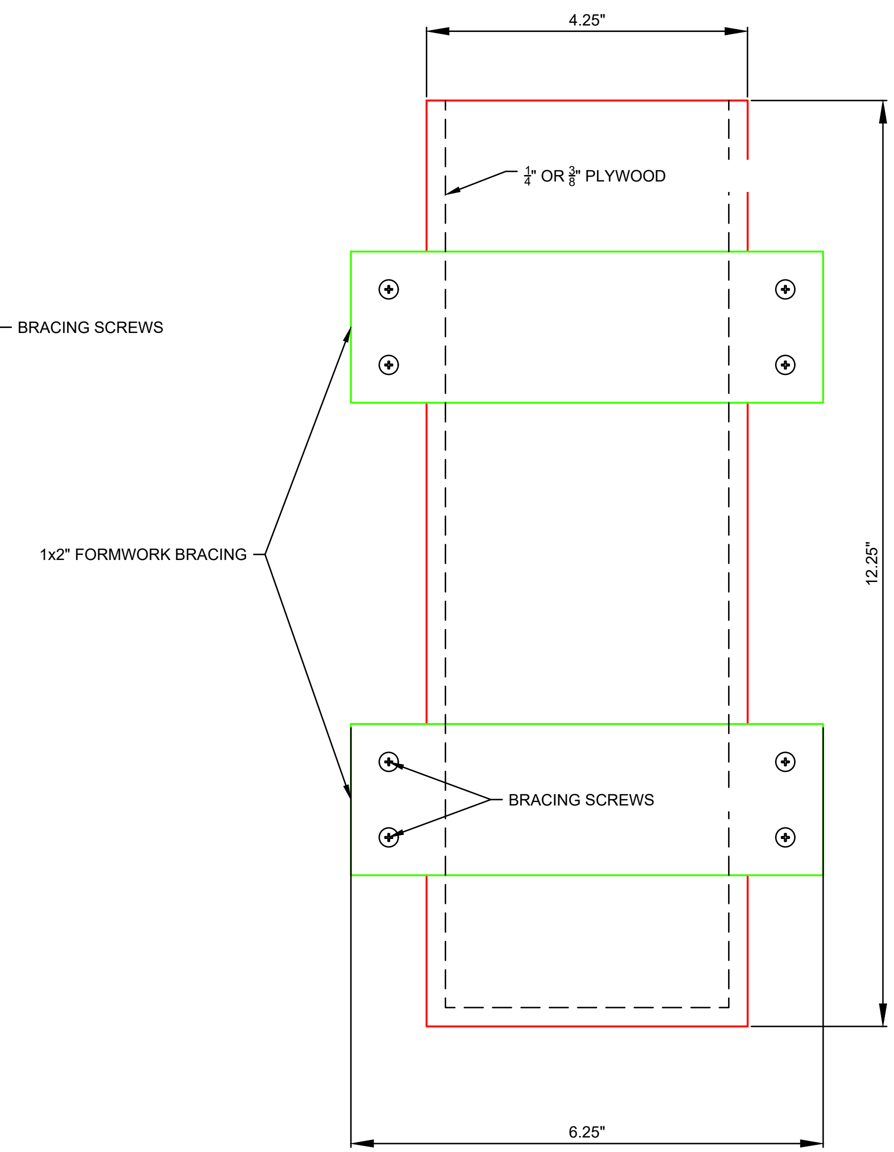
		REVISION DESC.	-







FORMWORK TOP VIEW
SCALE 1:100

FORMWORK SIDE VIEW
SCALE 1:100

FORMWORK FRONT VIEW
SCALE 1:100

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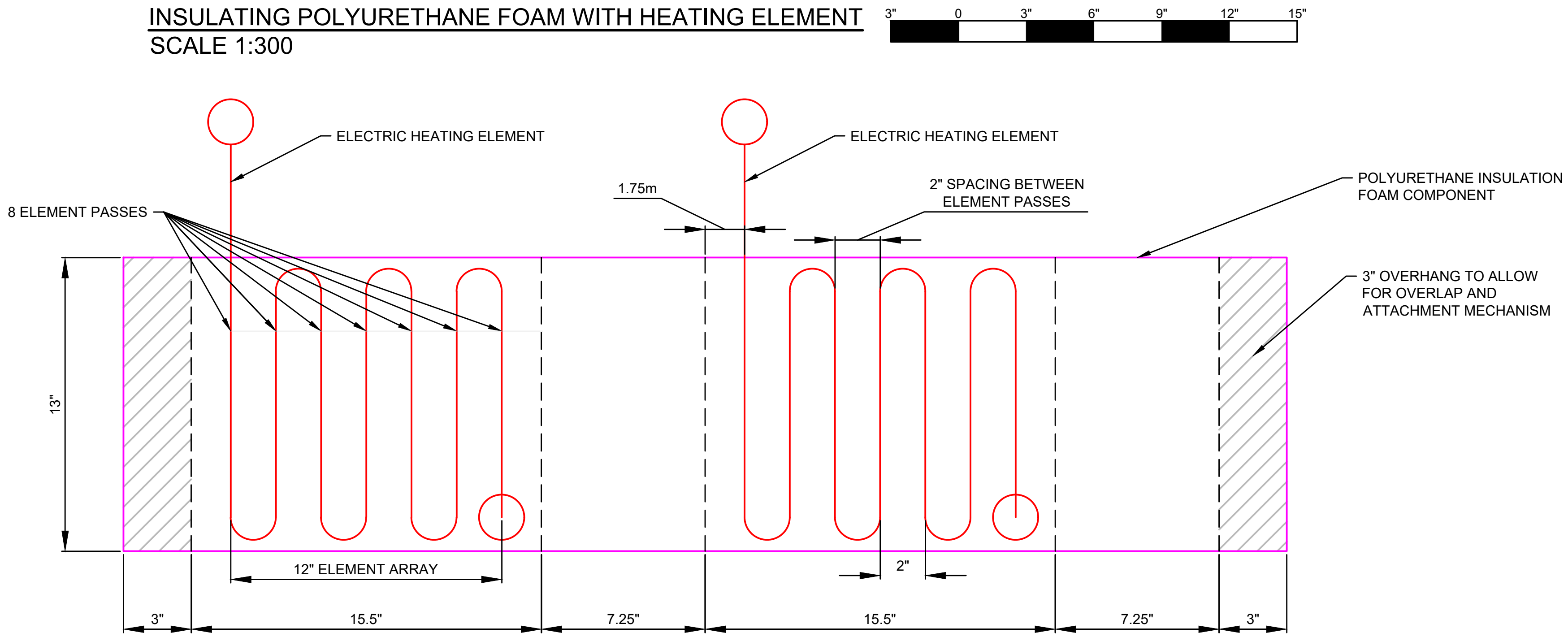
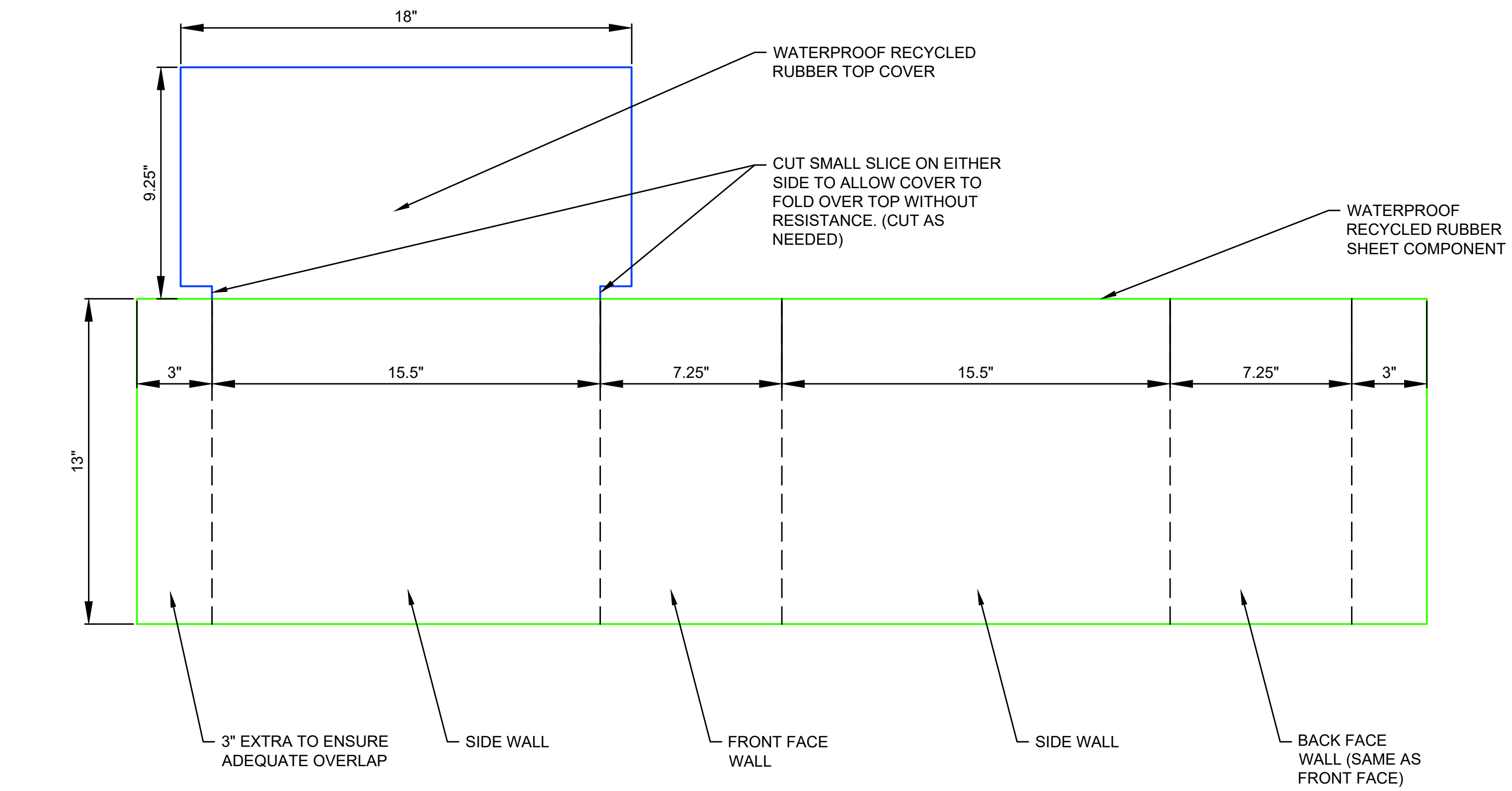
PROPOSED PROTO-TYPE

SHEET NAME:
PROTO-TYPE FORMWORK

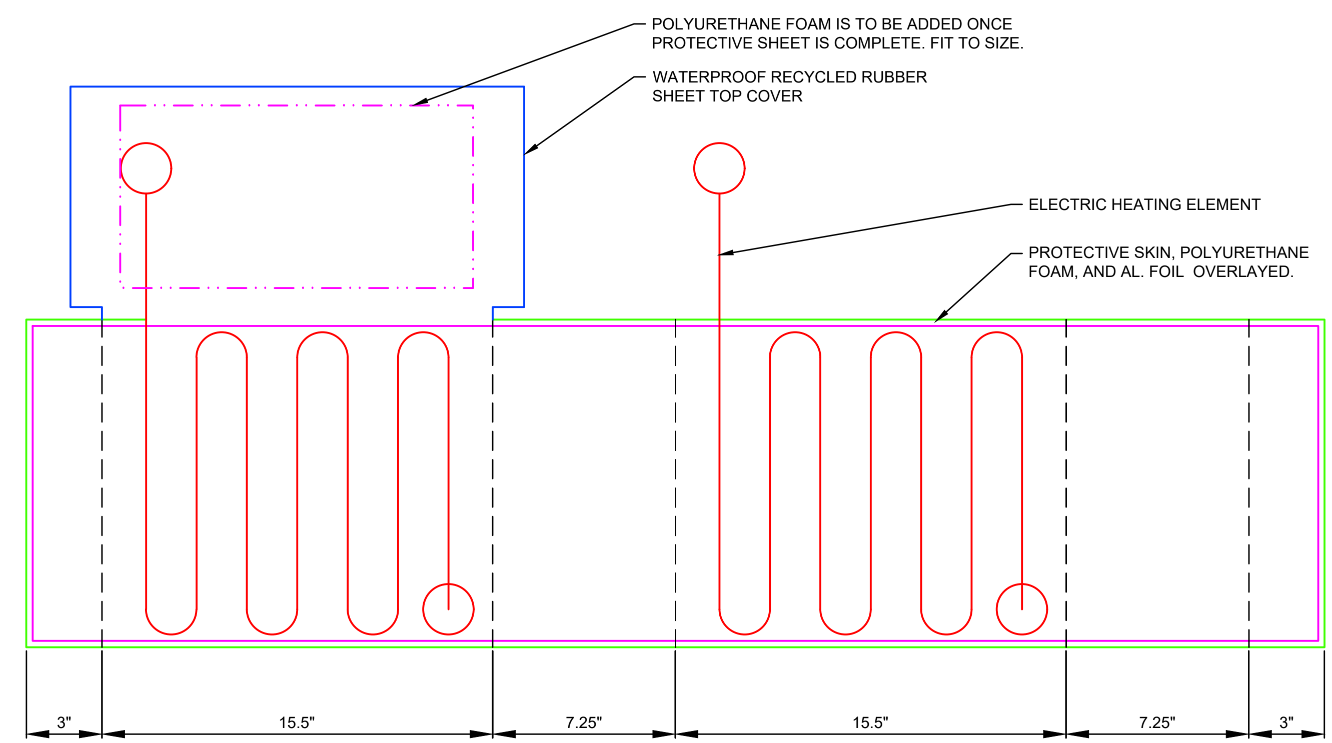
SCALE: As Indicated	REFERENCE DRAWING: ROV Engineering Consultants
DESIGN BY: Infrastructure Group A	DRAWING DATE: March 28, 2025
DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
REVIEWED BY: To Be Determined	REVISION DATE:-
CONCEPT DATE: JAN, 21, 2025	DWG#: 001

INSULATING POLYURETHANE FOAM WITH HEATING ELEMENT
SCALE 1:300





WATER PROOF RECYCLED RUBBER SHEET
SCALE 1:300



COMBINED COMPONENTS
SCALE 1:300

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	DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
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	CONCEPT DATE: JAN, 21, 2025	DWG#: 001

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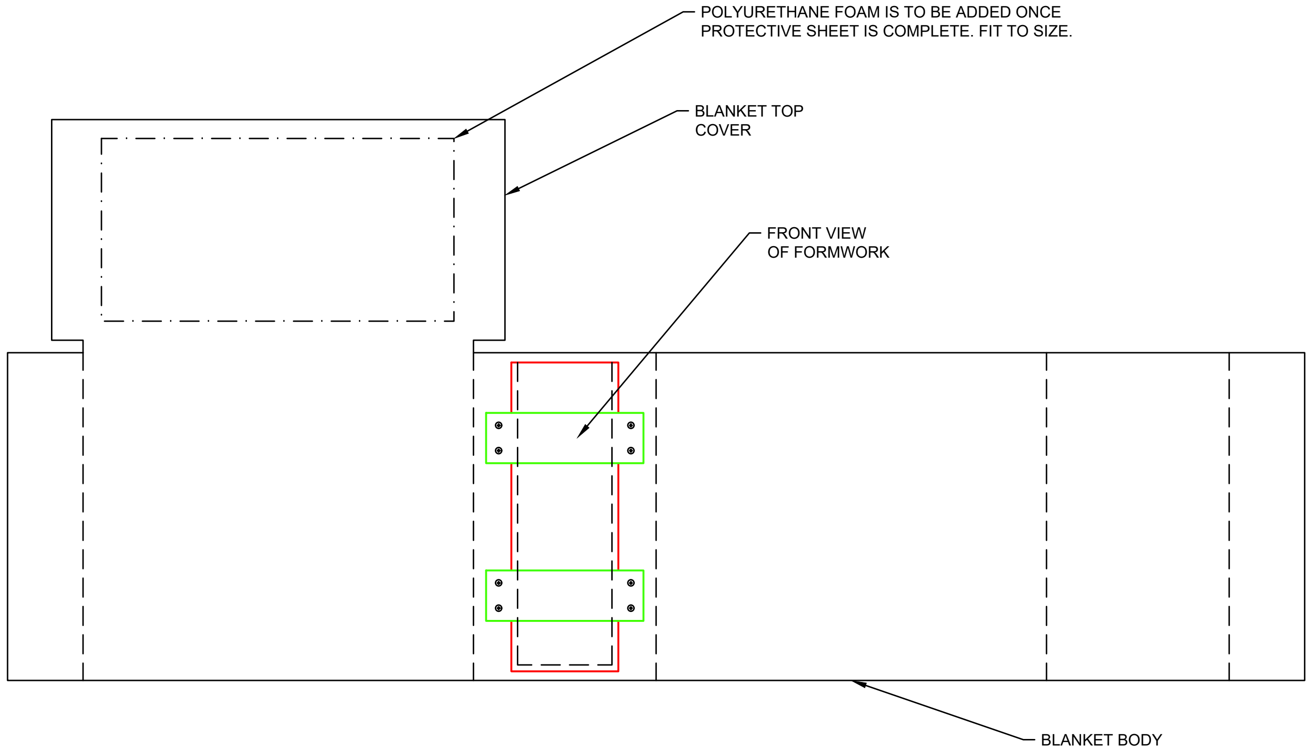

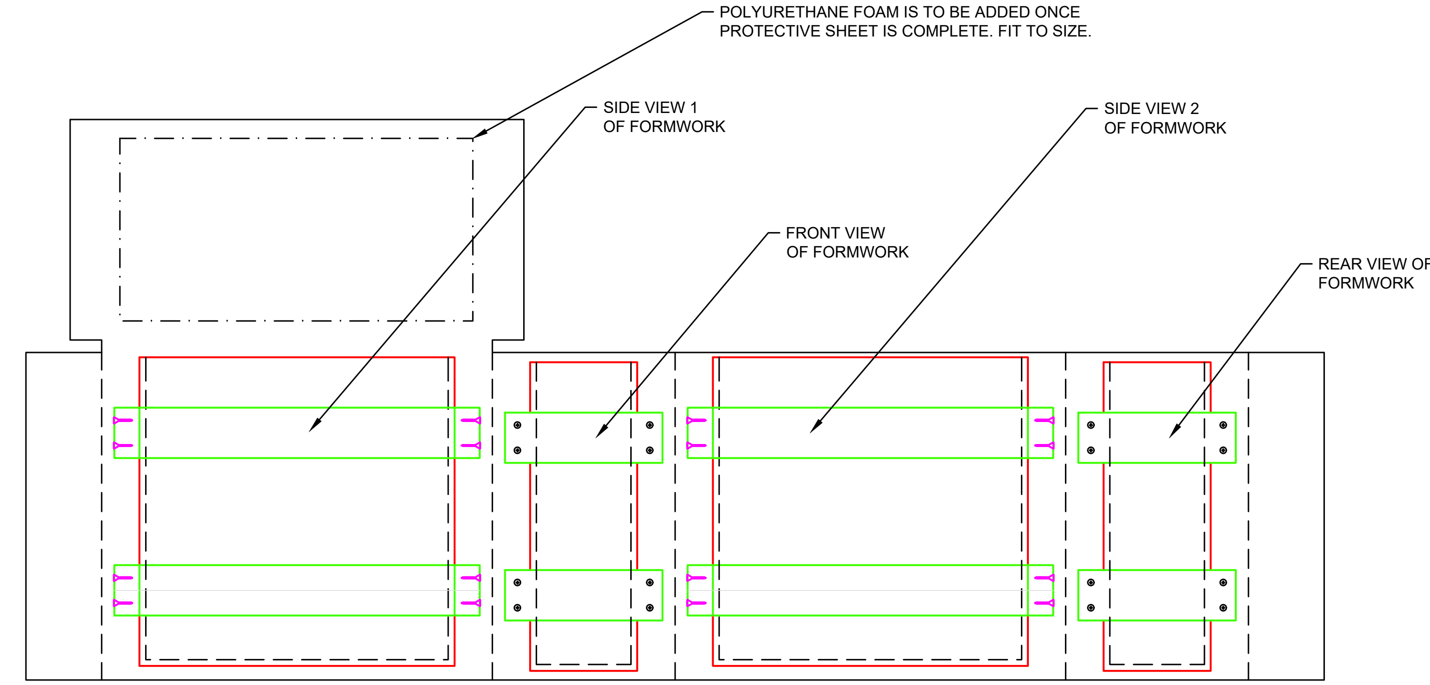

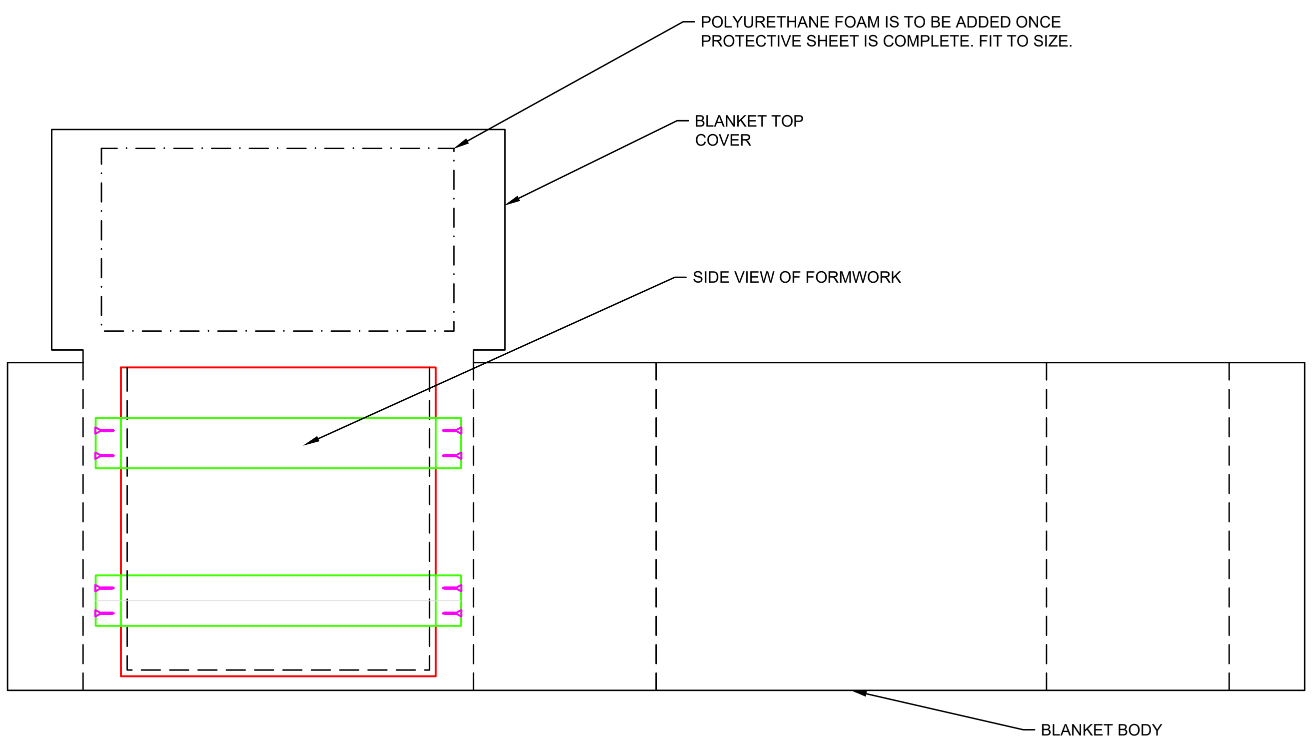

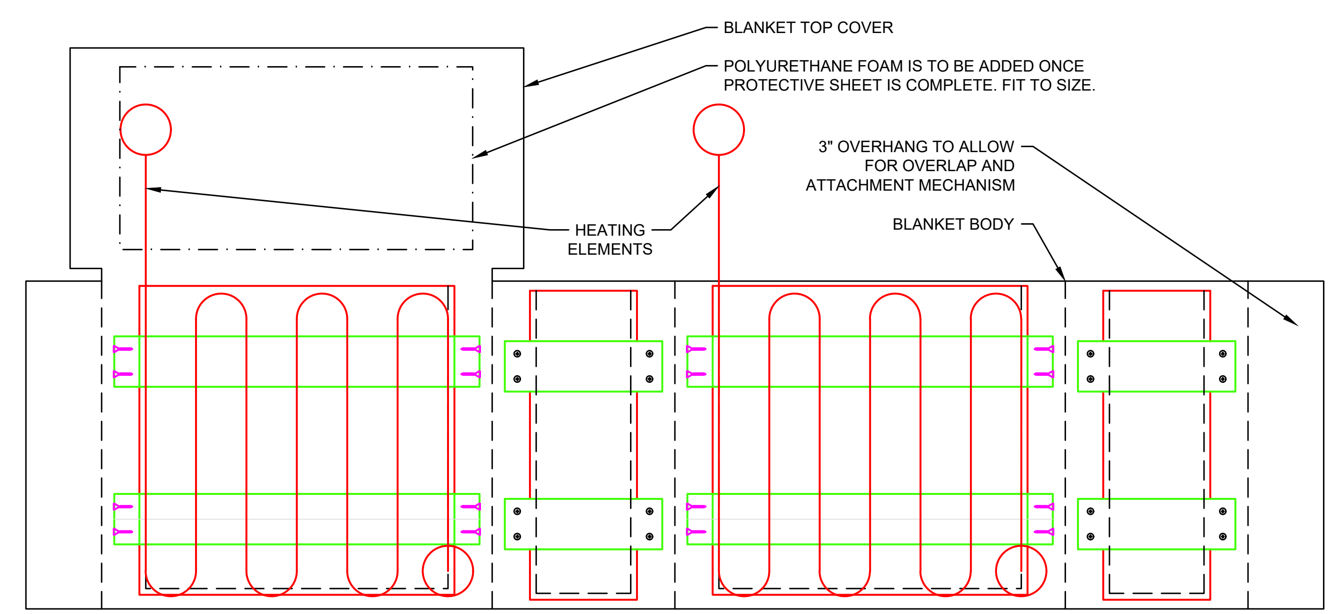

BLANKET COMPONENTS COMBINED WITH FORMWORK
SCALE 1:300

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SHEET NAME: INSULATING PROTOTYPE BLANKET ASSEMBLY

SCALE: As Indicated	REFERENCE DRAWING: ROV Engineering Consultants
DESIGN BY: Infrastructure Group A	DRAWING DATE: March 28, 2025
DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
REVIEWED BY: To Be Determined	REVISION DATE:-
CONCEPT DATE: JAN, 21, 2025	DWG#: 001

SHEET 4 OF 8

PROTOTYPE HOOK - TOP VIEW

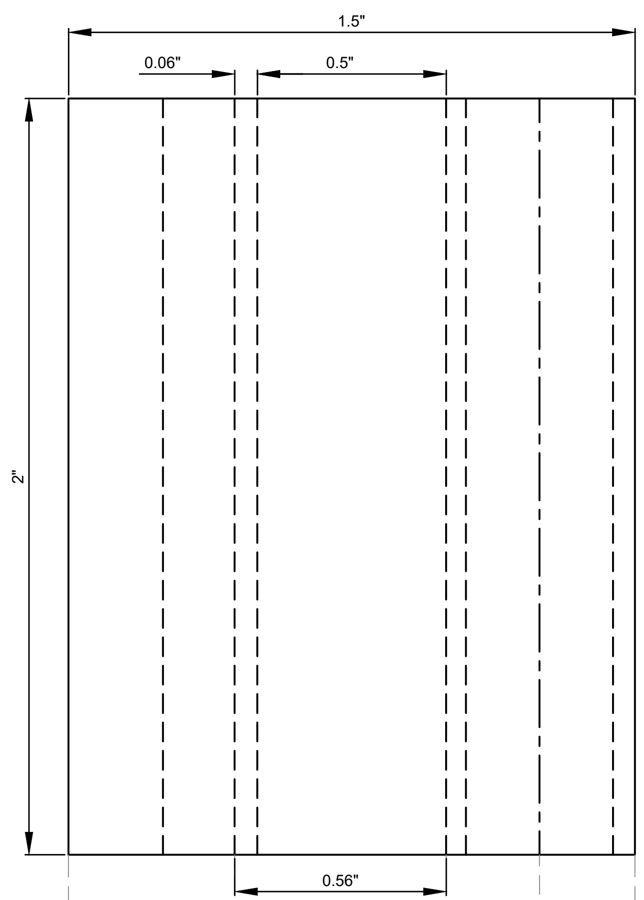
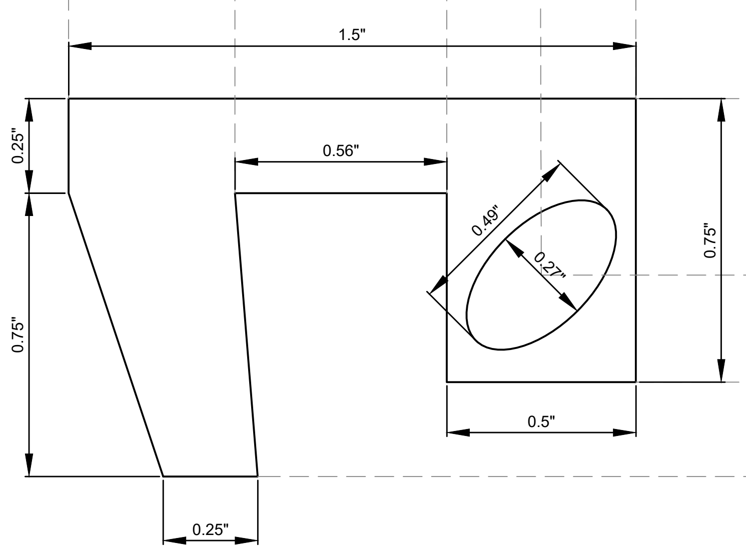
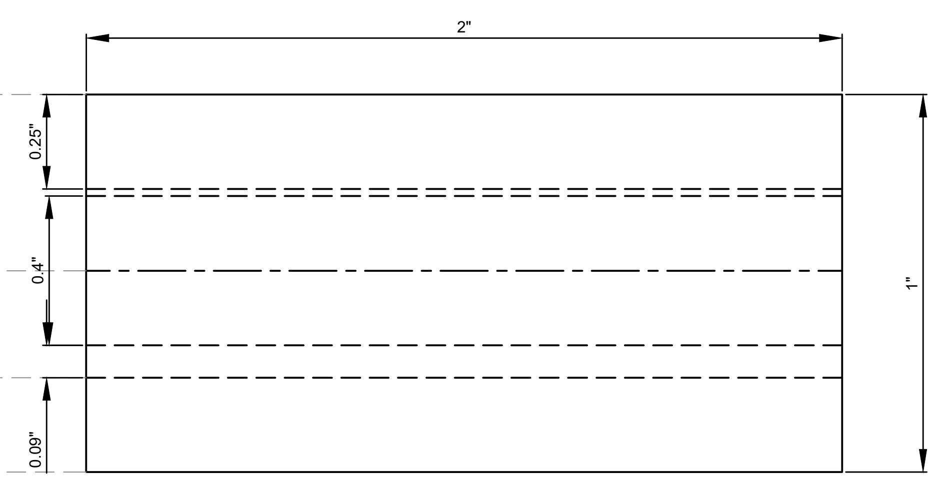


FIGURE TO THE LEFT WAS GENERATED BY SOLIDWORKS, AND REPLICATED ON AUTOCAD FOR CONSISTENCY. HOOK WAS DESIGNED AND DRAWN ON SOLIDWORKS BY SEBASTIAN SCHMIDT.



PROTOTYPE HOOK - SIDE VIEW



PROTOTYPE HOOK - FRONT VIEW

THE HOOK DESIGN IS INTENDED TO TRANSFER THE LOAD FROM THE BLANKET TO THE FORMWORK, REDUCING STRESS ON THE INSULATIVE MATERIAL AND FACILITATING EASIER HANDLING BY WORKERS. ALTHOUGH THE HOOKS WERE NOT IMPLEMENTED ON THE PROTOTYPE DUE TO THEIR UNNECESSITY, THEY WILL BE PRODUCED USING A 3D PRINTER FOR DEMONSTRATION PURPOSES.

PROTOTYPE HOOK IS TO BE MADE FROM RECYCLED THERMOPLASTIC.

ACTUAL HOOK IS TO BE CONSTRUCTED OF ALUMINUM 356-T6, DESIGN DIMENSIONS ARE TO BE DETERMINED.

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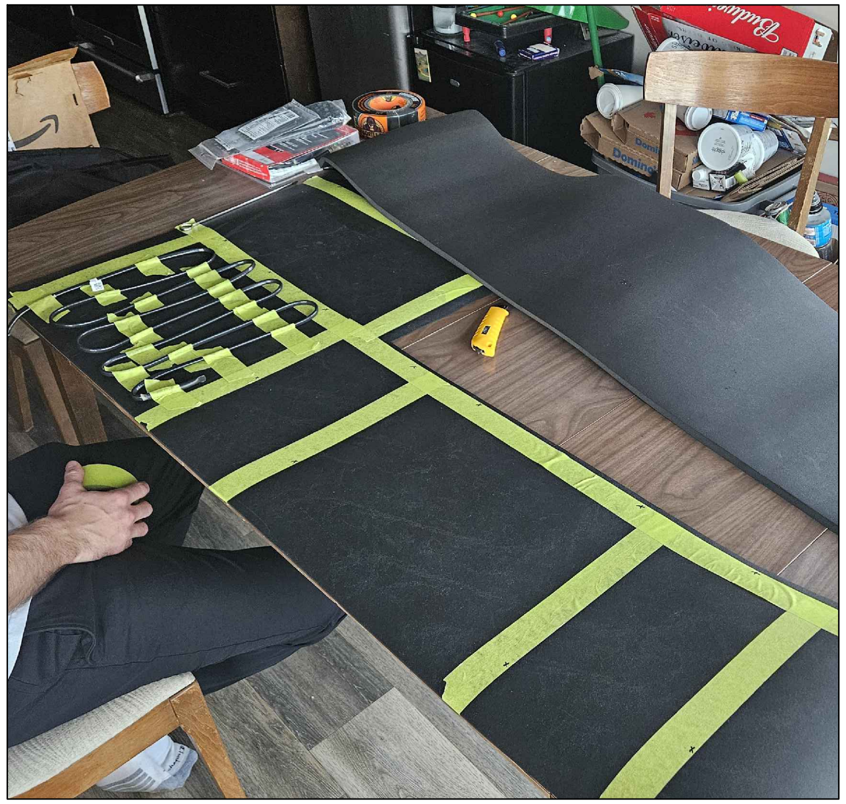
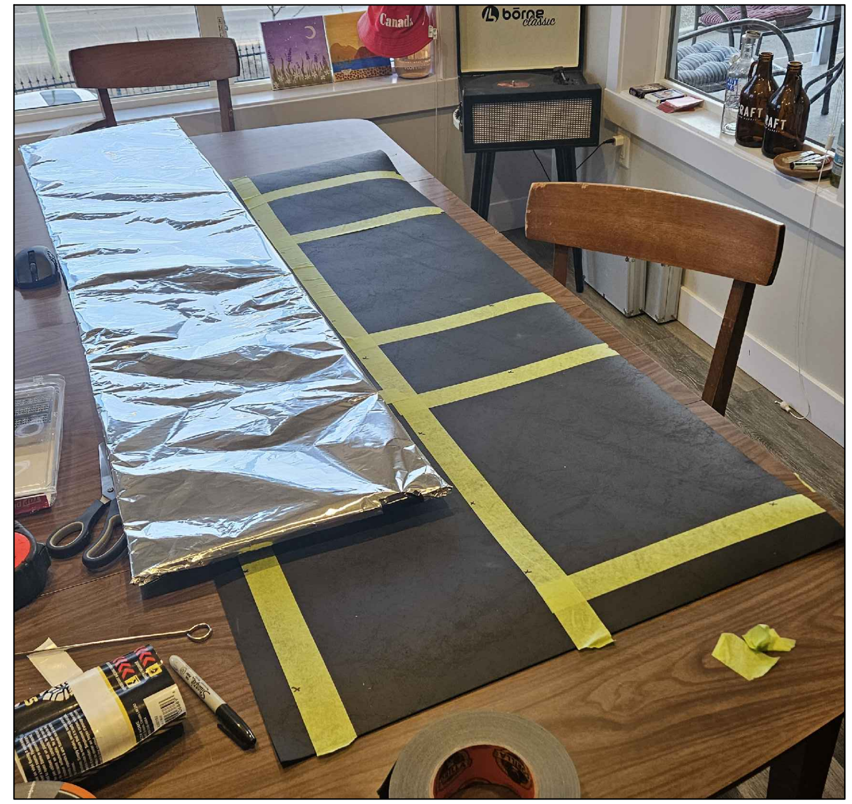
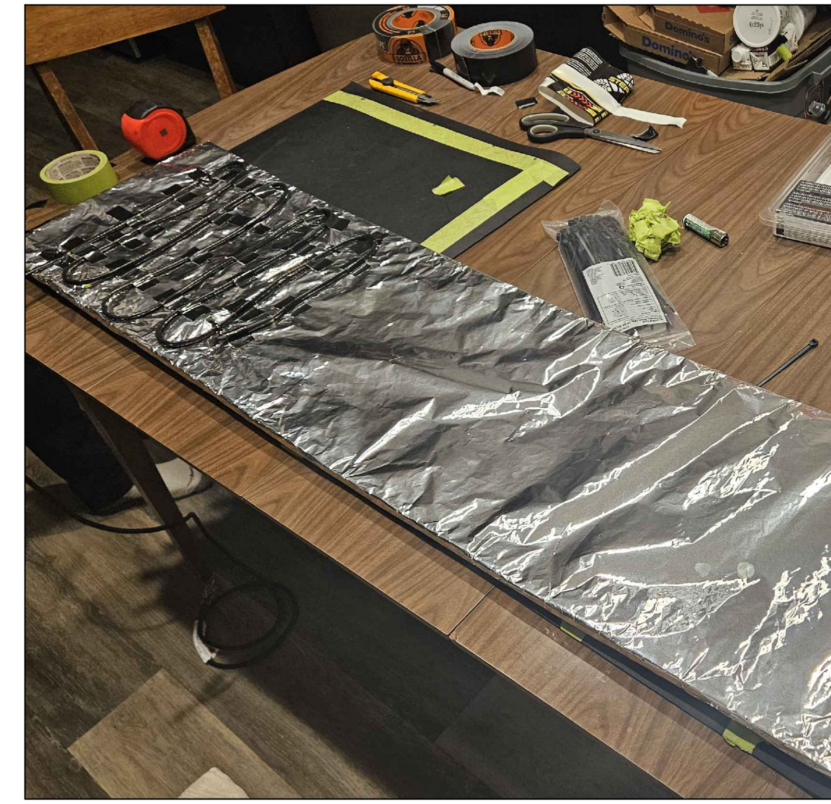
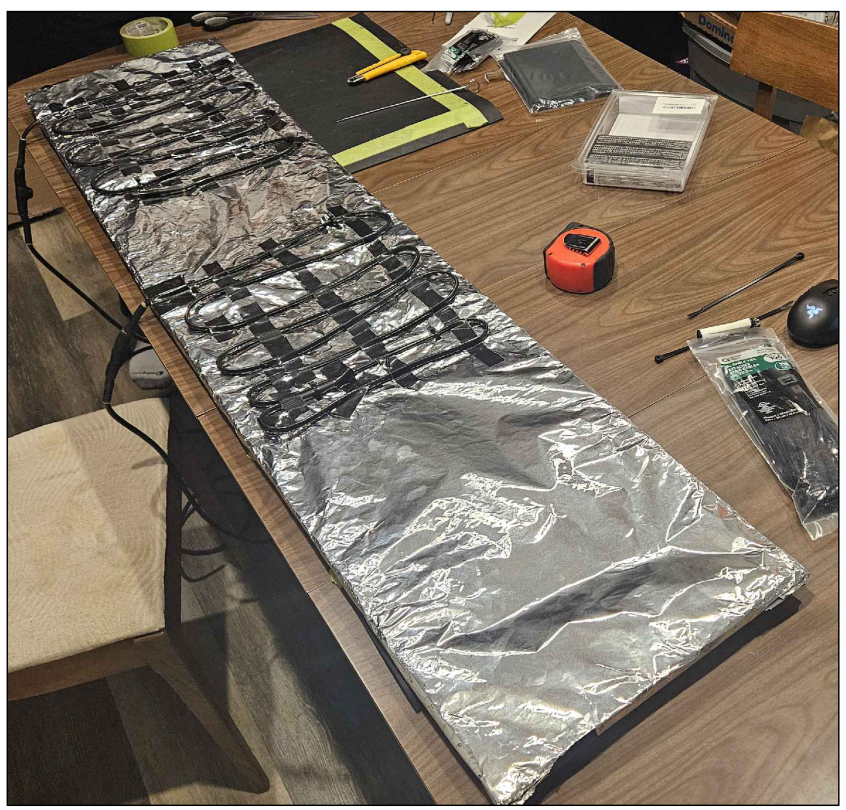
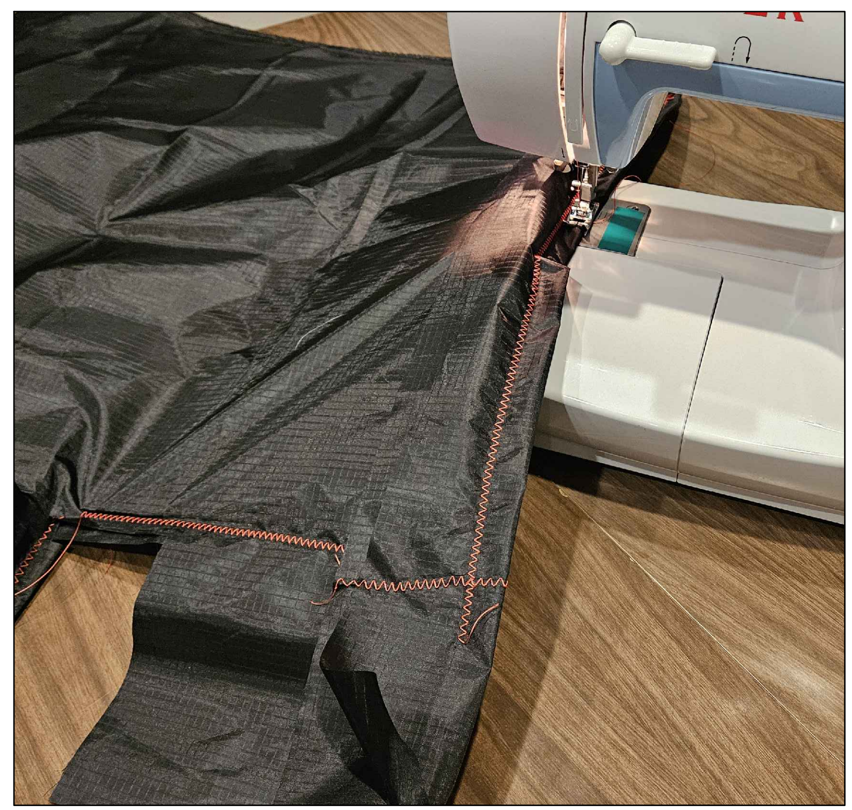
	DESIGN BY: Infrastructure Group A	DRAWING DATE: March 28, 2025	5
	DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0	OF 8
SHEET NAME:	REVIEWED BY: To Be Determined	REVISION DATE:-	
PROTOTYPE HOOK DESIGN	CONCEPT DATE: JAN, 21, 2025	DWG#: 001	


Blanket Components


Initial Assembly


Applying Electrical Heating Element


Finished Internal Components


Sewing Process


Protective Skin and Inner Components

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PROPOSED PROTO-TYPE

SHEET NAME:
PROTOTYPE ASSEMBLY PHOTOS

SCALE: As Indicated	REFERENCE DRAWING: ROV Engineering Consultants
DESIGN BY: Infrastructure Group A	DRAWING DATE: March 28, 2025
DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
REVIEWED BY: To Be Determined	REVISION DATE:-
CONCEPT DATE: JAN, 21, 2025	DWG#: 001

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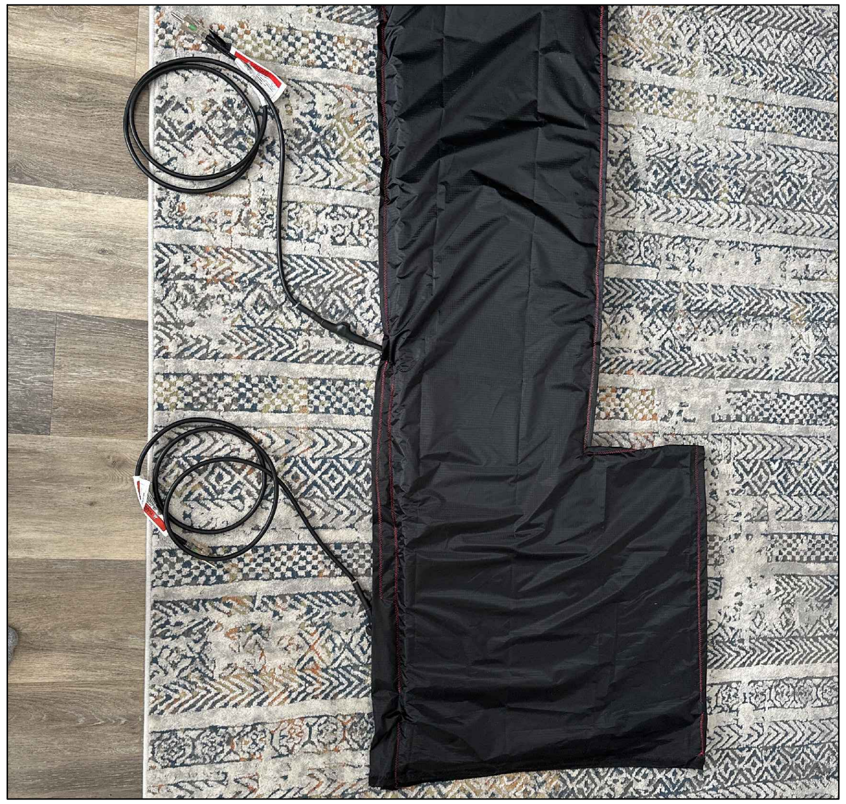
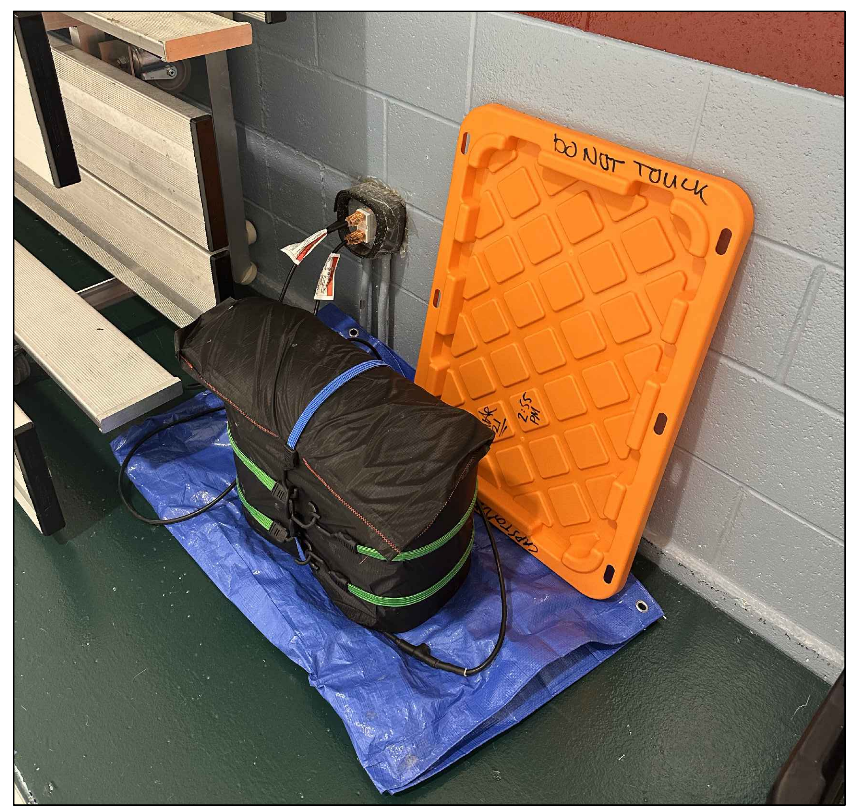
OF 8


Finished Prototype - 1

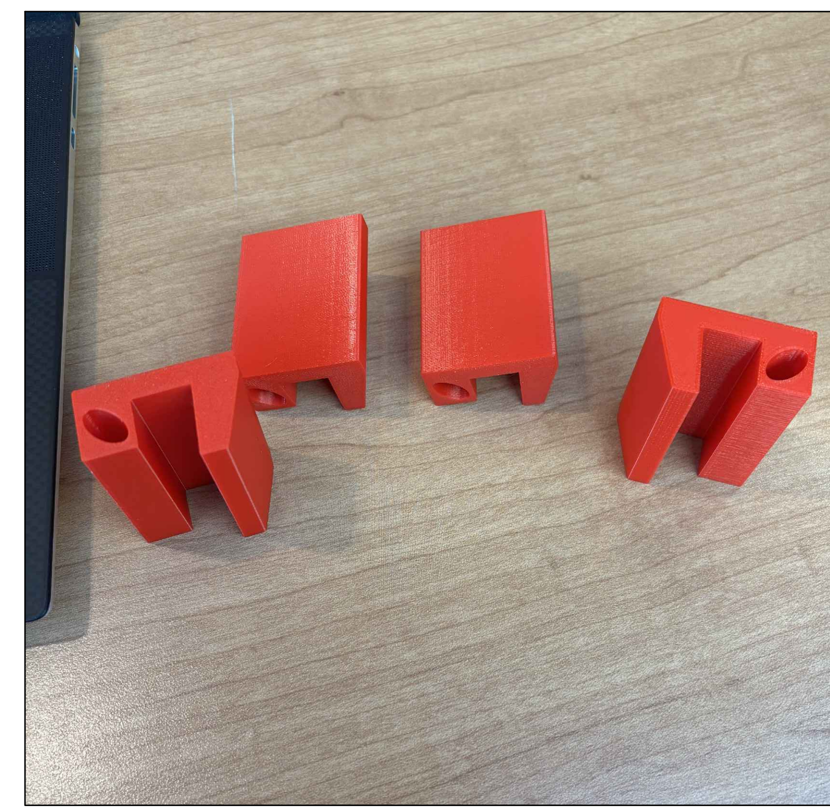

Finished Prototype - 2


Prototype Concrete Formwork


Prototype Transportation



Prototype In Use


Prototype Hooks

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SHEET NAME:
FINISHED PROTOTYPE PHOTOS

SCALE: As Indicated	REFERENCE DRAWING: ROV Engineering Consultants
DESIGN BY: Infrastructure Group A	DRAWING DATE: March 28, 2025
DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
REVIEWED BY: To Be Determined	REVISION DATE:-
CONCEPT DATE: JAN, 21, 2025	DWG#: 001

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OF 8

Formwork with Concrete Sample

Concrete Sample

Concrete Compression Strength Test

Cold Environment Concrete Sample

Prototype Covered Concrete Sample

Baseline Concrete Sample (Ideal Conditions)

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PROPOSED PROTO-TYPE

SHEET NAME: PROTOTYPE CONCRETE TESTING PHOTOS

SCALE: As Indicated	REFERENCE DRAWING: ROV Engineering Consultants
DESIGN BY: Infrastructure Group A	DRAWING DATE: March 28, 2025
DRAWN BY: Jeffrey Robertson	REVISION NUMBER: 0
REVIEWED BY: To Be Determined	REVISION DATE:-
CONCEPT DATE: JAN, 21, 2025	DWG#: 001

SHEET 8 OF 8

Appendix H - Testing Results

Further details of the results presented in Section 5.2.4 are provided herein.

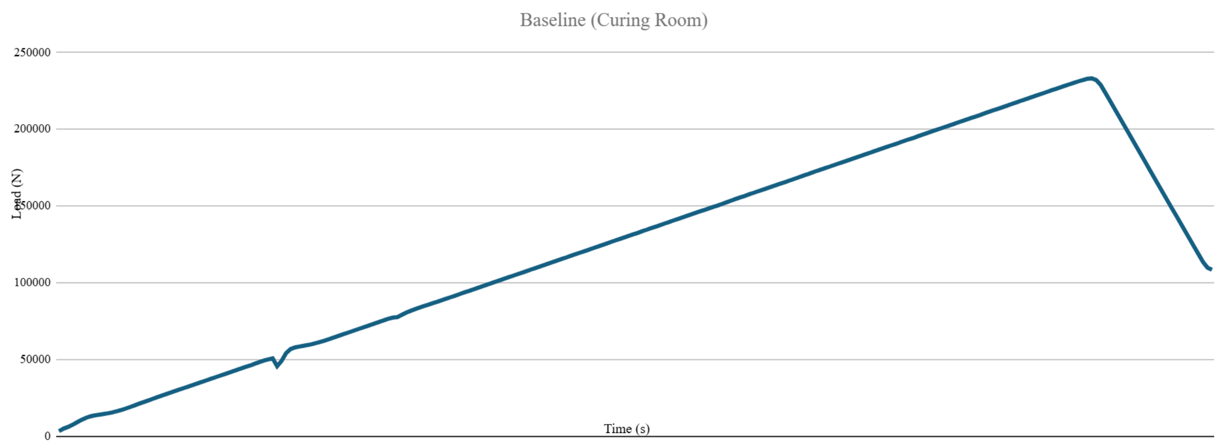

Figure H-1: Ideal conditions curing concrete compression test.

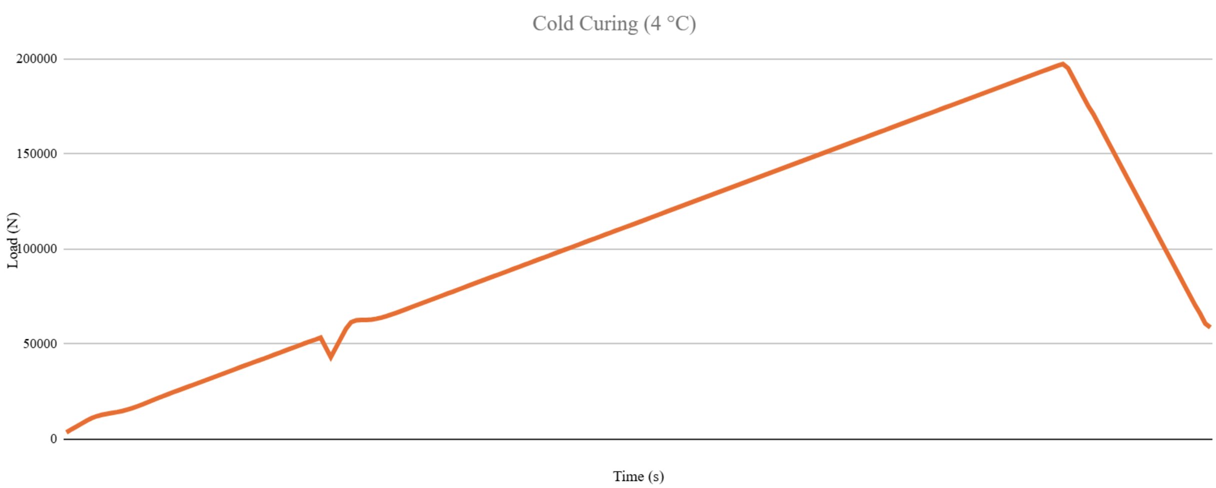

Figure H-2: Cold curing concrete compression test.

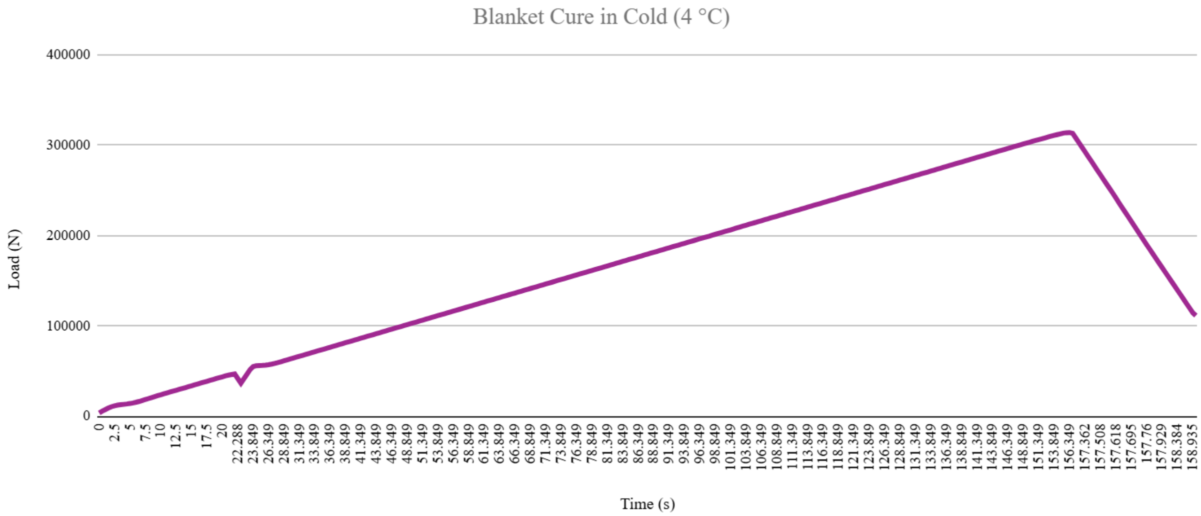

Figure H-3: Cold curing with heating apparatus concrete compression test.

Appendix *I* - Risk Assessment

This Appendix expands on Section 6. The problem statement pertains to the curing of concrete formwork in winter conditions.

Risks:

- **Falls** - Formwork often contains substantial concrete structures, posing large potential fall risks from an elevated structure or into excavated holes/pits. The work zone also has high potential for trips, slips and minor falls which together comprise the most frequent hazards experienced on worksites.
- **Material handling** - The possible solutions involve the carrying of excessive weight which can contribute to muscle, bone and body injuries resulting in serious and even fatal events.
- **Moving and stationary objects** (struck by, struck against, etc.) - Operators in the area of concrete formwork may be exposed to impacts from stationary or moving objects that can lead to serious or fatal injury. Concrete contains rebar which is often protruding from forms, introducing an impalement hazard.
- **Electrical potential** - Use of power tools, electrical equipment and machines lead to the risk of electrocution when high potential lines are exposed. Often sites are exposed to the elements, increasing the risk of interaction with electrical sources through water or moisture exposure.
- **Eye injury** - Projectiles, dust, sunlight, welding flash ect. May be common occurrences within the area of work, these can lead to temporary or permanent blindness when improper PPE or major interactions with dangers occur.
- **Health hazards** (chemical and physical) - Materials and chemicals such as paint, adhesives, concrete and concrete additives are often toxic, pressurized or carcinogenic and may impact the health of personnel on site. For example, concrete contains silica which is a significant health hazard for the respiratory system.
- **Confined space** - Formwork in pre-existing structures or small structures may create a risk of access to confined spaces. These areas have limited egress/access, light and visibility to other personnel. They are a high potential hazard that can result in injury or death.

- **Weather and environment** - Formwork is often installed in exposed areas where elements are in direct contact with operations. Hazards include heat stroke, freezing temperatures, lightning, rain and dust. These can interfere with safe operations.

Risk Analysis Table Legend

Related Risk Categories:

- Physical hazard (slip trip fall, impalement, crushing hazard, suffocation, burns, etc.)
- Chemical hazard (chemical burns, poisoning, possible carcinogens and airborne dangers)
- High potential energy hazards (electrification, moving objects, high pressure systems)
- Monetary hazard (loss of investment, liability risk, time)

Risk Potential levels:

1. High potential (deadly or serious injury)
2. Moderate potential (mild to serious injury with lowered frequency)
3. Low potential (both low and high frequency risks with a low physical impact or minor injury involved)

Risk Frequency levels:

1. High frequency (very likely to occur)
2. Moderate frequency (often to occur)
3. Low frequency (unlikely to occur)

Table *I*-1: Risk Matrix				
Risk event	Risk Category	Risk Potential Level	Risk Frequency	Mitigation
Formwork Includes large obstructions and major tripping hazards	Physical hazard	2	2	Signage and area restriction using both taped off sections or access railings
Heights over 6ft including deep holes or pits	Physical hazard	1	1	Fall arrest systems, railings limit access to areas
Falling objects including large wall structures	Physical hazard	1	2	PPE (hardhats) overhead cover systems
Rebar for concrete pouring often jutting from wall creating impalement hazard	Physical hazard	2	3	Signage and area restriction using both taped off sections or access railings
confined spaces	Physical hazard	2	1	Lockout tag out system, Confined space work system (constant supervision from outside of space)
Use of power equipment and minor electrical tools	High potential energy hazard	1	1	CSA approved equipment, wiring routing and covers
Concrete mixture includes silica	Chemical hazard	1	2	CSA approved half mask respirators with related filters

Operation of large motorized equipment in the local work area	Physical hazard	1	2	Hazard area analysis and restrict access. Operator radio and communication systems
Electrical shock	High potential energy hazard	2	2	Rubber gloves and shock resistant CSA safety boots
Formwork failure or premature removal resulting in concrete failure	Physical hazard	1	3	
Weather condition hazards (storms, cold, overheating)	Physical hazard	2	1	CSA boots, railings, textured walkways, salt and ice mitigation, shoe spikes. Housekeeping practices
Eye injury	Physical hazard	2	2	CSA safety glasses and face shields
Material handling	Physical hazard	2	3	Lifting equipment and procedures

Appendix J - Letter from the Client, Traine Construction

To reinforce the success of the project discussed in Section 7, Traine Construction, our client for this Capstone project, provided a letter expressing their satisfaction with our team's efforts over the 24/25W academic year. The letter is attached on the following page and permission was granted to use it in this report.

Although the project exceeded expectations, several refinements could further enhance performance and scalability:

1. **Smart temperature regulation:**
   - Implementing a PID-controlled heating system could further optimize energy efficiency by adjusting power output based on real-time temperature readings.
2. **Expanded field testing:**
   - Additional trials in more extreme cold environments (<0°C) would validate performance across broader winter conditions. A full-size set of prototypes covering an entire 16' x 11'-6" form (10 blankets total) to enable higher efficacy testing and results.
3. **Manufacturing optimization:**
   - Investigating mass production techniques (e.g., vacuum forming, automated cable placement) could improve scalability and reduce per-unit cost.
4. **Integration with IoT for remote monitoring:**
   - Adding a remote temperature monitoring system could provide real-time performance tracking for contractors and engineers.
5. **Exploring alternative heating elements:**
   - While resistive heating cables worked effectively, advanced material innovation could offer lighter, more flexible, and even more energy-efficient solutions in the future.

March 27, 2025

To whom it may concern:

We are pleased to provide the following letter in support of the Capstone project team proposal, “Developing Thermal-Controlled Formwork for Winter Concrete Pours”. Since September 2024 Traine Construction has had the privilege of participating and mentoring a keen group of UBC-Okanagan students through this project.

Based on the poster, this engineering team exceeded expectations in several significant ways with their thermal-controlled formwork project:

1. Superior test results: Their prototype not only outperformed the cold-exposed concrete sample (as expected) but also surprisingly exceeded the baseline sample cured under ideal conditions. The blanket-assisted sample showed a 10.66 MPa peak strength compared to 7.84 MPa for the baseline - a remarkable 36% improvement.

2. Energy efficiency: Their electrical design achieved 44% less power consumption per unit area compared to similar market products, drawing only 3.06 A at 120V.

3. Innovative design features: They developed a comprehensive solution with three key components:
    - Technical: A modular hooking system that interlocks with formwork dimensions
    - Electrical: Low-power resistive heating cables
    - Material: A dual-layer design combining polyurethane core with polyester skin

4. Practical implementation: They successfully tested their prototype in real-world conditions at the Kelowna Curling Club, demonstrating effectiveness in an actual cold environment (4°C).

5. Comprehensive approach: The team addressed not just the technical problem but also considered manufacturing scalability, cost efficiency, and material sustainability through GRANTA screening.

The poster specifically states in the conclusion: "We exceeded expectations with the test results and demonstrated the effectiveness of our design." This is substantiated by the compression test data showing their solution actually improved concrete strength beyond standard curing conditions, which is an exceptional outcome for what was initially a mitigation solution.

We look forward to Capstone Showcase in April.

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500 – 1708 Dolphin Ave, Kelowna, BC V1Y 9S4 | 778.484.4949 | info@traine.ca | info@mainlineliving.ca

Appendix K - Team Member Contributions and Budget Information

Appendix K.1 - Contribution Statements

Brandon:

- Scheduled the team meetings
- Attended all team meetings, and client meetings
- Provided the high level internal deliverable timelines at each weekly meeting
- Heavily involved in work delegation for all course deliverables and internal deliverables
- Co-designed the electrical aspect of our project with Dylan. Responsible for designing and selecting resistive heating cable, simulating the thermal requirements defined in the scope of the project.
- Aided in the mechanical design when needed, meeting with team members individually beyond regularly scheduled team meetings
- First Client Meeting:
  - Section 3 - Narrowing Physical Parameters (Slide 4)
- Second Client Meeting:
  - Section 4 ii) Actively Heated (electric) Blanket Proposal (Supplementary to Slides 10 & 11)
- Third Client Meeting:
  - Section 4 - Electrical System (Co-written with Dylan) (slides 12 & 13)
- Fourth Client Meeting:
  - Section 2 - Present Prototype Development Results (Co-written) (slide 8)
- Conceptual Design Sections:
  - 1.0 - Introduction
  - 3.0 - Technical Parameters EXCEPT 3.2 - Material Selection Analysis
  - Appendix A
  - Appendix B
  - Detailed Literature Review
  - Final editing, proofreading, typo and error correction, formatting and consistency check
- Final Report

    - 1.0 - Problem Specification
    - 3.1 - Existing Remedies Survey
    - 3.2 - Technical Parameters
    - 3.3 - Electrical Properties Selection
    - 4.1 - Health and Safety Considerations
    - 4.2 - Business and Public Welfare Considerations
    - 5.0 (Introduction)
    - 5.1.2 - Product Electrical Design
    - 5.1.3.1 - Final Product Dimensions
    - 7.0 - Overall Project Success
    - Appendix A - CSA A23.1 Relevant Standards
    - Appendix B - Peri Gang Form Volume
    - Appendix J - Letter from the Client, Traine Construction (credit to Isaiah for procuring the letter)
    - Final editing, proofreading, typo and error correction, formatting and consistency check, report structural design
- Final Presentation Video - Electrical Design and Thermal Simulation

Dylan:

- Project-long Faculty Advisor communication, including coordination of client meeting dates with Isaiah
- Attended all group and client meetings
- Maintained group Discord server for communication
- Worked with Brandon to choose a heating solution for the blanket, including research for heating solutions, theoretical performance calculations, and cost of implementation
- Client meeting 1: slide 3 (General Project Overview & Previously Narrowed Scope)
- Client meeting 2: slides 6, 7 (Heated Air with Insulation Solution Idea)
- Client meeting 3: slide 14 (Comparison to Leading Market Solution; worked with Brandon for slides 12-13)
- Client meeting 4: slides 8, 9 with Brandon (Prototype Electrical Properties)
- Conceptual design report
    - Literature review

    - Developed the problem statement
    - Worked with Sebastian for sections:
        - 1.0 - Introduction
        - 2.0 - Problem Definition, Needs and Constraint Identification
- Final report:
    - 2.0 Needs and Constraint Identification
    - 6.0 Risk Assessment and Risk Mitigation
    - 8.0 Conclusion
    - Report design and trimming of extraneous content
- Participated in and edited the Project Video Presentation

Isaiah:

- Project Startup
    - Worked closely with Matt F. and Jeremy V. to define and scope the real-world construction problems the project aimed to address.
    - Coordinated with UBC Okanagan during the project application phase, ensuring all administrative and academic channels were satisfied.
    - Navigated and completed all necessary applications and approvals to formally launch the project through the Capstone Program
- Client Communication & Project Coordination
    - Acted as the primary and sole point of contact with Traine Construction throughout the project.
    - Scheduled all client meetings, responded to questions, and facilitated ongoing communication.
    - Initiated and organized the project at the start of the year by confirming participation and expectations between Traine, the university, and the student team.
    - Coordinated logistics for in-person Client Meetings 1 and 2, arriving early to handle room setup and technical arrangements.
    - Created detailed meeting agendas for Client Meetings 3 and 4 to guide presentation flow and talking points.

    - Led efforts to incorporate client feedback into the project direction, especially around real-world constraints and construction practices.
    - Secured a project completion satisfaction letter from Jeremy (Traine Construction), and shared the final poster and showcase event details with the client.
- Independently developed and delivered the Conceptual Design Project Presentation, including:
    - Writing the presentation script.
    - Designing the full slide deck.
- Participated in the term 1 site visit (with Jeff and Sebastian) to gather project-specific data and constraints from the field.
- Design & Technical Work
    - Worked with Sebastian to design the interface between the blanket and the Peri Gang Form, considering geometry and site handling.
    - Contributed to early mechanical design and dimensioning of the blanket in Semester 2.
    - Reached out to the Kelowna Curling Club and other cold storage companies to explore real-world product testing sites.
    - Coordinated a site meeting with Matt F. to gather field-specific information for refining the final design.
    - Ordered materials off Amazon to support prototype construction, assisting Nick in sourcing key components for blanket assembly and testing.
- Client Meetings & Deliverables
    - Created the slide decks for all four client meetings, ensuring content quality and technical clarity.
    - Attended all meetings on time and played an active role in discussions and presentation delivery.
- Final Report & Presentation
    - Participated in the Final Project Video, contributing both to the script with Nick and presentation delivery.
    - Took the lead on creating the Project Poster for the final showcase:

        - Reviewed the entire final report to extract and condense information.
        - Designed the layout and selected content to highlight key technical and project points.

Jeff:

- General
    - Worked with other teammates to achieve goals
    - Often met with other teammates individually to work out project issues, and aided other teammates when needed
    - Gathered great deal of research
    - Developed project management task manager (even though no one used it)
- Team Meetings
    - Attended every meeting set in term 1 2024, and term 2 2025.
    - Participated in term 1 site visit to gather info about project (with Sebastian and Isaiah)
- Client Meeting 1
    - Slide 4 narrowing logistical parameters
    - Investigated problem statement and project scope/constraints
- Client Meeting 2
    - Prepped research: Concrete Standards, current solution, scientific papers, and other research
    - Slide 10 - Explained passively insulated Blanket
    - Slide 11 - Material Selection Process
- Client Meeting 3
    - Slide 7: Material selection process, and progress made using Software and Research
    - Slide 8: Material Categories, and functions. Provided CAD diagram model of idea
- Client Meeting 4
    - Slide 5: Prototype progress, material selection results, and materials used/acquired
    - Slide 6: Prototype Assembly, materials, and function.
- Prototype Design/Assembly

    - Designed Prototype insulating Blanket
    - AutoCAD Drawings of Prototype (11x17 paper)
    - Provided sewing Machine and thread
    - Worked with Nick assemble pieces of prototype to make into components, then into product Took photos and uploaded to drive
- Prototype Testing
    - Worked Nick in the concrete testing facility to crush concrete, and gather results of prototype success. Took photos and uploaded to drive in timely manner
- Conceptual Report
    - 3.2 Material Selection Analysis
    - Appendix C
    - Granta analysis
- Final Report
    - AutoCAD Drawings of Actual Design (11x17 paper)
    - Extensive GRANTA and Microsoft Excel Material selection Analysis
    - 3.4 Material Selection Analysis
    - 3.5 Material Specifications
    - 4.3 Environmental Considerations
    - 5.1.1 Final Material Design
    - Appendix C - Additional Material Selection Analysis Information
    - Appendix D - Parameter Variations with Respect to Thickness
    - Appendix E - Sustainability Analysis
    - Appendix F.1 - Final Design Engineering Drawings
    - Appendix G - Prototype and Mold Engineering Drawings
- Project Video
    - Participated in Video presentation

Nick:

- Involved in meeting planning and ensuring deadlines are met.
- Worked with Jeff and Sebastian on product mechanical design and prototype design.
- Purchasing and pickup of prototype materials and testing materials.

- 10+ Hours in woodshop constructing 3 concrete molds
- 15+ hours spent on prototype design and construction alongside Jeff.
    - Construction included mockup, cutting of materials to required dimensions.
    - Sewing of the outer shell with an electric sewing machine.
    - Laying and installation of the electrical heating cable.
- Meeting with ArcticGlacier to investigate possible cold testing sites
- Concrete testing:
    - 2 Hours spent mixing and preparing concrete samples into mold
    - Delivered and picked up samples to/from Kelowna Curling Club for cold cure conditions
    - Alongside Jeff spent 3 hours demolding concrete, setup of compressive test apparatus with help from Structures lab Technicians.
    - Performed tests and prepared final data for presentation and analysis
- Client meeting 1:
    - Cost narrowing and scoping
- Client meeting 2:
    - Active air heating blanket proposed design
- Client meeting 3:
    - Testing procedure creation and description to client
- Client meeting 4:
    - Prototype design description and display. Testing procedure lock in.
- Completed Final design report sections 5.2.1 ,5.2.4, 5.2.5, Appendix H.

Sebastian:

- Took meeting minutes for all group meetings. Ensuring week-week plans and next steps were documented.
- Involved with meeting Planning and stayed in constant communication with team members.
- Worked with Isaiah to create a design out of how our initially proposed blankety design could interface with the client's Peri Gang Form.
- Worked with Nick and Jeff on physical and prototype design.

- Created and optimized the method for attaching our blanket to the specific formwork used by the client.
- Helped Jeff with material Selection for the prototype.
- Designed and 3D printed the hooks for our prototype blanket.
- Set up testing availability with Kelowna Curling Club to use their space for cold curing testing.
- Mixed and prepared concrete for our sample molds with Nick.
- First Client Meeting:
  - Delivered questions to defer to KRM/Trades (other companies that work with Traine)
  - Completed the client update meeting minutes
- Second Client Meeting:
  - Had to miss it due to a midterm that was given to us by a professor after the client meeting was already planned. Kept communication with the group and offered help where needed.
- Third Client Meeting:
  - General Design review. Created preliminary drawings for the blanket that included dimensions, form and transport possibilities.
  - Completed the third client update meeting minutes
- Fourth Client Meeting:
  - Prototype vs Production model differences.
  - Prototyped hook dimensions and production hook material selection.
  - Completed the fourth client update meeting minutes
- Conceptual Design Sections:
  - Worked on and edited the following alongside Dylan for the Conceptual Design Report Sections: 2.0 Problem Definition, Needs and Constraint Identification
  - Helped to refine the conceptual design presentation slideshow.
  - Running through the script with Isaiah to make improvements to what was being said and ensure the presentation stayed within the time limit.
- Final Report
  - Created slides for Final Video Presentation

- 5.1.3.2 Hook Design
- Appendix F.2 - SolidWorks Hook Finite Element Analysis

Appendix K.2 - Financial Information

Date	Item Name	Quantity	Item Cost	Purchased by
2025-02-05	TOPDURE JHSD 9-feet Pipe Heating Cable Built-in Thermostat	2	$114.88	Isaiah
2025-02-25	Home Depot (Rubber sheet and zip ties	-	44.28	nick
2025-02-20	Rona Material (Tape + exacto	-	77.33	nick
2025-02-23	Amazon - Exterior shell material	2	38.77	nick
2025-03-25	Wood screws	1	6.03	nick
2025-03-11	Plywood Sheet 0.5*4*8	1	43.66	nick
2025-03-25	Concrete, Tape, Bungee Cords for blanket attachment, Totes for transportation, Tarp for curling rink mess prevention		117.91	nick
2025-03-05	Wood Planks	1	11.87	nick
		Ongoing Cost $	$442.86	